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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Fracture and Deformation Division
Washington, DC 20234

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Final Report

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ANALYSIS OF FOREIGN AND DOMESTIC MATERIAL SPECIFICATIONS FOR SHIPS COMPONENTS

J. G. Early and L. D. Ballard

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

NOTICE

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ABSTRACT

Under United States law, United States flag vessels must satisfy applicable United States codes and further, the materials of construction of these vessels must satisfy the material requirements specified in these codes. For vessels manufactured in foreign countries, a determination must be made as to whether materials of construction produced under foreign specifications for specific components such as piping and flanges, are acceptable in performance to materials produced under approved U.S. specifications.

The evaluation process used by inspectors for determining the compatability between approved domestic material specifications and foreign specifications is not always uniform. Current procedures often emphasize only chemical and mechanical characteristics and do not always give sufficient weight to such factors as processing differences and weldability or to the effect on mechanical property data of location, geometry, and orientation of test specimens.

In many of the published specification compilations, comparisons of foreign and domestic material specifications are made only on the basis of first, chemical composition, and second mechanical property limits. The result of this limited approach is often an extensive but unusable list of apparently equivalent specifications. The absence of a more comprehensive technical analysis of the equivalency or lack thereof necessitates a case-by-case review and the possibility of inconsistent determinations of acceptability.

A program has been initiated at the National Bureau of Standards under the sponsorship of the United States Coast Guard to develop a manual of equivalent engineering standards which specifies those foreign specifications that are equivalent to acceptable domestic specifications, those foreign specifications that are not equivalent, and those that would be equivalent if certain additional criteria are met. Results are presented here of a detailed technical comparison between foreign specifications, principally Deutsche Industrie-Normen (DIN) standards and Japanese Industrial Standards (JIS), and selected domestic material specifications issued by the American Society for Testing and Materials (ASTM) and the American Society of Mechanical Engineers (ASME). This comparison has identified technical areas of commonality, difference, and omission that could have a significant impact on component performance.

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INTRODUCTION

Under United States law, United States flag vessels must satisfy applicable United States codes, and further, the materials of construction of these vessels must satisfy the material requirements specified in these codes. For vessels manufactured either in foreign countries or manufactured domestically with foreign produced materials, a determination must be made as to whether materials of construction produced under foreign specifications for specific components such as piping and flanges, are acceptable substitutes for materials produced under approved U.S. specifications.

The evaluation process used by inspectors for determining the compatibility between approved domestic material specifications and foreign specifications is not always uniform. Current procedures often emphasize only chemical and mechanical characteristics and do not always give sufficient weight to such factors as processing differences, weldability, or the effect of location, geometry, and orientation of test specimens on mechanical property measurements.

In many of the published specification compilations (1-4)[(a)], comparisons of foreign and domestic material specifications are made only on the basis of first, chemical composition, and second, mechanical property limits. The result of this limited approach is often an extensive but unusable list of apparently equivalent specifications. The absence of a more comprehensive technical analysis of the equivalency or lack thereof necessitates a case-by-case review and the possibility of inconsistent determinations of acceptability.

PURPOSE

A program has been initiated at the National Bureau of Standards under the sponsorship of the United States Coast Guard to develop a manual of equivalent engineering standards which specifies those foreign specifications or specific grades within the specification that are equivalent to acceptable domestic specifications, those foreign specifications or grades that are not equivalent, and those that would be equivalent if certain additional criteria are met. Results are presented here of detailed technical comparisons between foreign specifications, principally Deutsche Industrie-Normen (DIN) standards and Japanese Industrial Standards (JIS), and selected domestic material specifications issued by the American Society for Testing and Materials (ASTM) and the American Society of Mechanical Engineers (ASME). These comparisons have identified technical areas of commonality, difference, and omission that could have a significant impact on component performance.

[(a)] The isolated numbers in parentheses refer to references listed at the end of this report.

COMPARISON CRITERIA

The process of determining whether or not one material specification is equivalent to another can be complex and is dependent on the evaluation of a variety of factors and a decision as to their relative importance. A finding that two material specifications are equivalent implies that these materials will be interchangeable in their many applications, that is, they will perform in a known manner, even though the specification documents are not principally performance standards.

Comparing foreign material specifications to domestic specifications is further complicated by differences in the philosophy of specification writing, not only for foreign versus domestic, but different specification styles among domestic specifications. Some specifications are highly specific in listing typical applications or end-uses while others are highly specific in listing end-uses for which the specification does not apply either because of inappropriateness or because another specification covers that application. Some specifications contain hints about the rationale for specific requirements or limits while others provide no guidance. Some specifications state the environment of the application, i.e. temperature and/or pressure conditions, without specifying properties for these conditions, while others specify additional requirements for these conditions. A complete evaluation of these considerations cannot be carried out in a vacuum, that is, without knowledge of the specific end use of the material and its operating environment. Thus, there are situations where the ultimate determination of equivalence between material specifications that are not identical will depend on the actual end use of the material in a structure and the design parameters for that structure.

Design engineers, however, still make material selection decisions based in part on specified material properties and these property requirements can be compared and a generalized determination of equivalence or suitability made on this basis. However, it is not sufficient to simply compare lists of numbers representing chemical and physical characteristics and conclude equivalence or lack thereof.

Evaluation of chemical composition is always the first step in comparing specifications as measures of equivalence but cannot stand alone and must be interpreted with other considerations, such as knowledge about primary metal production methods and their effect on chemistry and the interrelationship between chemistry, mechanical properties, fabrication requirements and, in the case of steels, such qualitative requirements as weldability. In some specifications, chemical requirements are not directly controlling but are determined from the desired mechanical property requirements and the allowed methods of primary metal production.

Mechanical properties such as strength and ductility are typically referred to direcly in codes and thus are the major comparison criteria. Mechanical properties depend not only on such obvious factors as chemistry and thermo/mechanical processing, but can be strongly influenced by more subtle factor such as the location within the material from where test specimens are taken and the orientation of test specimens with respect to processing directions or metallurgical effects, and the geometry (size and shape) of test specimens and its effect on measured parameters, or product effects. In addition, there are situations where each specification may require the same qualitative test but use a different acceptance criterion to determine what constitutes passing the test. Thus, an evaluation of the acceptance criteria must be made to determine if the difference is significant. Caution must be exercised when direct comparisons are made between mechanical property numbers to insure that both numbers are a measure of the same phenomena normalized for differences in test conditions and test specimens.

Composition Criteria

Chemical composition requirements are the starting point for any comparison procedure because of the dominant role chemistry has in controlling metal properties, especially mechanical properties. Chemical requirements can be expressed as maximum or minimum values, or as a range of acceptable values. Generally, a determination of chemical equivalence is straight forward since a direct absolute comparison of numbers can be carried out without ambiguity. Most chemical requirements are specified on the basis of ladle or heat analyses of molten samples taken from the refining furnace, representing the homogeneous alloy composition. If the product form covered by the specification is subject to a significant non-uniform distribution of alloying elements or chemical segregation, then a product analysis may be permitted in which the product is sampled and wider chemical limits allowed to compensate for the segregation effect. The critical factor in making comparisons of chemical composition limits is to distinguish between differences in alloying element concentration that strongly affect properties, e.g. corrosion resistance, weldability, and those that do not. This evaluation becomes particularly difficult when the affected properties are not directly addressed by the specification.

Metallurgical Effects

All of the typically measured mechanical properties, i.e. ultimate tensile strength, yield strength, percent elongation, percent reduction-in-area, bend behavior, and impact resistance can be affected by metallurgical factors such as the microstructure even for identical chemical compositions.

The thickness effect on properties in many wrought steel products is an important example of a metallurgical effect.

As-cast steel ingots typically exhibit chemical segregation zones because of the very slow cooling rates from the molten state. The extent of the segregation zone is dependent on the deoxidation practice used and is smallest for killed steels and largest for rimmed steels. As the ingots are reduced in size, the influence of the non-uniform chemical composition is affected. When high thickness reductions from ingot to final product thickness occur, the microstructural and chemical variations found in the as-cast ingot are minimized. Thick products tend to retain more of the chemical and microstructural inhomogeneities from the ingot than thin products which can result in property variations through the thickness of the product. When comparisons are made between specifications for products in a wide range of sizes, two common approaches are followed. First, for products below certain dimensions, most specifications require full-thickness test specimens so that the effects of inhomogeneities are averaged out. Data would then be compared between full-thickness specimens. Second, where product dimensions allow test specimens less than full-product thickness, the locations within the material from which specimens are taken may be specified to minimize the effects of chemical and structural inhomogeneities.

Another influence of thickness results in variations in cooling rate which affects mechanical properties. For example, thick steel rolled products because of a slower cooling rate through the transformation temperature will typically exhibit lower strength and higher ductility than thin products because of differences in their resulting microstructures. Specifications usually deal with this problem in one of two ways. First, the chemical limits of the major alloying elements can be held reasonably constant and the mechanical property requirements adjusted based on product size or thickness to compensate for the cooling rate effect. Second, the mechanical property requirements can be held reasonably constant and the chemistry, primarily carbon and manganese levels for steels, adjusted to maintain the same properties as the size or thickness changes.

As a consequence of this strong influence of cooling rate on microstructure for both ferrous and nonferrous castings, the casting section thickness controls the resulting as-cast mechanical properties. If the casting is not subjected to additional thermal treatments to further modify the microstructure and mechanical properties, properties measured from separately cast test bars or coupons will not necessarily be representative of the properties of the casting. Theapproach taken in ASTM specifications for gray iron castings attempts to adjust over a limited range the test bar dimensions according to the controlling or critical section thickness of the casting. In copper alloy castings, however, the permitted test bars or test coupons have essentially the same dimensions, independent of the casting section thickness, with differences in mold design depending on whether the alloy is a high-shrinkage or low-shrinkage type. In either situation, however, mechanical property comparisons should be carried out on the basis of similarly sized test bars without regard to the correlation between test bar properties and casting properties.

After fabrication, many wrought metal products exhibit mechanical properties that vary depending on the orientation of the test specimen within the product. This non-uniformity or anisotropy of properties (5) arises generally from one of two sources, crystallography or structural discontinuities. Although the individual grains in a commercial alloy are very anisotropic in strength properties because of their crystallographic nature, a reasonably random orientation of the grains would result in similar properties in all directions due to the averaging of the orientation anisotropy. Sufficient plastic deformation, however, can produce a preferred or non-random orientation of the grains which causes anisotropic behavior in the commercial alloy similar to that observed in the individual grains. The yield strength of nonferrous alloys, for example, can be increased or decreased in the direction of the principal deformation depending on the type of preferred orientation which is produced.

Ferrous alloys are more likely to develop anisotropic mechanical properties due to the preferred alignment of structural discontinuities such as inclusions, voids, and second phases in the direction of the principal deformation. This type of microstructure is often observed in forgings and rolled plate products. This preferred alignment or banding as it is often called relates to the three principal deformation directions in these products. The longitudinal direction is the principal direction of working and longitudinal specimens have their axis aligned parallel to this direction. The short-transverse direction is the direction of minimum product dimension, for example the plate thickness, and the long-transverse direction is perpendicular to the longitudinal and short-transverse directions. Often the properties in the short-transverse direction cannot be measured because of insufficient material for a specimen. For plate products, longitudinal properties and/or long-transverse properties (often just called transverse) are specified.

Although little difference between the ultimate tensile strength and yield strength values of longitudinal and transverse specimens have been found for forgings and plate products, substantial variations in the tensile ductility parameters occur. Higher values for percent elongation and reduction-in-area of from to 10% and 50%, respectively have been observed in longitudinal specimens compared to transverse specimens (6-8). For some applications, properties in certain directions assume special importance. For example, in piping and cylindrical pressure vessels which experience internal pressure, the transverse properties are of greater importance because the largest principal stress in the component acts in the transverse direction. Further, even in the absence of a methodology for relating tensile ductility parameters to component design, the transverse reduction-in-area has been shown to be an indicator of steel quality, especially for forgings, for certain types of applications and may be the limiting design parameter. Generally, when specifications do not specify specimen orientation the longitudinal orientation is assumed, but in any event only requirements for the same orientation of specimen can be compared.

Size and Shape Effects

For over a century, investigators have reported size and shape effects on material strength properties. In a recent review of this phenomena, Harter (9) reveals the considerable controversy in the literature on specimen size and shape effects on static strength properties. Although a comprehensive theory or model is lacking, a number of studies of size effects on the static strength properties of metals draw similar conclusions. A common factor in these studies was that most metals possessed sufficient ductility so that load redistribution during testing can occur by plastic deformation. Templin (10) carried out extensive tests on various strength aluminum alloys using rectangular specimens with a range of dimensions. The results showed that except for a few extreme cases, the ultimate tensile strength and yield point values were essentially unaffected by the wide variations in specimen geometry. Similar results were reported by Zlochevskii (11) for several steels with both round and rectangular specimens. A later study by Lyse and Keyser (12) reviewed earlier results by Bach (13) and Moore (14) and presented additional new data for steel. The results indicated that the size and shape of test specimens, including round and rectangular specimens, had no effect on either the ultimate tensile strength or yield strength. Further, the results of all three investigators demonstrated that for round specimens, the percent reduction-in-area was practically independent of the specimen diameter. Miklowitz (15,16) found that although the variation of true stress at ultimate load for round specimens was slight for a wide range of sizes, a larger effect of size was observed for rectangular specimens. The interpretation of the rectangular specimen results focused on the role of restraint by the specimen shoulders on the strain behavior in the reduced section. However, the overall evidence supports the conclusion that ultimate tensile strength and yield strength are relatively independent of specimen size and shape, assuming the metallurgical factors like microstructure are size independent.

A different situation exists for the tensile ductility parameter, percent elongation. Numerous studies (9,10,12-16) have demonstrated the strong effect of specimen size and shape on percent elongation. Oliver (17) formalized a number of empirical relationships between percent elongation, gage length, and cross-sectional area into the following widely used general equation for elongation:

$$e = \sigma \left(\frac{\sqrt{A}}{L}\right)^{\alpha} \quad \ldots\ldots \qquad [1]$$

where e is percent elongation, L is the specimen gage length, A is the specimen cross-sectional area, and σ and α are constants. This equation is used by the American Society for Testing and Materials (ASTM) to normalize percent elongation values between the two rectangular and one round ASTM standard test specimens. For round specimens, A can be replaced by the specimen diameter, D. For many types of carbon and alloy steels in a variety of heat-treated conditions, the value $\alpha = 0.4$ has been found to give reasonable conversions between different specimen sizes and shapes while $\alpha = 0.127$ can be used for annealed austenitic stainless steels.(18) For copper and brass, a value of $\alpha = 0.2$ has been reported.(17) The ASTM round specimen has a constant ratio of L/D of 4 or the equivalent $L/\sqrt{A}$ of 4.51 while the rectangular specimens have a variable $L/\sqrt{A}$ ratio because the specimen thickness is generally the full-thickness of the material. In a similar fashion, foreign standards-writing organizations like Deutsche Industrie-Normen (DIN) and Japanese Industrial Standards Committee (JIS) have developed standard test specimens. The DIN standard specimens for wrought products, whether round or rectangular, all have a constant ratio of L/D of 5 or the equivalent value of 5.65 for $L/\sqrt{A}$. The JIS standard specimens for wrought products include examples with $L/\sqrt{A}$ ratios of 4 to 9 and L/D ratios of 3.54 to 8 as well as specimens with variable $L/\sqrt{A}$ ratios.

Oliver's relationship can be used to convert specification requirements for percent elongation based on one specimen to an equivalent value based on another specimen. Since the percent elongation is a function of gage length L and shape through A, elongation values can be easily converted between specimens of different sizes and shapes by writing equation [1] for each specimen and dividing one by the other to make a ratio. Thus, for two specimens X and Y:

$$e_X = e_Y \left(\frac{\sqrt{A_X}\ L_Y}{\sqrt{A_Y}\ L_X}\right)^{\alpha} \quad \ldots\ldots \qquad [2]$$

For example, to convert an ASTM requirement based on a specimen with L/D = 4 ($L/\sqrt{A} = 4.51$) to an equivalent DIN value for a specimen with L/D = 5 ($L/\sqrt{A} = 5.65$) for carbon steels, equation [2] can be solved with $\alpha = 0.4$ to yield:

$$e_{DIN} = 0.91 \, e_{ASTM}$$

or the equivalent DIN value is only 91% of the ASTM requirement.

Bend tests are used primarily to establish a qualitative measure of a material's ability to undergo plastic deformation without cracking, and thus represent a qualitative forming limit. It is a yes/no type of test in which a specimen is typically bent 180° about a radius of curvature and passes the test if a crack does not develop on the outer or tensile surface of the specimen and fails if a crack or cracks develop. The test itself is considerably more complex than the yes/no criterion indicates because of the strong role that specimen dimensions have on the severity of the test.(19)

In simple bending of a rectangular specimen, the strain tangent to the bend radius or circumferential strain is assumed to vary only in the thickness direction of the specimen and has its maximum tensile value at the outer specimen surface. The actual circumferential strain distribution across the specimen width is fairly uniform except at the edges, where it is somewhat higher. However, the strain distribution in the specimen width direction is very nonuniform, being compressive and decreasing with distance from the specimen edges, and thus has a greater effect as the specimen width and thickness affect the in-plane or biaxial strain or stress distribution within the specimen. The ability of the specimen to undergo plastic deformation, or its ductility, is a function of the stress state in the outer tensile surface of the specimen. A biaxial tensile stress state reduces the ductility of the material and so specimens with a low width to thickness ratio (w/t) exhibit a high strain to produce fracture because the transverse strain is compressive and must be overcome before a tensile biaxial stress state can be produced. As the width to thickness ratio increases, the effect of the compressive strain decreases and therefore the strain to produce fracture decreases until it reaches its saturation or minimum value at about $w/t = 8$. Thus, for specimens with a $w/t < 8$, the specimen dimensions strongly affect the minimum bend radius below which the material will crack on the outer tensile surface.

RESULTS

The following section contains the individual specification comparisons included in this study. Each comparison is between two specifications: the domestic ASTM and/or ASME document and the JIS or DIN document. Each comparison stands alone and consists of two parts.

The first part contains a brief introductory discussion of the two specifications and the conclusions about their relative equivalence. Highlights of any general differences in the typical intended applications are included along with the determination of equivalence for each grade or class of material within each specification.

The second part contains the detailed technical analyses of each of the significant property requirements referred to in the domestic specification. A brief interpretation of the comparison process is included where necessary as well as the methodology followed to insure that similarly measured parameters were being compared. It is intended that the first part containing the conclusions could be separated from the detailed analysis part without loss of content.

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JIS G3101-76//ASTM A36-77a

INTRODUCTION

The scope statements for these two specifications are very similar and refer to the same type of steel products, namely rolled carbon steel plates, shapes, and bars intended for use in bridges, buildings, and general structural purposes.

The structural applications of these products are for non-pressurized environments and thus the static strength properties, ultimate tensile strength and yield strength, are usually the principal design criteria. The percent elongation requirement, characterizing the tensile ductility behavior of the steel, is not usually considered to be a useful design parameter. Percent elongation, as a measure of ductility, is not a unique parameter because it depends on specimen geometrical factors in addition to gage length and the materials intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G3101 are considered equivalent to the requirements of ASTM A36 if the JIS values fall within the range from 5% above the A36 maximum value to 5% below the A36 minimum value; (2) the percent elongation requirements of JIS G3101 are considered equivalent to the requirements of ASTM A36 if the JIS values are higher than or within 15% of the A36 minimum value. Allowance of the larger difference for percent elongation is based on (1) the actual expected JIS elongation values would normally exceed the JIS minimum requirement and thus approach the A36 value, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Material furnished under specification A36-77a must conform to the applicable requirements of ASTM A6-77b, General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use. (The appropriate edition of A6 to use is that edition concurrent with the edition of A36 of interest.) The relevant sections of A6 used in this comparison include: Section 3, Description of Terms; Section 7, Chemical Analysis; Section 10, Test Methods; Section 11, Tension Tests; Section 15, Retests; and Supplementary Requirements.

CONCLUSIONS

(1) JIS Class 1 (SS34) and JIS Class 4 (SS55) from JIS G3101-76 are not equivalent to ASTM A36-77a except under the extreme conditions as noted.

(2) JIS Class 2 (SS41) from JIS G3101-76 is generally equivalent to ASTM A36-77a, based on the criteria discussed earlier, subject to the following limitations:

(a) The maximum carbon content (ladle analysis) should be limited to 0.30 percent by weight to insure adequate weldability

(b) The JIS minimum yield strength for products 40 mm to 200 mm thick falls between 13% and 17% below the A36 minimum requirement. The strength requirements are the principal design parameters and thus to be acceptable, JIS Class 2 products in this size range must be shown to fall within the strength acceptance criterion.

(c) The JIS minimum percent elongation for plates over 140 mm thick (less than 610 mm wide) falls 17% below the A36 minimum requirement. To be acceptable, JIS Class 2 plates in this size range must be shown to fall within the elongation acceptance criterion.

(3) JIS Class 3 (SS50) from JIS G3101-76 is generally equivalent to ASTM A36-77a, based on the criteria discussed earlier, although subject to more limitations than JIS Class 2. These limitations include:

(a) The maximum carbon content (ladle analysis) should be limited to 0.30 percent by weight to insure adequate weldability.

(b) The JIS maximum allowable tensile strength for all products in this class is 10% above the A36 maximum allowable tensile strength. Material exceeding the A36 tensile strength limit would be acceptable provided the carbon content limit and the elongation acceptance criteria are both satisfied.

(c) The JIS minimum percent elongation for both plates (less than 610 mm wide) and shapes 6.4 mm to 16 mm thick, plates (greater than 610 mm wide) 8 mm to 16 mm thick, plates (less than 610 mm wide) greater than 90 mm thick, and plates (greater than 610 mm wide) greater than 140 mm thick fall from 15% to 26% below the A36 minimum requirement. To be acceptable, JIS Class 3 plates and shapes in these size ranges must be shown to fall within the elongation acceptance criteria.

(4) ASTM A36-77a allows the following exceptions:

(a) Shapes less than 1 in^2 (645 mm^2) in cross-section and bars, other than flats, less than 1/2" (13 mm) in thickness or diameter need not be subjected to tension tests by manufacturer.

(b) Bearing plates over 1 1/2" (38 mm) thick except when used in bridges do not require mechanical tests provided they contain 0.20 to 0.33 percent carbon and satisfy sulfur and phosphorous requirements.

(c) No rimmed or capped steel shall be used for plates and bars over 1/2" (13 mm) thick or for shapes other than Group 1 (see Table A, A6-77b).

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CHEMICAL REQUIREMENTS

JIS Class 1 (SS34)
JIS Class 2 (SS41)
JIS Class 3 (SS50)

The JIS chemical composition requirements for these three classes are limited to maximum levels for phosphorus and sulfur. The carbon and manganese levels are not specified. The absence of extensive chemical composition requirements allows wider chemistry limits on important elements such as carbon and manganese and thus reduces the cost of these products since both chemical requirements and mechanical property requirements do not have to be satisfied. For hot-finished carbon structural steels, the mechanical properties and fusion weldability are usually the important criteria. When this steel is produced to mechanical property requirements, typical practice allows the carbon and manganese levels to vary in order to compensate for the effect of product thickness. Typically in these steels, strength properties decrease and tensile ductility (often measured by percent elongation) increases as product thickness increases. However, an upper limit on the carbon content is necessary in order to maintain adequate weldability because A36 refers to the use of this steel in welded construction. Thus, based on a ladle analysis, the carbon content of these three JIS classes should not exceed 0.30 weight percent.

The higher JIS maximum allowed phosphorus level should not have a significant influence on the properties of these steels and the sulfur requirement is identical to that of A36.

JIS Class 4 (SS55)

The JIS phosphorus and sulfur limits are identical with the A36 requirements. The JIS maximum carbon and manganese limits of this class exceed or are at the maximum levels specified in A36 for all products. The higher carbon and manganese levels are consistent with the higher strength properties and lower tensile ductility properties (percent elongation) of this class compared to A36. JIS Class 4 products at the highest carbon and manganese levels would probably not satisfy the A36 tensile property requirements regardless of product.

MECHANICAL PROPERTIES

JIS Class 1 (SS34)

Strength Requirements

This JIS Class for plates and sheets, strips and flats, and bars will not in general satisfy the tensile strength requirements or the minimum yield point or yield strength requirements of A36. However, material at the high end of the JIS tensile strength range could satisfy A36 and because of the higher tensile strength these materials could exhibit a sufficiently high yield point or yield strength to also meet A36 requirements.

Ductility Requirements

The JIS percent elongation minimum for plates and sheets, strip and flats 5 mm or less in thickness is based on a test specimen (50 mm gage length, 25 mm wide) which has no ASTM equivalent. The permitted ASTM test specimens (see Section 11, A6-77b) is rectangular, 12.5 mm wide with a 50 mm gage length. Using the relationship between percent elongation, gage length, and cross-sectional area, and the reduction in percent elongation permitted by section 11.6.1 of A6 for thin plates, the JIS specimen must exhibit an elongation of 22% or greater to satisfy the A36 50 mm gage length requirement. Thus for plates, sheets, strip and flats 5 mm or less in thickness, the JIS minimum elongation satisfies the A36 requirement.

The JIS percent elongation minimum for plates and sheets, strip and flats over 5 mm to 16 mm in thickness and over 16 mm to 50 mm in thickness satisfies the A36 requirements. (The 50 mm thickness limit is probably in error and should be 40 mm based on the next size category specified.)

The JIS percent elongation minimum for plates and sheets and flat steel over 40 mm in thickness is based on a test specimen with a gage length 3.54 times the diameter. The equivalent ASTM specimen has a gage length that is four times the diameter. Using the relationship between percent elongation, gage length and cross-sectional area, the equivalent ASTM elongation would be about 95% of the JIS value. Thus for plates over 40 mm to 90 mm in thickness, and sheets and flat steel, the JIS minimum elongation satisfies A36.

For plates over 90 mm thick, the JIS elongation requirement is lowered 1% for each 25 mm additional thickness up to a maximum of 3% at 165 mm thick, and remains constant for thickness above 165 mm. In all cases, the JIS requirement satisfies A36.

The JIS percent elongation minimum for bars not over 25 mm in diameter, side or distance across flats is based on a test specimen which has no ASTM equivalent. However, the JIS specimen has a gage length 8 times the diameter so that for equal diameters, the JIS elongation value will be about 75% of the ASTM value based on the relationship between percent elongation, gage length, and cross-sectional area for a standard specimen where the gage length is only 4 times the diameter. Based on this analysis and, because the JIS minimum value already exceeds the A36 requirement, the JIS elongation minimum satisfies A36.

The JIS percent elongation minimum for bars over 25 mm in diameter, side or distance across flats satisfies the A36 requirement.

JIS Class 2 (SS41)

Strength Requirements

This JIS Class for plates and sheets, strip, flats and shapes, and bars satisfies the tensile strength range requirements of A36. The JIS minimum yield strength requirements for plates and sheets, strips, flats and shapes, and bars up to 40 mm in thickness or greater than 200 mm in thickness satisfy or are within about 5% of the A36 requirements. The minimum JIS yield strength requirements for materials over 40 mm to 200 mm in thickness are between 13% and 17% below the A36 minimum requirement.

Ductility Requirements

The JIS percent elongation minimum for plates and sheets, strips, flats and shapes 5 mm or less in thickness is based on a test specimen (50 mm gage length, 25 mm wide) which has no ASTM equivalent. The permitted ASTM test specimen (see Section 11, A6-77b) is rectangular, 12.5 mm wide with a 50 mm gage length. Using the relationship between percent elongation, gage length, and cross-sectional area, and the reduction in percent elongation permitted by section 11.6.1 of A6 for thin plates the JIS specimen must exhibit an elongation 22% or greater for plates less than 610 mm wide or 20% or greater for shapes and plates greater than 610 mm wide. Thus for plates and sheets, strips, flats and shapes 5 mm or less in thickness, the JIS minimum elongation satisfies the A36 requirement.

The JIS percent elongation minimum for plates and sheets, strips, flats and shapes over 5 mm to 16 mm in thickness is 9% less than the A36 requirement for shapes above 7 mm in thickness or for plates less than 610 mm wide but above 7 mm in thickness. For plates wider than 610 mm, the JIS requirement is within 5% of the A36 requirement.

The JIS percent elongation minimum for plates and sheets, strips, flats and shapes over 16 mm to 50 mm in thickness satisfies the A36 requirement. (The 50 mm thickness limit is probably in error and should be 40 mm based on the next size category specified.)

The JIS percent elongation minimum for plates and sheets, flats and shapes over 40 mm in thickness is based on a test specimen with a gage length 3.54 times the diameter. The equivalent ASTM specimen has a gage length four times the diameter. Using the relationship between percent elongation, gage length and cross-sectional area, the equivalent ASTM elongation would be about 95% of the JIS value. Thus for plates over 40 mm to 90 mm in thickness and sheets, strips, flats and shapes, the JIS requirement satisfies A36 for plates wider than 610 mm and for all shapes. For plates less than 610 mm wide, the JIS requirement is within 5% of the A36 minimum.

For plates over 90 mm thick, the JIS elongation requirement is lowered 1% for each 25 mm additional thickness up to a maximum of 3% at 165 mm thick, and remains constant for thicknesses above 165 mm. For plates over 90 mm to 115 mm thick, the JIS requirement satisfies A36 for plates wider than 610 mm and is 9% smaller than the A36 requirement for plates less than 610 mm wide. For plates over 115 mm to 140 mm thick, the JIS requirement is within 5% of the A36 requirement for plates wider than 610 mm and is 13% smaller than the A36 minimum for plates less than 610 mm wide. For plates over 140 mm thick, the JIS requirement is about 10% and 17% smaller than the A36 requirement for plates more than 610 mm wide and less than 610 mm wide, respectively.

The JIS percent elongation minimum for bars not over 25 mm in diameter, side or distance across flats is based on a test specimen which has no direct ASTM equivalent. However, the JIS specimen has a gage length 8 times the diameter so that for equal diameters, the JIS elongation value will be about 75% of the ASTM value for a standard specimen with a gage length 4 times the diameter (gage length = 50 mm). Based on this discussion, the JIS elongation minimum satisfies the A36 requirement.

The JIS percent elongation minimum for bars over 25 mm in diameter, side or distance across flat, satisfies A36.

JIS Class 3 (SS50)

Strength Requirements

This JIS class for plates and sheets, strips, flats, bars, and shapes satisfies in general the tensile strength range requirements of A36. The maximum JIS allowed tensile strength exceeds the A36 maximum by 10% but this is not a problem if the tensile ductility requirements of A36 as measured by percent elongation are satisfied. The JIS yield strength requirements satisfy the A36 requirements.

Ductility Requirements

The JIS percent elongation requirement for products 5 mm or less in thickness is based on a test specimen (50 mm gage length, 25 mm wide) which has no direct ASTM equivalent. For reasons discussed earlier for JIS Class 2 (SS41), the JIS minimum elongation is 14% below the A36 requirement for plates less than 610 mm wide and within 5% of the A36 requirement for plates greater than 610 mm wide and for shapes.

The JIS percent elongation minimum for plates and sheets, strips, flats, and shapes over 5 mm to 16 mm thick is within 15% of the A36 requirements for shapes or plates over 5 mm to 6.4 mm thick less than 610 mm wide, and from 15% to 25% below the A36 requirement for shapes or plates over 6.4 mm to 16 mm thick less than 610 mm wide. For plates wider than 610 mm, the JIS requirement satisfies or is within 15% of the A36 requirement for plates up to 8 mm thick and is 17% smaller than the A36 value for plates 8 mm to 16 mm thick.

The JIS percent elongation minimum for plates and sheets, strips, flats and shapes over 16 mm to 50 mm thick satisfies the A36 requirement for shapes and plates wider than 610 mm and is within 5% of the A36 requirement for plates less than 610 mm thick. (The 50 mm thickness limit is probably in error and should be 40 mm based on the next size category specified.)

The JIS percent elongation minimum for plates and sheets, flat bars and shapes over 40 mm thick is based on a test specimen with a gage length (50 mm) 3.54 times the diameter. The equivalent ASTM specimen has a gage length (50 mm) 4 times the diameter. Using the relationship between percent elongation, gage length and cross-sectional area, the equivalent ASTM elongation would be about 95% of the JIS value, Thus, the JIS requirement satisfies A36 for wide-flange shapes greater than 426 lb/ft and is within 5% of the A36 value for all other shapes and plates over 40 mm to 90 mm thick wider than 610 mm. The JIS requirement is 13% smaller than the A36 requirement for plates over 40 mm to 90 mm thick less than 610 mm wide.

For plates over 90 mm thick, the JIS elongation requirement is lowered 1% for each 25 mm additional thickness up to a maximum of 3% at 165 mm thick, and remains constant above 165 mm thick. For plates over 90 mm to 115 mm thick, the JIS requirement is about 9% and 17% smaller, respectively, than the A36 requirement for plates more than 610 mm wide and less than 610 mm wide. For plates over 115 mm to 140 mm thick, the minimum JIS requirement is about 14% and 22% below the minimum A36 requirement, respectively, for plates more than 610 mm wide and less than 610 mm wide. For plates over 140 mm thick, the minimum JIS requirement is about 19% and 26% below the minimum A36 requirement, respectively, for plates more than 610 mm wide and less than 610 mm wide.

The JIS percent elongation minimum for bars not over 25 mm in diameter, side or distance across flats is based on a test specimen which has no direct ASTM equivalent. However, the JIS specimen has a gage length 8 times the diameter so that for equal diameters, the JIS elongation value will be about 75% of the ASTM value for a standard specimen with a gage length 4 times the diameter (gage length = 50 mm). Based on this discussion, the JIS elongation minimum satisfies the A36 requirement.

The JIS percent elongation minimum for bars over 25 mm in diameter, side or distance across flat is almost 9% smaller than the A36 requirement.

JIS Class 4 (SS55)

Strength Requirements

This JIS class for plates and sheets, strips, flats, bars, and shapes has a minimum tensile strength requirement that is only 3% below the maximum strength limit allowed for A36. In general, it would be expected that material produced to this class would exceed this maximum A36 value and thus not satisfy A36. The JIS minimum yield strength requirement far exceeds the A36 minimum and thus satisfies A36.

Ductility Requirements

The JIS percent elongation requirement for plates and sheets, strips, flats, and shapes 5 mm or less in thickness is based on a test specimen which has no direct ASTM equivalent. For reasons discussed previously for JIS Class 2 (SS41), the JIS minimum elongation is 19% below the A36 requirement for plates less than 610 mm wide, and 11% below the A36 requirement for plates greater than 610 mm wide and for shapes.

The JIS percent elongation requirements for plates and sheets (less than 610 mm wide), strips, flats, and shapes over 5 mm to 16 mm thick is from 20% to 35% below the A36 minimum. For plates wider than 610 mm, the JIS requirement is about 9% smaller than the A36 requirement for plates from 5 mm to less than 6 mm thick, and is from 16% to 28% smaller than the A36 requirement for plates 6 mm to 16 mm thick.

The JIS percent elongation requirement for plates and sheets, strips, flats and shapes over 16 mm to 40 mm thick is within 5% of the A36 value for plates more than 610 mm wide. For plates less than 610 mm wide, the JIS requirement is 15% less than the A36 minimum.

The JIS percent elongation minimum for bars not over 25 mm in diameter, side, or distance across flat is based on a test specimen which has no direct ASTM equivalent. However, the JIS specimen has a gage length 8 times the diameter so that for equal diameters, the JIS elongation value will be about 75% of the ASTM value for a standard specimen with a gage length 4 times the diameter (gage length = 50 mm). Based on this discussion, the JIS minimum is 28% below the A36 minimum value.

The JIS percent elongation minimum for bars over 25 mm to 40 mm in diameter, side, or distance across flat is 26% below the A36 minimum requirement.

Table 1 contains a summary of the comparison results for chemical and mechanical properties.

A36 Supplementary Requirement S14 Bend Test
See A6-77b for requirements.

Bend Test

JIS Class 1 (SS34)

For constant specimen width/thickness ratio, the JIS requirement satisfies A6 requirements for materials greater than 19 mm thick and does not satisfy A6 for materials 19 mm or less in thickness.

JIS Class 2 (SS41)

For constant specimen width/thickness ratio, the JIS requirement satisfies A6 requirements for materials greater than 51 mm thick and does not satisfy A6 for materials 51 mm or less in thickness.

JIS Class 3 (SS50)
JIS Class 4 (SS55)

For constant specimen width/thickness ratio, the JIS requirement does not satisfy A6 requirements.

Table 1. Summary Table

JIS 3101-76

EQUIVALENT TO A36-77a

Tensile Requirements

Grade	Chemistry	Strength[(a)]	Percent Elongation[(b)]
JIS Class 1	Yes, provided maximum carbon content (ladle analyses) limited to 0.30 percent	No, except at high end of JIS ranges	Yes
JIS Class 2	↓	Tensile strength - yes Yield strength - yes, except products over 40 mm to 200 mm thick	Yes, except plates over 140 mm thick less than 610 mm wide.
JIS Class 3	↓	Yes	Yes, except plates (less than 610 mm wide) and shapes greater than 6.4 mm to 16 mm thick, plates 8 mm to 16 mm thick greater than 610 mm wide, plates greater than 90 mm thick less than 610 mm wide, and plates greater than 140 mm thick and greater than 610 mm wide.
JIS Class 4	Yes, provided maximum manganese content (ladle analysis) limited to 1.2 percent	Tensile strength - No, except at lowest JIS value Yield strength - yes	No, except shapes 5 mm or less thick, plates 5 mm or less thick greater than 610 mm wide, plates from 5 mm to 6 mm thick wider than 610 mm, and plates over 16 mm to 40 mm thick.

(a) Strength Criteria

Yes - JIS requirements lie within the range from 5% above the A36 maximum value to 5% below the A36 minimum value

No - JIS requirements are more than 5% above the A36 maximum value or more than 5% below the A36 minimum value

(b) Elongation Criteria

Yes - JIS requirement is higher than or within 15% of the A36 minimum value

No - JIS requirement is more than 15% below the A36 minimum value

DIN 17100-66//ASTM A36-77a

INTRODUCTION

The scope statements for these two specifications (Scope and Definition sections in DIN 17100) are similar and refer to the same type of steel products, i.e. rolled carbon steel plates, shapes, and bars intended for use in bridges, buildings, and general structural purposes.

The structural applications of these products are for non-pressurized environments and therefore the ultimate tensile strength and yield strength properties are generally the principal design parameters. The percent elongation requirement, characterizing the tensile ductility behavior of the steel, is not usually considered to be a useful design parameter because of the dependence of elongation on specimen geometry in addition to gage length and the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17100 are considered equivalent to the requirements of ASTM A36 if the DIN values fall within the range from 5% above the A36 maximum value to 5% below the A36 minimum value; (2) the percent elongation requirements of DIN 17100 are considered equivalent to the requirements of ASTM A36 if the DIN values are higher than or within 15% of the A36 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the DIN minimum requirement, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Material furnished under specification A36-77a must conform to the applicable requirements of ASTM A6-77b, General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use. (The appropriate edition of A6 to use is that edition concurrent with the edition of A36 of interest.) The relevant sections of A6 used in this comparison include: Section 3, Description of Terms; Section 7, Chemical Analysis; Section 10, Test Methods; Section 11, Tension Tests; Section 15, Retests, and Supplementary Requirements.

CONCLUSIONS

(1) DIN grades St 33-1 and St 33-2 from DIN 17100 are not equivalent to ASTM A36-77a because as a result of the lack of chemical limits for St 33-1 and the absence of carbon or manganese limits for St 33-2, the minimum yield point for these DIN grades falls too far below the A36 minimum value.

(2) DIN grades USt 34-1, RSt 34-1, USt 34-2, and RSt 34-2 are not equivalent to ASTM A36-77a because their maximum carbon content is too low compared to the A36 limits resulting in a tensile strength range which does not generally satisfy the A36 minimum requirements.

(3) DIN grades USt 37-1, RSt 37-1, USt 37-2, RSt 37-2, and St 37-3 are not generally equivalent to ASTM A36-77a because only the top 50% of the DIN tensile strength range satisfies A36 and the DIN minimum yield point values fall from 6% to 14% below the A36 minimum requirements.

(a) DIN grades USt 37-1 and USt 37-2 (for plates and bars less than 13 mm thick and certain shapes), and RSt 37-1, however, with higher permitted carbon levels could exhibit tensile strength values at the high end of the DIN range with accompanying higher minimum yield points. To be acceptable, these DIN grades must be shown to fall within the strength acceptance criteria.

(4) DIN grades USt 42-1, RSt 42-1, USt 42-2, RSt 42-2, and St 42-3 are generally equivalent to ASTM A36-77a, based on the criteria discussed earlier, subject to the following limitations:

(a) DIN grades USt 42-1 and USt 42-2 are not allowed for plates and bars over 13 mm thick or for shapes other than Group 1 (Table A, ASTM A6-77b).

(b) For products greater than 100 mm thick, the DIN yield point requirements are subject to agreement and must equal at least 25 Kg/mm^2 for plate above 100 mm to 200 mm thick and shapes and bars above 100 mm thick, and at least 21 Kg/mm^2 for plate above 200 mm thick.

(5) DIN grades RSt 46-2 and St 46-3 are generally equivalent to ASTM A36-77a, based on the criteria discussed earlier.

(6) DIN grade St 52-3 is generally equivalent to ASTM A36-77a, based on the criteria discussed earlier. Although the maximum allowed DIN tensile strength exceeds the A36 maximum value by 9%, DIN St 52-3 is acceptable because (1) its carbon limit is well within the A36 limits and (2) its minimum elongation values fall within the elongation acceptance criterion.

(7) DIN grades St 50-1 and St 50-2 are generally equivalent to ASTM A36-77a, based on the criteria discussed earlier, subject to the following limitations:

(a) The maximum carbon content (ladle analysis) should be limited to 0.30 percent by weight to insure adequate weldability.

(b) The DIN maximum allowable tensile strength is 7% above the A36 tensile strength limit. Material exceeding the A36 tensile strength limit would be acceptable provided both the carbon content limit and the elongation acceptance criteria are both satisfied.

(c) The DIN minimum percent elongation for hot-rolled plates 5 mm or more in thickness and greater than 610 mm wide, falls from 16% to 22% below the A36 minimum requirement. To be acceptable, DIN St 50-1 and St 50-2 hot-rolled plates in this size range must be shown to fall within the elongation acceptance criteria.

(8) DIN grades St 60-1, St 60-2, and St 70-2 are not equivalent to ASTM A36-77a because the minimum DIN tensile strength values for these grades exceed the maximum A36 tensile strength requirement by more than 5% and the DIN minimum percent elongation values for most products are well below the elongation acceptance criteria.

(9) ASTM A36-77a contains the following general requirements:

(a) Shapes less than 1 in^2 (645 mm^2) in cross-section and bars, other than flats, less than 1/2" (13 mm) in thickness or diameter need not be subjected to tension tests by manufacturer.

(b) Bearing plates over 1 1/2" (38 mm) thick except when used in bridges do not require mechanical tests provided they contain 0.20 to 0.33 carbon and satisfy sulfur and phosphorus requirements.

(c) No rimmed or capped steel shall be used for plates and bars over 1/2" (13 mm) thick or for shapes other than Group 1 (see Table A, ASTM A6-77b).

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DIN 17100-66//ASTM A36-77a

STEELMAKING PROCESS

ASTM A36-77a does not allow rimmed or capped steel for plates and bars over 13 mm thick or for shapes other than Group 1 (see Table A, ASTM A6-77b) because rimmed steel is characterized by a lack of chemical homogeneity especially for carbon, sulfur, and phosphorus (see ASTM A6). Therefore, DIN steel grades USt 34-1, USt 34-2, USt 37-1, USt 37-2, USt 42-1, and USt 42-2 are not equivalent to A36 for these products. Further, according to A36, the product tolerance limits do not apply to bar-sized shapes and flat bars 13 mm or less in thickness because rimmed steels are permitted in which extensive segregation would be expected.

CHEMICAL REQUIREMENTS

The DIN chemical composition requirements are limited to maximum levels of carbon, phosphorus, sulfur, and nitrogen. The manganese and silicon levels are not generally specified. The nitrogen level, not specified in A36, is often related to the phenomenon of strain aging in plain carbon steels. The amount of nitrogen available to cause strain aging depends not only on the deoxidation practice through the addition of aluminum and/or silicon but also on the subsequent thermal treatment of the steel. Nitrogenized steels provide increased yield strength without raising the carbon content.

The DIN chemical requirements establish the maximum carbon level but allows the manganese level to vary so as to provide some flexibility in meeting both chemical and mechanical property requirements. For hot-finished carbon structural steels, the mechanical properties and weldability are usually the important criteria. When this steel is produced to mechanical property values, usual practice allows the carbon and manganese levels to vary to compensate for the effect of product thickness. Typically in these steels, strength properties decrease and tensile ductility (often measured by percent elongation) increases as the product thickness increases. The maximum carbon levels for DIN grades USt 34-1, RSt 34-1, USt 34-2, RSt 34-2, USt 37-2, RSt 37-2, St 37-3 lie 28% or more below the maximum carbon levels for any product allowed by A36. Thus, it is expected that these DIN grades probably would not satisfy the minimum A36 tensile strength and yield strength requirements, especially as the product thickness increases. However, an upper limit on the carbon content is necessary to insure adequate fusion weldability because A36 refers to the use of this steel in welded construction. Thus, based on a ladle analyis, the carbon content should not exceed 0.30 weight percent.

The maximum sulfur level for all DIN grades based on ladle analyses satisfies the requirements of A36. The maximum phosphorus level for all DIN grades based on ladle analyses exceeds the A36 heat analysis limits. The DIN phosphorus limit based on check analyses exceeds the A6 product tolerance limits for all DIN grades except St 37-3, St 42-3, St 46-3, and St 52-3. Since the structural applications identified in A36 involve only mild forming (i.e. no deep drawing) a greater latitude is often permitted in the levels of sulfur and phosphorus. The somewhat higher phosphorus levels in the DIN grades should not have a major influence on the properties of these steels for structural applications.

The DIN maximum carbon limit based on ladle analyses for grades St 60-1, St 60-2, and St 70-2 exceeds the maximum A36 carbon content for any product and further exceeds the maximum A36 carbon content for any product and further exceeds the limit set for adequate fusion weldability.

MECHANICAL PROPERTIES

Strength Requirements

DIN grades St 33-1 and St 33-2 will not consistently satisfy the minimum tensile strength requirements or the minimum yield point requirements of A36 although material at the high end of the DIN tensile strength range would satisfy A36. However, the DIN minimum yield point requirement falls from 25% to 34% below the A36 minimum requirement, depending on thickness, and probably would not satisfy A36 even for material at the high end of the DIN tensile strength range.

DIN grades USt 34-1, RSt 34-1, USt 34-2, and RSt 34-2 will not in general satisfy the minimum tensile strength requirements or the minimum yield point requirements of A36. Only the top 14% of the DIN tensile strength range exceeds the A36 minimum requirement while the DIN minimum yield point requirement falls between 15% and 18% below the A36 minimum depending on product thickness.

DIN grades USt 37-1, RSt 37-1, USt 37-2, RSt 37-2, and St 37-3 will not consistently satisfy the minimum tensile strength requirements or the minimum yield point requirements of A36. However, material in the highest 50 percent of the DIN tensile strength range does satisfy A36 and the DIN minimum yield strength value for products up to 16 mm thick is within 6% of the A36 minimum, for products over 16 mm to 40 mm thick the DIN value is within 10%, and for products over 40 mm to 100 mm thick, the DIN value is within 14%. Above 100 mm thick, the DIN requirements are subject to agreement and thus must equal 25 Kg/mm^2 for plate above 100 mm to 200 mm thick, for shapes and bars above 100 mm thick, and 21 Kg/mm^2 for plate above 200 mm thick. Material at the high end of the DIN tensile strength range would probably have a sufficiently high yield point to satisfy A36.

DIN grades USt 42-1, RSt 42-1, USt 42-2, RSt 42-2, and St 42-2 satisfy the tensile strength requirements of A36. The DIN minimum yield strength value satisfies or is within 6% of the A36 requirement for all products up to 100 mm. Above 100 mm thick, the DIN requirements are subject to agreement and thus must equal 25 Kg/mm^2 for plate above 100 mm to 200 mm thick, shapes and bars above 100 mm thick, and 21 Kg/mm^2 for plate above 200 mm thick.

DIN grades RSt 46-2 and St 46-3 satisfy the tensile strength requirements and minimum yield strength requirements of A36.

DIN grade St 52-3 generally satisfies the tensile strength requirements of A36. The maximum DIN allowed tensile strength exceeds the A36 maximum by 9% but this should not be a problem if the tensile ductility requirements of A36 as measured by percent elongation are satisfied. The DIN minimum yield strength value satisfies the A36 requirement.

DIN grades St 50-1 and St 50-2 generally satisfy the tensile strength requirements of A36. The maximum DIN tensile strength value is 7% higher than the maximum allowable A36 value but this should not be a problem if the carbon limits and tensile ductility requirements of A36 are satisfied.

The minimum tensile strength for DIN grades St 60-1, St 60-2, and St 70-2 exceeds the maximum allowed tensile strength for A36 by more than 5%.

Ductility Requirements

The dimensions of the DIN standard tensile test specimens are scaled so as to maintain a constant ratio of gage length to diameter equal to 5 for round specimens or the equivalent ratio of gage length to the square root of the cross-sectional area equal to 5.65 for specimens of other shapes. For all products equal to or greater than 19 mm thick, ASTM A6 allows either rectangular or round test specimens. The standard ASTM round specimen maintains a constant ratio of gage length to diameter equal to 4 with a gage length of 50 mm. Thus the DIN minimum elongation values represent 91% of the A36 minimum values for 50 mm gage length. The analysis in Table 1 is based on this comparison.

Table 1. Products equal to or greater than 19 mm Thick
Satisfy A36 Minimum Requirement

DIN Grade	Plates		Shapes		Bars
	<610 mm wide	>610 mm wide	>426 lb/ft	Other	
St 33-1,-2	15% Below	24% Below	Yes	Yes, within 5%	15% Below
USt 34-1,-2 RSt 34-1,-2	Yes	Yes	Yes	Yes	Yes
USt 37-1,-2 RSt 37-1,-2 St 37-3	Yes	Yes	Yes	Yes	Yes
USt 42-1,-2 RSt 42-1,-2 St 42-3 RSt 46-2 St 46-3 St 52-3	Yes	Yes, for normalized and within 6% for hot rolled	Yes	Yes	Yes

Table 1. (continued)

Products equal to or greater than 19 mm Thick
Satisfy A36 Minimum Requirement

DIN Grade	Plates <610 mm wide	Plates >610 mm wide	Shapes >426 lb/ft	Other	Bars
St 50-1,-2	Yes, within 5%	6% below for normalized and 16% below for hot-rolled	Yes	Yes	Yes, within 5%
St 60-1,-2	28% below	32% below for normalized and 43% below for hot-rolled	13% below	21% below	28% below
St 70-2	52% below	58% below for normalized and 68% below for hot-rolled	42% below	47% below	52% below

For the routine testing of plate, strip and wide flats over 5 mm thick DIN 17100 allows flat specimens of variable width with a gage length of 200 mm to be used. Results from these specimens are corrected for differences in the ratio of gage length to square root of cross-sectional area. For plate 5 mm thick to less than 19 mm thick, A6 allows only flat specimens 40 mm wide with 200 mm gage length or 12.5 mm wide with 50 mm gage length. For plate less than 8 mm thick, A36 lowers the minimum elongation requirements for the 200 mm gage length specimen. The analysis in Table 2 is based on a comparison of the A36 minimum elongation values for 200 mm gage length, 40 mm wide specimen with the DIN minimum values corrected for the 200 mm gage length specimen of the same width and thickness. For the worst case, the correction value is taken to be 0.8 from Table 4, DIN 17100.

Table 2. Satisfies A36 Minimum Requirement

DIN	Plates ≥5 mm to <8 mm thick <610 mm wide	 >610 mm wide	 ≥8mm to <19 mm thick <610 mm wide	 >610 mm wide
St 33-1,-2	Yes for 5 mm thick and 3% to 16% below for other thicknesses	Within 16% for normalized and within 14% for 6 mm and smaller hot-rolled and more than 15% below for hot-rolled plates greater than 6 mm thick	21% below	22% below
USt 34-1,-2 RSt 34-1,-2	Yes	Yes	Yes	Yes
USt 37-1,-2 RSt 37-1,-2 St 37-3	Yes	Yes	Yes	Yes
USt 42-1,-2 RSt 42-1,-2 St 42-3 RSt 46-2 St 46-2 St 52-3	Yes	Yes, normalized and within 6% for hot rolled	Yes, within 5%	Yes, within 5% for normalized and 12% below for hot rolled
St 50-1,-2	Yes, or within 7%	With 7% for normalized and within 16% for hot rolled	13% below	12% below for normalized and 22% below for hot rolled
St 60-1,-2	From 20% to 30% below	From 20% to 32% below for normalized and from 32% to 43% below for hot rolled	35% below	More than 37% below for normalize 47% below for hot rolled
St 70-2	From 45% to 53% below	From 50% to 58% below for normalized and from 62% to 68% below for hot rolled	56% below	61% below for normalized and 70% below for hot rolled

For shapes and bars less than 19 mm thick or side, A6 allows only flat specimens 40 mm wide with 200 mm gage length or 12.5 mm wide with 50 mm gage length. The DIN specimen is scaled so as to maintain a ratio of gage length to square root of cross-sectional area equal to 5.65 and thus if the thickness of the ASTM specimens is adjusted to create the same ratio, a direct comparison can be made. The analysis in Table 3 is based on this assumption for 200 mm gage length specimens.

Table 3. Satisfies A36 Minimum Requirement

DIN Grade	$\geq$8 mm to <19 mm thick Shapes and Bars
St 33-1,-2	Within 10%
USt 34-1,-2 RSt 34-1,-2	Yes
USt 37-1,-2 RSt 37-1,-2 St 37-3	Yes
USt 42-1,-2 RSt 42-1,-2 St 42-3 RSt 46-2 St 46-2 St 52-3	Yes
St 50-1,-2	Yes
St 60-1,-2	25% below
St 70-2	50% below

For shapes and flats less than 8 mm thick, A36 and A6 lower the minimum elongation requirements for both the 200 mm and 50 mm gage length specimens. The DIN values are based on a standard test specimen with a ratio of gage length to square root of the cross-sectional area equal to 5.65 for all thicknesses. However, the 200 mm ASTM specimen has a minimum thickness of 5 mm. For the range in thickness from 5 mm to 8 mm, the 200 mm gage length ASTM specimen has a ratio from about 14 to 11. Based on this difference in gage length area ratio, the ASTM specimen would measure elongation values equivalent to about 69% (for 5 mm thick) to 76% (for 8 mm thick) of the DIN values. For the range of thicknesses from 3 mm to 5mm, the 50 mm gage length ASTM specimen has a ratio from about 8 to 6. Based on this difference in gage length ratio, the ASTM specimen would measure elongation values equivalent to about 86% (for 3 mm thick) to 96% (for 5 mm thick) of the DIN values. The analysis in Table 4 is based on this assumption.

Table 4. Satisfies A36 Minimum Requirement

DIN Grade	≥3 mm to <5 mm thick Shapes	 Flats	5 mm to <8 mm thick Shapes and Flats
St 33-1,-2	Yes	Yes	17% or more below
USt 34-1,-2 RSt 34-1,-2	Yes	Yes	Yes
USt 37-1,-2 RSt 37-1,-2 St 37-3	Yes	Yes	Yes
USt 42-1,-2 RSt 42-1,-2 St 42-3 RSt 46-2 St 46-2 St 52-3	Yes	Yes	Yes, or within 8%
St 50-1,-2	Yes	Yes	Within 7% at 5 mm thick to within 16% at 8 mm thick
St 60-1,-2	Within 3% at 3 mm to within 11% at 5 mm	Within 16% at 3 mm to within 21% at 5 mm	30% below at 5 mm to 37% below at 8 mm
St 70-2	37% below at 3 mm to 40% below at 5 mm	44% below at 3 mm to 47% below to 5 mm	54% below at 5 mm to 58% below at 8 mm

For plate above 3 mm thick to 5 mm thick, DIN permits flat specimens of variable width with a 100 mm gage length and corrects the results for differences in the ratio of gage length to square root of cross-sectional area. The ASTM specimen for this thickness range has a width of 12.5 mm and a 50 mm gage length. Based only on the difference in gage length, assuming equal specimen widths, the comparison in Table 5 is made between the DIN minimum values corrected for the fixed 100 mm gage length and A36. The worst case correction factor is taken to be 0.8 from Table 4, DIN 17100.

Table 5. Satisfies A36 Minimum Requirement

Plates >3 mm to <5 mm thick

DIN Grades	<610 mm wide	>610 mm wide
St 33-1,-2	Yes	Yes
USt 34-1,-2 RSt 34-1,-2	Yes	Yes
USt 37-1,-2 RSt 37-1,-2 St 37-3	Yes	Yes
USt 42-1,-2 RSt 42-1,-2 St 42-3 RSt 46-2 St 46-2 St 52-3	Yes	Yes
St 50-1,-2	Yes	Yes
St 60-1,-2	Yes or within 12%	Yes for normalized for 3 mm and within 17% for 5 mm. For hot-rolled, 21% or more below
St 70-2	32% or more below	41% or more below for normalized and 60% or more below for hot-rolled

For plates 3 mm thick, DIN requires a flat specimen 20 mm wide with a gage length of 80 mm. The ASTM specimen has a width of 12.5 mm and a 50 mm gage length. The analysis in Table 6 is based on the relationship between gage length and cross-sectional area.

Table 6. Satisfies A36 Minimum Requirement

Plates 3 mm thick

DIN Grades	<610 mm wide	>610 mm wide
St 33-1,-2	Yes	Yes
USt 34-1,-2 RSt 34-1,-2	Yes	Yes
USt 37-1,-2 RSt 37-1,-2 St 37-3	Yes	Yes
USt 42-1,-2 RSt 42-1,-2 St 42-3 RSt 46-2 St 46-2 St 52-3	Yes	Yes
St 50-1,-2	Yes	Yes
St 60-1,-2	Yes, within 7%	Yes, within 13% for normalized but 32% for hot-rolled
St 70-2	41% below	55% below for normalized and 75% below for hot-rolled

A36 Supplementary Requirement S14 Bend Test
See A6-77b for Requirements

The ratio of specimen width to thickness is assumed to be equal and constant for both the DIN and ASTM specimens in the analysis in Table 7.

Table 7. Equivalent to A36 (A6)

DIN Grades		
St 33-1,-2	Yes	for products over 51 mm thick
USt 34-1,-2 RSt 34-1,-2	Yes	
USt 37-1,-2 RSt 37-1,-2 St 37-3	Yes	for products over 19 mm thick
USt 42-1,-2 RSt 42-1,-2 St 42-3	Yes	for products >38 mm thick
RSt 46-2 St 46-3	No	
St 52-3	No	

JIS G3454-76//ASTM A53-78

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to carbon steel pipe for pressure service. Specification ASTM A53-78 includes two grades of seamless and three grades of welded black (uncoated) and hot-dipped galvanized pipe in nominal sizes from 6 mm to 660 mm diameter in a variety of wall thicknesses. The pipe can be furnished as furnace-butt welded, electric-resistance (ERW), or seamless. Specification JIS G3454-76 contains two grades of seamless and two grades of welded black (uncoated) pipe in nominal sizes from 6 mm to 500 mm diameter in a variety of wall thicknesses. The JIS pipe, however, can be furnished only as seamless or electric-resistance welded.

The major design criteria for the intended applications of these materials are the static strength properties, ultimate tensile strength and yield strength. In addition, qualitative tests for material soundness, pressure tightness, and weld ductility are also specified. These include hydrostatic tests, bend tests, flattening tests, and nondestructive tests. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition, and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G3454 are considered equivalent to the requirements of ASTM A53 if the JIS values exceed or are within 5% of the A53 minimum value; (2) the percent elongation requirements of JIS G3454 are considered equivalent to the requirements of ASTM A53 if the JIS values exceed or are within 15% of the A53 minimum values; (3) JIS G3454 pipe to be equivalent must satisfy the qualitative test requirements of A53. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) JIS class 2 (STPG 38) from JIS G3454-76 is generally equivalent to ASTM A53-78 Grade A based on the criteria discussed earlier, subject to the following limitations:

(a) To be acceptable, longitudinal tests on JIS seamless pipe and ERW pipe, and transverse tests on ERW base metal and weld metal must be carried out.

(1) For ERW pipe to be acceptable, the transverse JIS elongation requirements for class 2 pipe, for both base metal (pipe OD >219 mm) and weld metal (pipe OD $\geq$200 mm), for wall thickness greater than 7.1 mm must be shown to satisfy the percent elongation acceptance criteria.

(b) To be acceptable, JIS class 2 ERW pipe must pass the total collapse flattening test.

(c) To be acceptable, JIS class 2 seamless pipe must pass the flattening test with a maximum surface strain of 0.09 rather than 0.08 as required by JIS G3454 for class 2, and also pass the total collapse flattening test.

(d) To be acceptable, JIS schedule 20 class 2 pipe with 50 mm, 65 mm, 80 mm, 90 mm, and 350 mm outside diameter must satisfy the A53 Grade A hydrostatic test pressures.

(e) To be acceptable, JIS schedule 40 class 2 pipe with 32 mm, 40 mm, 50 mm, 65 mm, 80 mm, 90 mm, 100 mm, 125 mm, 350 mm, 450 mm, and 500 mm outside diameter must satisfy the A53 Grade A hydrostatic test pressures.

(f) To be acceptable, JIS schedule 60 class 2 pipe with 32 mm, 40 mm, 50 mm, 65 mm, 80 mm, 90 mm, and 100 mm outside diameter, must satisfy the A53 Grade A hydrostatic test pressures.

(g) To be acceptable, JIS schedule 80 class 2 pipe with 50 mm, 65mm, and 90 mm outside diameter must satisfy the A53 Grade A hydrostatic test pressures.

(h) To be acceptable, JIS class 2 ERW pipe 50 mm and larger outside diameter must pass the nondestructive test requirements of A53 Section 11.

(2) JIS class 3 (STPG 42) from JIS G3454-76 is generally equivalent to ASTM A53-78 Grade B based on the criteria discussed earlier, subject to the following limitations:

(a) To be acceptable, the weld seam in JIS ERW pipe must be heat treated after welding to 540 C or above or so processed so that untempered martensite is not present.

(b) To be acceptable, longitudinal tests on JIS seamless pipe and ERW pipe, and transverse tests on ERW base metal and weld metal must be carried out.

(1) For ERW pipe to be acceptable, the transverse JIS elongation for class 3 pipe for both base metal (pipe OD $\geq$219 mm) and weld metal (pipe OD $\geq$200 mm), for wall thickness greater than 6.4 mm must be shown to satisfy the percent elongation acceptance criteria.

(c) To be acceptable, JIS class 3 ERW pipe must pass the total collapse flattening test.

(d) To be acceptable, JIS class 3 seamless pipe must pass the total collapse flattening test.

(e) To be acceptable, JIS schedule 20 class 3 pipe with 50 mm, 65 mm, 80 mm, 90 mm, 100 mm, 400 mm, and 500 mm diameters must satisfy the A53 Grade B hydrostatic test pressures.

(f) To be acceptable, JIS schedule 30 class 3 pipe with 300 mm and 350 mm diameters must satisfy the A53 Grade B hydrostatic test pressures.

(g) To be acceptable, JIS schedule 40 class 3 pipe with 50 mm, 65 mm, 80 mm, 90 mm, 100 mm, 125 mm, 150 mm, and 200 mm diameters must satisfy the A53 Grade B hydrostatic test pressures.

(h) To be acceptable, JIS schedule 60 class 3 pipe with 50 mm, 65 mm, 80 mm, 90 mm, 100 mm, 125 mm, and 150 mm diameters must satisfy the A53 Grade B hydrostatic test pressures.

(i) To be acceptable, JIS schedule 80 class 3 pipe with 50 mm, 65 mm, 90 mm, 100 mm, 125 mm, and 150 mm diameters must satisfy the A53 Grade B hydrostatic test pressures.

(j) To be acceptable, JIS class 3 ERW pipe 50 mm and larger outside diameter must pass the nondestructive test requirements of A53 Section 11.

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CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analysis for JIS class 2 (STPG 38) pipe satisfy the chemical limits for ASTM A53 grade A pipe. The JIS maximum carbon level is identical to the A53 requirement while the maximum JIS levels of the impurities sulfur and phosphorus are below the A53 maximum levels. The maximum JIS manganese limit is slightly below the A53 maximum limit but is not significant provided the A53 mechanical property requirements are satisfied. The silicon content of A53 grade A is not specified because it depends on the deoxidation practice employed. The silicon limit permitted by G3454 is typical for killed steels and is not inconsistent with A53.

The chemical composition limits based on ladle analyses for JIS class 3 (STPG 42) pipe satisfy the chemical limits for ASTM A53 grade B pipe. The JIS maximum carbon level is identical to the A53 requirement while the maximum JIS levels of the impurities sulfur and phosphorus are below the A53 maximum levels. The maximum JIS manganese level is below the A53 maximum level but is not significant provided the A53 mechanical property requirements are satisfied. The silicon content of A53 grade B is not specified because it depends on the deoxidation practice employed. The silicon level permitted by G3454 is typical for killed steels and is not inconsistent with A53.

MECHANICAL PROPERTIES

Heat Treatment

Electric-resistance welded pipe produced to ASTM A53 grade B must have the weld heat treated so that no untempered martensite remains. The higher maximum carbon level in grade B pipe combined with the high weld cooling rates experienced in electric-resistance welding increases the possibility of the formation of untempered martensite, a brittle, undesirable structure, in the weld region. In JIS G3454, heat treatment of the weld in electric-resistance welded pipe is not mandatory and thus untempered martensite could be present resulting in weld cracking.

Strength Requirements

The ASTM test specimen requirements are taken from both ASTM A53 and ASTM A370, Sections S5 and S6. For both seamless pipe and ERW pipe, longitudinal specimens (parallel to pipe axis) are required and can be either rectangular (preferred and w/curved cross-section) located 90° from weld (for ERW) or full sections. Longitudinal specimens containing the weld are not required. For the transverse orientation, base metal and weld metal specimens are required for ERW pipe and are to be taken from flattened ring sections. Transverse tests are not required for seamless pipe. Finally, the longitudinal and transverse strength requirements in A53 for both the base metal and weld metal of ERW pipe and seamless pipes, for each grade, are equal.

In JIS G3454, longitudinal and transverse tests are required for both seamless and ERW pipe, although for ERW pipe, no specific distinction is made between base metal and weld metal. For both seamless pipe and ERW pipe, longitudinal specimens can be either rectangular (w/curved cross-section) located at an unspecified location from weld or full section, as in A53. Transverse specimens are to be taken from a flattened pipe section in a similar manner to the requirement in A53. Thus, the strength requirements of the two specifications can be directly compared, provided both weld metal and base metal from ERW pipes are tested.

The minimum ultimate tensile strength and yield strength requirements specified for JIS G3454 class 2 (STPG 38) exceed the A53 minimum requirements for Grade A for either seamless or ERW pipe.

The minimum ultimate tensile strength and yield strength requirements specified for JIS G3454 class 3 (STPG 42) exceed or are within 1% of the A53 minimum requirements for Grade B for either seamless or ERW pipe.

Ductility Requirements

These two specifications contain differing approaches to the question of tensile ductility as measured by percent elongation for 50 mm gage length from ultimate tensile strength and specimen cross-sectional area through an empirical equation as follows:

$$e = 625{,}000 \frac{A^{0.2}}{U^{0.9}}$$

where A = specimen cross-sectional area
U = ultimate tensile strength for grade
e = percent elongation in 50 mm

Thus, the minimum percent elongation for each grade of A53 pipe is different and depends on the type of test specimen used and pipe wall thickness as shown in A53 Table X7. There is no distinction between longitudinal and transverse specimen requirements. Longitudinal tensile tests are required for all sizes of both seamless pipe and ERW pipe. Transverse tests are required only for the ERW welds for pipes 200 mm or greater in diameter and for ERW pipe base metal for pipes greater than 219 mm in outside diameter.

In JIS G3454, a minimum percent elongation is specified for longitudinal and transverse specimens for each grade based on ultimate tensile strength but independent of pipe wall thickness and specimen cross-sectional area. No distinction is made between seamless and ERW pipe and thus it is assumed that longitudinal tests are required on all sizes while transverse tests are required for all pipe 200 mm or more in outside diameter. Further, G3454 does not require pipe less than 20 mm in diameter to satisfy the elongation requirements.

The preferred ASTM test specimens for longitudinal tests are strap specimens with the curved cross-section between the 50 mm gage marks and standard specimen widths of 19 mm, 25 mm, and 38 mm. For pipe with very thick wall sections, the standard round 50 mm gage length, specimen (L/D = 4) is permitted. Also if desired, full sections with 50 mm gage length can be used.

For transverse tests of both ERW welds and base metal, the preferred ASTM specimen is flattened, 38 mm wide, 50 mm gage length, and full wall thickness.

The preferred JIS test specimens for longitudinal tests are also strap specimens with curved cross-sections, 50 mm gage length, and standard widths of 19 mm, 25 mm, and 38 mm. For pipe with very thick wall sections, a standard round 50 mm gage length specimen (L/D = 3.54) is permitted. Also, full sections with 50 mm gage length can be used. For transverse tests, the preferred JIS specimen is also a flattened, 50 mm gage length, specimen but the width is only 25 mm.

The comparison of the elongation requirements for these two specifications was carried out in the following manner. For longitudinal requirements, the preferred specimens from A53 and G3454 are the same and thus can be directly compared. Using Table X7 in A53, the percent elongation range for Grade A pipe, seamless or ERW, lies between 24% and 36% depending on wall thickness. The percent elongation range for Grade B pipe lies between 19 1/2% and 29 1/2% depending on wall thickness. These ranges can be compared with the JIS requirement based on the pipe size - specimen size requirements of Table 5 in JIS G3454. For the longitudinal requirements, the JIS class 2 minimum elongation requirement exceeds or is within 15% of the A53 Grade A minimum requirement for all pipe sizes. Similarly, the JIS class 3 elongation requirements exceed or are with 15% of the A53 Grade B minimum requirement for all pipe sizes.

For comparison of transverse requirements, an adjustment must be made because the cross-sectional area of the JIS test specimen is only 66% of the ASTM specimen. Using the empirical relation between percent elongation and specimen area, the JIS equivalent elongation is 92% of the ASTM elongation. Based on this adjustment, the minimum JIS class 2 elongation requirement for all pipe diameter with a wall thickness equal to or smaller than 7.1 mm exceed or are within 15% of the requirements for A53 Grade A pipe. The minimum JIS class 3 elongation requirement for all pipe diameters with a wall thickness equal to or smaller than 6.4 mm exceed or are within 15% of the requirements for A53 Grade B pipe.

Bend Test Requirements

Bend tests of various types are typically used as qualitative measures of material ductility, especially with respect to forming operations. Generally, the material must be bent to some minimum angle around a mandrel, and passes the test if no cracking is observed and fails the test if cracks occur. For pipe or tubing, bend tests are usually required only for small outside diameter sizes and the lower range of wall thicknesses. For larger diameter pipe and thick-walled pipe, a flattening test replaces the bend test as a measure of ductility and soundness. Thus, although the type of test required is strongly influenced by the pipe dimensions, both are a measure of the same qualitative behavior.

The bend test requirements in A53 for Grade A and Grade B pipe, both seamless and ERW pipe for regular or close coiling usage, are required for pipe

50 mm or smaller in diameter. Specification JIS G3454 contains the identical requirements for class 2 and class 3 pipe 40 mm or smaller in diameter. For pipe larger than these two sizes, both A53 and G3454 require flattening tests. There appears to be no basis for concluding for this one size of pipe, i.e. JIS 50 mm, that one test is more severe than the other because these tests are only qualitative "go/no go" tests.

Flattening Test Requirements

Specification A53 requires flattening tests on all pipe, both seamless and ERW, over 50 mm in nominal outside diameter and weight classes Schedule 80 and lighter. The test is a multipart test which qualitatively measures ductility of both weld and base metal and pipe soundness.

For electric-resistance welded pipe, A53 contains a three-part test. Part 1, a measure of weld ductility, calls for a section of pipe with the weld located at various positions with respect to the direction of force, to be flattened to a fixed fraction of the pipe diameter without cracking. In Part 2, a measure of base metal ductility, the pipe must be flattened further to a smaller fraction of the pipe diameter without base metal cracking. Finally, in Part 3, a measure of internal soundness, the pipe is totally collapsed and examined for evidence of delamination in the base metal or an incomplete weld. For ERW pipe greater than 50 mm diameter, both A53 Grade A and Grade B and JIS G3454 class 2 and class 3 have almost identical requirements for the Part 1 and Part 2 tests. In JIS G3454, the weld must be located 90° from direction of force, the most severe location, while A53 requires, in addition, other less severe weld orientations. If the JIS pipe satisfies the other ductility requirements, both quantitative and qualitative, this deficiency in the JIS requirements should not be substantial. However, JIS G3454 is deficient because it does not contain the A53 Part 3 test.

For seamless pipe, A53 contains only a two-part test due to the absence of the weld. Part 1, a measure of pipe ductility, requires a section of pipe to be flattened to a fraction of the pipe diameter without cracking. This critical height is a function of pipe diameter, wall thickness, and maximum allowed strain. The equation relating these parameters can be derived from theoretical analysises of bending of a curved section. This equation can be written as:

$$e = \frac{1 - \frac{H}{D}}{\frac{H}{D} \cdot \frac{D}{t} - 1}$$

where H = distance between flattening plates
t = wall thickness
D = pipe outside diameter
e = maximum strain at outer pipe surface

Both A53 and JIS G3454 base their flattening test requirements on this exact equation. This equation does not account for the experimental observation that the actual maximum strain experienced in flattening pipe exceeds substantially the calculated value from the above equation. This effect, called "peaking", is not important for this discussion since both ASTM and JIS use only the theoretical equation.

The maximum strain required by the test is 0.07 for both A53 Grade B and JIS G3454 class 3 and thus the requirements are identical. However, for Grade A, A53 requires a maximum surface strain of 0.09 compared to 0.08 required for JIS G3454 class 2. The A53 Grade A pipe must experience greater strain (greater flattening), about 12% more, before cracking than JIS class 2.

Finally, Part 2 of the A53 test, a measure of internal soundness of seamless pipe, requires that the pipe be totally collapsed and examined for evidence of delamination. However, JIS G3454 is deficient because it does not contain this requirement.

Hydrostatic Test Requirements

Specification A53 requires all lengths of pipe to be hydrostatically tested at pressures depending on pipe size and wall thickness without leaking. Specification JIS G3454, also requires a hydrostatic test but permits the hydrostatic test to be replaced by an unnamed but equivalent nondestructive test. For this comparison, the hydrostatic test requirement for JIS pipe will be taken as applicable.

All pipe sizes of JIS schedule 10 pipe in class 2 and class 3 satisfy the A53 requirements for Grade A and Grade B, respectively. For JIS schedule 20 class 2 pipe, all sizes satisfy the A53 requirements for Grade A pipe except the 50 mm, 65 mm, 80 mm, 90 mm, and 350 mm diameters which are from 10% to 53% below the A53 requirements. For JIS schedule 20 class 3 pipe, all sizes satisfy the A53 requirements for Grade B pipe except the 50 mm, 65 mm, 80 mm, 90 mm, 100 mm, 400 mm and 500 mm diameters which are 8% to 43% below the A53 requirements. For JIS schedule 30 class 2 pipe, all sizes satisfy the A53 requirements for Grade A pipe. For JIS schedule 30 class 3 pipe, all sizes satisfy the A53 requirements for Grade B pipe except the 300 mm and 350 mm diameters which are 9% and 11%, respectively, below the A53 requirements. For JIS schedule 40 class 2 pipe, all sizes satisfy the A53 requirements for Grade A pipe except the 32 mm, 40 mm, 50 mm, 65 mm, 80 mm, 90 mm, 100 mm, 125 mm, 350 mm, 450 mm, and 500 mm diameters which are 11% to 60% below the A53 requirements. For JIS schedule 40 class 3 pipe, all sizes satisfy the A53 requirements for Grade B pipe except the 50 mm, 65 mm, 80 mm, 90 mm, 100 mm, 125 mm, 150 mm and 200 mm diameters which are 9% to 43% below the A53 requirements. For JIS schedule 60 class 2 pipe, all sizes satisfy the A53 requirements for Grade A pipe except the 32 mm, 40 mm, 50 mm, 65 mm, 80 mm, 90 mm, and 100 mm diameters which are 12% to 43% below the A53 requirements. For JIS schedule 60 class 3 pipe, all sizes satisfy the A53 requirements for Grade B pipe except the 50 mm, 65 mm, 80 mm, 90 mm, 100 mm, 125 mm, and 150 mm diameters which are 13% to 31% below the A53 requirements. For JIS schedule 80 class 2 pipe, all sizes satisfy the A53 requirements for Grade A pipe except the 50 mm, 65 mm, and 90 mm diameters which are 9% to 26% below the A53 requirements. For JIS schedule 80 class 3 pipe, all sizes satisfy the A53 requirements for Grade B pipe except the 50 mm, 65 mm, 90 mm, 100 mm, 125 mm, and 150 mm diameters which are 7% to 20% below the A53 requirements.

Nondestructive Test Requirements

The weld quality of ERW pipe 50 mm and larger must be checked according to A53 by an ultrasonic or electromagnetic technique capable of detecting flaws in the weld with a sufficient sensitivity as contained in A53. Flaws that do no reduce the wall thickness by more than 12 1/2% of the wall thickness are allowed by A53. Specification JIS G3454 permits but does not require the use of such nondestructive tests.

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to carbon steel pipe for pressure service. Specification A53-78 includes two strength grades of seamless pipe and three strength grades of welded black (uncoated) and hot-dipped galvanized pipe in nominal sizes from 6 mm to 660 mm outside diameter in a variety of wall thicknesses. The A53-78 welded pipe can be furnished as either furnace - butt welded or electric-resistance welded (ERW). Specification DIN 1626-65 contains four strength grades of plain end, welded black pipe in nominal sizes from 6 mm to 1016 mm outside diameter in a variety of wall thicknesses. The DIN welded pipe can be furnished as either fusion welded, pressure welded (furnace-butt welded) or pressure electric welded (ERW).

The major design criteria for the intended applications of these materials are the static strength properties, ultimate tensile strength and yield strength. In addition, qualitative tests for material soundness, pressure tightness, and weld ductility are also specified. These include hydrostatic tests, bend tests, flattening tests, and nondestructive tests. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition, and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 1626 are considered equivalent to the requirements of ASTM A53 if the DIN values exceed or are within 5% of the A53 minimum value; (2) the percent elongation requirements of DIN 1626 are considered equivalent to the requirements of ASTM A53 if the DIN values exceed or are within 15% of the A53 minimum values; (3) DIN 1626 pipe to be equivalent must satisfy the qualitative test requirements of A53. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Specification DIN 1626-65 classifies welded steel pipes into three quality categories: commercial quality, quality specification, and specially tested pipes with quality specifications. Commercial quality, the lowest category, is described in Sheet 2 of DIN 1626-65 with primarily chemical, tensile test and hydrostatic test requirements.

Quality specification, the intermediate level described by Sheet 3, contains additional requirements including flattening and bending tests for fusion welded pipe and flattening tests for butt-welded pipe to insure weld quality and base metal soundness. In the highest quality category, described in Sheet 4, additional requirements for nondestructive tests for weld quality are included. Generally, this comparison will focus on the Sheet 4 requirements but where necessary reference will also be made to the lower quality categories.

CONCLUSIONS

(1) DIN grades St 37 (1.0110) and St 42 (1.0130) of Sheet 2 quality from DIN 1626-65 with butt-welded joints are not generally equivalent to ASTM A53-78 Type F pipe because these DIN grades have marginal longitudinal ductility and inadequate transverse ductility as measured by percent elongation, lack any flattening test requirements, and have severely deficient hydrostatic test requirements.

(2) DIN grade St 34-2 (1.0102) of Sheet 3 quality from DIN 1626-65 with a butt-welded joint is not generally equivalent to ASTM A53-78 Type F pipe because of a severely deficient hydrostatic test requirement for most pipe sizes.

(3) DIN grade St 34-2 (1.0102) of Sheet 4 quality from DIN 1626-65 with a butt-welded joint is generally equivalent to ASTM A53-78 Type F pipe based on the criteria discussed earlier, subject to the following limitations:

> (a) To be acceptable, longitudinal strength and percent elongation requirements for DIN pipe with outside diameters greater than 200 mm must satisfy the respective acceptance criteria for A53 Type F.
>
> (b) To be acceptable, all sizes of the DIN pipe must pass the part 2 and part 3 requirements in A53 for the flattening test.
>
> (c) To be acceptable, the following pipe sizes must satisfy the A53 Type F hydrostatic test requirement:
>
> 10.2 mm OD, wall thickness greater than 2.3 mm
> 13.5 mm OD, wall thickness greater than 2.9 mm
> 17.2 mm OD, wall thickness greater than 3.2 mm
> 21.3 mm OD, wall thickness greater than 7.1 mm
> 27.2 mm OD, wall thickness greater than 7.1 mm
> 33.7 mm OD, wall thickness greater than 8.8 mm
> 42.4 mm OD, wall thickness greater than 3.6 mm
> 48.3 mm OD, wall thickness greater than 3.6 mm
> 60.3 mm OD, wall thickness greater than 4.0 mm
> 88.9 mm OD, wall thickness greater than 5.6 mm
> 101.6 mm OD, wall thickness greater than 4.0 mm

(4) DIN grades St 34-2 (1.0102) and St 37-2 (1.0112) of Sheet 3 quality from DIN 1626-65 with electric-resistance weld joints are not generally equivalent to ASTM A53-78 Type E grade A because of a lack of mandatory NDE tests for weld quality, and severely deficient hydrostatic test requirements for most pipe sizes.

(5) DIN grade St 34-2 (1.0102) of Sheet 4 quality from DIN 1626-65 with an electric-resistance weld joint is generally equivalent to ASTM A53-78 Type E grade A based on the criteria discussed earlier, subject to the following limitations:

(a) To be acceptable, longitudinal strength and percent elongation requirements for DIN pipe with outside diameters greater than 200 mm must satisfy the respective acceptance criteria for A53 Type E grade A.

(b) To be acceptable, all sizes of DIN pipe must pass the part 2 and part 3 requirements in A53 for the flattening test.

(c) To be acceptable, the following pipe sizes must satisfy the A53 Type E grade A hydrostatic test requirement:

10.2 mm OD, wall thickness greater than 2.3 mm
13.5 mm OD, wall thickness greater than 2.9 mm
17.2 mm OD, wall thickness greater than 3.2 mm
21.3 mm OD, wall thickness greater than 7.1 mm
27.2 mm OD, wall thickness greater than 7.1 mm
33.7 mm OD, wall thickness greater than 7.1 mm
42.4 mm OD, all wall thicknesses
48.3 mm OD, all wall thicknesses
60.3 mm OD, all wall thicknesses
88.9 mm OD, all wall thicknesses
101.6 mm OD, wall thickness greater than 3.2 mm
114.3 mm OD, wall thickness greater than 3.2 mm
139.7 mm OD, wall thickness greater than 3.6 mm
168.3 mm OD, wall thickness greater than 4.5 mm
219.1 mm OD, wall thickness greater than 6.3 mm
273 mm OD, wall thickness greater than 8.8 mm
323 mm OD, wall thickness greater than 10 mm
355.6 mm OD, wall thickness greater than 11 mm
406.4 mm OD, wall thickness greater than 14.2 mm
457.2 mm OD, wall thickness greater than 14.2 mm
508 mm OD, wall thickness greater than 12.5 mm
609.6 mm OD, wall thickness greater than 17.5 mm
660.4 mm OD, wall thickness greater than 14.2 mm

(d) To be acceptable, the sensitivity of the DIN nondestructive tests must satisfy the requirements of A53.

(6) DIN grade St 37-2 (1.0112) of Sheet 4 quality from DIN 1626-65 with electric-resistance weld joint is generally equivalent to ASTM A53-78 Type E grade A based on the criteria discussed earlier, subject to the following limitations:

(a) To be acceptable, the longitudinal strength and percent elongation elongation requirements for DIN pipe with outside diameters greater than 200 mm must satisfy the respective acceptance criteria.

(b) To be acceptable, the transverse percent elongation for DIN pipe must satisfy the elongation acceptance criterion for A53 Type E grade A.

(c) To be acceptable, all sizes of DIN pipe must pass the part 2 and part 3 requirements in A53 for the flattening test.

(d) To be acceptable, the pipe sizes identified in Section (5)(c) of this Conclusion section must satisfy the A53 Type E grade A hydrostatic test requirements.

(e) To be acceptable, the sensitivity of the DIN nondestructive tests must satisfy the requirements of A53.

(7) DIN grades St 42-2 (1.0132) and St 52-3 (1.0841) of Sheet 4 quality from DIN 1626-65 with ERW joint is generally equivalent tc ASTM A53-78 Type E grade B based on the criteria discussed earlier, subject to the following limitations:

(a) To be acceptable, the longitudinal strength and percent elongation requirements for DIN pipe with outside diameters greater than 200 mm must satisfy the respective acceptance criteria for A53 Type E grade B.

(b) To be acceptable, the weld seam in DIN ERW pipe must be heat-treated to 540 °C or above after welding, or so processed to ensure untempered martensite is not present.

(c) To be acceptable, all sizes of DIN pipe must pass the part 2 and part 3 requirements in A53 for the flattening test.

(d) To be acceptable, the following pipe sizes must satisfy the A53 Type E grade B hydrostatic test requirements:

10.2 mm OD, wall thickness greater than 2.3 mm
13.5 mm OD, wall thickness greater than 2.9 mm
17.2 mm OD, wall thickness greater than 3.2 mm
21.3 mm OD, wall thickness greater than 7.1 mm
27.2 mm OD, wall thickness greater than 7.1 mm
33.7 mm OD, wall thickness greater than 8.8 mm
42.4 mm OD, all wall thicknesses
48.3 mm OD, all wall thicknesses
60.3 mm OD, all wall thicknesses
88.9 mm OD, all wall thicknesses
101.6 mm OD, all wall thicknesses
114.3 mm OD, all wall thicknesses
139.7 mm OD, all wall thicknesses
168.3 mm OD, all wall thicknesses
219.1 mm OD, all wall thicknesses
273 mm OD, wall thickness greater than 7.1 mm
323 mm OD, wall thickness greater than 8 mm
355.6 mm OD, wall thickness greater than 8.8 mm
406.4 mm OD, wall thickness greater than 11 mm

457.2 mm OD, wall thickness greater than 11 mm
508 mm OD, wall thickness greater than 12.5 mm
609.6 mm OD, wall thickness greater than 14.2 mm
660.4 mm OD, wall thickness greater than 14.2 mm

(d) To be acceptable, the sensitivity of the DIN nondestructive tests must satisfy the requirements of A53.

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FABRICATION PROCESS

The welded pipes covered by A53 can be fabricated by either of two processes. Furnace butt-welded pipe (Type F) has the longitudinal joint forge welded by mechanical pressure developed in rolling. Electric-resistance welded (ERW) pipe (Type E) has the longitudinal joint produced by heat from the resistance of the pipe to the passage of electric current. Neither the furnace butt welding or ERW process are fusion processes, that is, a molten weld zone is not formed. In DIN 1626, three welding processes can be used: fusion welding, pressure welding (similar to furnace butt-welding), and pressure electric welding (similar to ERW). This comparison will be limited to the furnace butt-welded pipe and ERW pipe as contained in A53. All three grades in DIN Sheet 2 quality pipe can be fabricated by either furnace butt-welding or ERW methods. In Sheet 3 quality, grades St 34-2 and St 37-2 can be fabricated by either furnace butt-welding, grades St 34-2 and St 37-2 can be fabricated by either furnace butt-welding or ERW while grades St 42-2 and St 52-3 can only be fabricated by ERW methods. Sheet 4 quality requires all grades, St 34-2, St 37-2, St 42-2, and St 52-3 to be fabricated by ERW methods.

Further, although both A53 Type F pipe and DIN 1626 Sheet 2 pipe are not intended for flanging, A53 requires flattening and bending tests while DIN Sheet 2 does not. DIN Sheet 3 and Sheet 4 pipe include these tests in addition to permitting flanging. Thus A53 Type F pipe can be compared with grades St 37 and St 42 as Sheet 2 quality and grades St 34-2 and St 37-2 as DIN Sheet 3 quality while Type E pipe can be compared with St 34-2, St 37-2, St 42-2, and St 52-3 as Sheet 3 or Sheet 4 quality.

CHEMICAL REQUIREMENTS

Specification DIN 1626-65 includes seven grades based on chemical composition. DIN Sheet 2 covers three grades, St 33 (1.0033), St 37 (1.0110), and St 42 (1.0130) and DIN Sheet 3 and Sheet 4 cover the same four grades, St 34-2 (1.0102), St 37-2 (1.0112), St 42-2 (1.0132) and St 52-3 (1.0841). Specification A53-78 includes three grades: one grade for Type F pipe and two grades for Type E pipe, Grade A and Grade B.

The chemical composition requirements for six of the seven DIN grades are limited to carbon, phosphorus, and sulfur while A53 Type F limits only phosphorus and sulfur and A53 Type E limits manganese as well as carbon, phosphorus, and sulfur. DIN grade St 52-3 has a maximum manganese level of 1.5%. Typically, for hot-finished carbon steels the mechanical properties are influenced by the product thickness. Thus, when steel is produced to mechanical property requirements, usual practice allows the carbon level or manganese level or both to vary to compensate for the effect of product thickness. The absence of a manganese limit for six of the seven DIN grades or carbon and manganese limits for A53 Type F provide this flexibility in meeting both chemical and mechanical property requirements. Therefore, the intent of the general chemical composition limits for these two specifications are similar.

The chemical composition limits based on ladle analyses for grade St 37 and St 42 from Sheet 2 and St 34-2 and St 37-2 from Sheet 3 satisfy the chemical limits for ASTM A53 Type F pipe. The DIN maximum permitted phosphorus and sulfur levels are identical to or below the A53 requirements.

The chemical composition limits based on ladle analyses for DIN grades St 34-2, St 37-2, St 42-2, and St 52-3 from Sheets 3 and 4 satisfy the chemical limits for ASTM A53 Type E, Grades A and B pipe. The DIN maximum carbon, phosphorus, and sulfur levels for St 34-2 and 52-3 are identical to or below the A53 requirements. Although the manganese limit for St 52-3 is higher than the A53 requirements (0.95% max for Grade A and 1.2% max for Grade B), this is balanced by the lower carbon maximum permitted by DIN St 52-3. The DIN maximum carbon and sulfur levels for St 37-2 and St 42-2 are identical to or below the A53 requirements while the DIN phosphorus maximum for these two grades is slightly higher than the A53 maximum value. This somewhat greater phosphorus limit for these two DIN grades should not be a problem provided the DIN grades pass the flattening and bend tests as a measure of weld quality and base metal soundness.

MECHANICAL PROPERTIES

Heat Treatment

Electric-resistance welded pipe produced to ASTM A53 grade B must have the weld heat treated so that no untempered martensite remains. The higher maximum carbon level in grade B pipe combined with the high weld cooling rates for ERW increases the possibility of the formation of untempered martensite, a brittle, undesirable structure. In DIN 1626, heat treatment of the ERW grades after fabrication is optional and thus untempered martensite could be present resulting in weld cracking.

Strength Requirements

The ASTM test specimen requirements are taken from both ASTM A53 and ASTM A370, Sections S5 and S6. For both butt-welded pipe and ERW pipe, longitudinal specimens (parallel to pipe axis) are required and can be either rectangular (preferred and w/curved cross-section) located 90° from weld or full pipe section specimens. For the transverse orientation (perpendicular to the weld), weld metal specimens are required for both butt-welded pipe and ERW pipe 200 mm or large in outside diameter while base metal specimens are required for ERW pipe 219 mm or large in outside diameter. The longitudinal and transverse strength requirements in A53 for both base metal and weld metal of butt-welded pipe and ERW pipe, for each grade, are equal.

The test specimen requirements for DIN 1626-65 are specific for each level of quality as described in Sheets 2, 3, and 4. For Sheet 2 quality, only base metal properties from longitudinal specimens from an undefined location are guaranteed. For Sheet 3 and Sheet 4 qualities, base metal properties from longitudinal specimens located 90° from the weld are required for pipes with outside diameter equal to or less than 200 mm while transverse specimen tests on base metal and weld metal are required for pipes greater than 200 mm outside diameter. These specimen requirements are independent of the welding process used to fabricate the pipes. Flat rectangular test specimens with curved cross-sections are required for both longitudinal and transverse tests although for small diameter pipe, full section specimens are permitted. The strength requirements for each DIN grade are the same for both longitudinal and transverse specimens and both butt-welded and ERW pipe.

The minimum ultimate tensile strength and yield strength requirements for DIN 1626 grades St 34-2 and St 37-2 exceed or are within 1% of the A53 minimum requirements for Type E grade A pipe.

The minimum ultimate tensile strength and yield strength requirements for DIN 1626 grades St 42-2 and St 52-3 exceed or are within 1% of the A53 minimum requirements for Type E grade B pipe.

Ductility Requirements

These two specifications contain differing approaches to the question of tensile ductility as measured by percent elongation. ASTM A53 calculates the minimum percent elongation for 50 mm gage length from ultimate tensile strength and specimen cross-sectional as follows:

$$e = 625.000 \frac{A^{0.2}}{U^{0.9}}$$

where A = specimen cross-sectional area
U = ultimate tensile strength for grade
e = percent elongation in 50 mm

Thus, the $L/\sqrt{A}$ ratio (L = gage length) varies for each specimen and the minimum percent elongation for each pipe grade of A53 is different and depends on type of test specimen and pipe wall thickness as shown in A53 Table X7. There is no distinction between longitudinal and transverse requirements. Longitudinal tensile tests are required for all sizes of both butt-welded and ERW pipe. Transverse tests of welds are required for ERW and butt-welded pipe 200 mm or greater in outside diameter and for ERW base metal for pipes greater than 219 mm in outside diameter.

In DIN 1626, a minimum percent elongation is specified for longitudinal specimens for each grade based on ultimate tensile strength but independent of pipe wall thickness and specimen cross-sectional area. The transverse requirements are lower by two units. No distinction is made between butt-welded pipe and ERW pipe and longitudinal tests are required on on pipe $\leq$ 200 mm outside diameter while transverse tests are required only on pipe >200 mm outside diameter.

The preferred ASTM test specimen for longitudinal tests are strap specimens with a curved pipe cross-section between 50 mm gage marks, full wall thickness, and standard specimen widths of 19 mm, 25 mm, and 38 mm. For pipe with very thick wall sections, the standard round 50 mm gage length specimen (L/D = 4) is permitted also, if desired, full sections with 50 mm gage length can be used. For transverse tests, the sections with 50 mm gage length can be used. For transverse tests, the preferred specimen is flattened, 38 mm wide, 50 mm gage length, and full wall thickness.

The preferred DIN test specimen for both longitudinal and transverse tests is a flat specimen, full wall thickness, with a changing gage length to yield a constant $L/\sqrt{A}$ ratio of 5.65 or L/D ratio of 5. The transverse specimen is taken from flattened pipe rings. As a result of the two approaches to establishing the minimum percent elongation requirements, a direct comparison between A53 and DIN 1626 cannot be easily made. However, since for all DIN specimens, $L/\sqrt{A}$ is 5.65, it is possible using A53 Table X7 to calculate the specimen area for constant L = 50 mm at the same $L/\sqrt{A}$ and then compare for any ASTM specimen the resulting expected percent elongation. Assuming the correlation between gage length and specimen area does not change over the range of pipe wall thicknesses in A53, then the conclusion can be drawn that if requirements of both specifications are satisfied at the same $L/\sqrt{A}$ ratio, then the requirements will be satisfied as the specimen dimensions change. With this approach, the minimum percent elongation for Type F pipe is 26.5%, Type E grade A pipe is 25%, and Type E grade B pipe is 20%.

The minimum longitudinal percent elongation for Sheet 2 DIN grades St 37 and St 42 are 13% and 25%, respectively, below the A53 minimum requirement for Type F pipe. Assuming the DIN transverse minimum values are 2% below the longitudinal values, the minimum transverse percent elongation for Sheet 2 DIN grades St 37 and St42 are 21% and 32%, respectively, below the A53 minimum requirements for Type F pipe.

The minimum longitudinal percent elongation for Sheet 3 and Sheet 4 DIN grades St 34-2 and St 37-2 are 2% and 13%, respectively, below the A53 minimum requirement for Type F pipe. The minimum transverse elongation requirements for Sheet 3 and Sheet 4 DIN grades St 34-2 and St 37-2 are 9% and 21%, respectively, below the A53 minimum requirement for Type F pipe.

The minimum longitudinal elongation requirements for Sheet 3 and Sheet 4 DIN grades St 34-2 and St 37-2 satisfy or are within 8% of the A53 minimum requirement for Type E grade A pipe. The minimum transverse percent elongation for Sheet 3 and Sheet 4 DIN grades St 34-2 and St 37-2 are 4% and 16%, respectively, below the A53 minimum requirement for Type E grade A pipe.

The minimum longitudinal elongation requirements for Sheet 3 and Sheet 4 DIN grades St 42-2 and St 52-3 satisfy or are within 2% of the A53 minimum requirements for Type E grade B pipe. The minimum transverse percent elongation for Sheet 3 and Sheet 4 DIN grades St 42-2 and St 52-3 are 12% and 2%, respectively, below the A53 minimum requirements for Type E grade B pipes.

Bend Test Requirements

Bend tests of various types are typically used as a qualitative measure of material ductility, especially with respect to forming operations. Generally, the material must be bent to some minimum angle around a mandrel, and passes the test if no cracking occurs and fails the test if cracks develop. For pipe or tubing, bend tests using whole pipe sections are usually required only for small outside diameter sizes and the lower range of wall thicknesses. For larger diameter pipe and heavier section pipe, a flattening test replaces the bend test as a measure of ductility and metal soundness. Thus, although the type of test required may depend on the pipe dimensions, both tests are a measure of similar qualitative behavior.

The bend test requirements in A53 for Type F pipe and Type E grade A and grade B pipe for regular or close coiling usage are required for pipe 50 mm or smaller in nominal diameter. In A53, full sections of Type F or Type E pipe for regular usage must be bent cold without cracking 90° around a mandrel whose diameter is twelve times the pipe diameter. For close coiling, full sections of Type E pipe must be bent cold without cracking through 180° around a mandrel whose diameter is eight times the pipe diameter.

Specification DIN 1626, for Sheet 3 and Sheet 4 qualities, contains a bend test requirement for fusion welded pipe only. Further, this is a test of plate specimens rather than full pipe sections and thus has different mandrel diameter requirements. Thus, there is no bend test requirements in DIN 1626 equivalent to the A53 requirements.

Flattening Test Requirements

Specification A53 requires flattening tests on all pipe, both butt-welded and ERW, over 50 mm in nominal outside diameter and weight classes Schedule 80 (Extra Strong) and lighter. The test is a multipart test which qualitatively measures ductility of both weld and base metal and pipe soundness.

For electric-resistance welded pipe (Type E), A53 contains a three part test. Part 1, a measure of weld ductility, calls for a section of pipe, with the weld located at various positions with respect to the direction of force, to be flattened to a fixed fraction (2/3) of the pipe diameter without weld cracking. In part 2, a measure of base metal ductility, the pipe must be further flattened to a smaller fraction (1/3) of the pipe diameter without base metal cracking. In the third part, a measure of internal soundness, the pipe is totally collapsed to look for evidence of delamination in the base metal or an incomplete weld.

For butt-welded pipe (Type F), A53 also contains a three part test. The pipe section is oriented so that the weld is 90° from the line of force, and for the first part, the pipe is flattened to a distance, 3/4, of the original pipe outside diameter without weld cracking. For the second part, the pipe is further flattened to a distance of 0.6 of the original pipe diameter without base metal cracking. Finally, in the last part, the pipe is totally collapsed to evaluate metal soundness.

On DIN 1626 Sheet 3 and Sheet 4 qualities, flattening tests are required on all pipe sizes with the weld located at both 90° to the direction of force and in line with the applied force. For ERW pipe greater than 50 mm nominal diameter, both A53 grade A and grade B and DIN 1626 have almost identical requirements for part 1 of the test. The DIN requirements are more severe than the A53 Type F requirements. Although A53 also calls for intermediate weld positions for ERW pipe and DIN 1626 does not, this deficiency should have no significant effect. For part 2 of the test, DIN 1626 also requires further flattening, but down to a distance that varies but not smaller than 1/3. The actual distance is calculated from an equation derived from theoretical analyses of bending of a curved section which is:

$$H = \frac{(1 + e)t}{e + \frac{t}{D}}$$

where H = distance between flattening plates
t = wall thickness
D = pipe outside diameter
e = maximum strain at outer pipe surface

Depending on the combination of pipe diameter and wall thickness, the distance H can be greater or smaller than 1/3. (This equation is identical to that used in A53 for seamless pipe where e = 0.09 for St 34-2 and St 37-2 and e = 0.07 for St 42-2 and St 52-3 corresponding, respectively to A53 grade A and grade B). Thus, for both Type F and Type E pipe, the distance H from DIN 1626 may not satisfy either of the A53 requirements for part 2 of the flattening test. DIN 1629 does not, however, require the third part, or total collapse test.

Although A53 requires a bend test for weld ductility for pipe 50 mm diameter or smaller and DIN 1626 requires a flattening test for all pipe sizes, there appears to be no basis for concluding that one test is more severe than the other because these tests are used as qualitative rather than quantitative measures of ductility.

Hydrostatic Test Requirements

Specification A53 requires all lengths of pipe to be hydrostatically tested at pressures, depending on pipe type and grade, pipe size and wall thickness, without leaking. Specification D1626 also requires all pipe to be tested but uses a different fixed pressure for each quality level, i.e. Sheet 2, Sheet 3, and Sheet 4.

For Sheet 2 quality, the DIN test pressure is 19% or more below the lowest permitted A53 pressure for either Type E or Type F pipe. For Sheet 3 quality, the DIN test pressure satisfies the A53 requirements for Type F and Type E grade A and grade B pipe for diameters 10.2 mm, 13.5 mm, 17.2 mm, 21.3 mm, and 33.7 mm in the Schedule 40 wall thickness. For all other diameters in Schedule 40 pipe and for all diameters in all other wall thickness schedules, the DIN pressure is 16% or more below the A53 requirement for either Type F or Type E pipe. For Sheet 4 quality, the DIN test pressure satisfies the A53 requirements for the following pipe:

10.2 mm OD, up to 2.3 mm wall thickness for Type F and Type E grades A and B
13.5 mm OD, up to 2.9 mm wall thickness for Type F and Type E grades A & B

17.2 mm OD, up to 3.2 mm wall thickness for Type F and Type E grades A & B
21.3 mm OD, up to 7.1 mm wall thickness for Type F and Type E grades A & B
27.2 mm OD, up to 7.1 mm wall thickness for Type F and Type E grades A & B
33.7 mm OD, up to 8.8 mm wall thickness for Type F and Type E grades A & B
42.4 mm OD, up to 3.6 mm wall thickness for Type F only
48.3 mm OD, up to 3.6 mm wall thickness for Type F only
60.3 mm OD, up to 4.0 mm wall thickness for Type F only
88.9 mm OD, up to 5.6 mm wall thickness for Type F only
101.6 mm OD, up to 4 mm wall thickness for Type F
101.6 mm OD, up to 3.2 mm wall thickness for Type E grade A
114.3 mm OD, up to 4.0 mm wall thickness for Type F
114.3 mm OD, up to 3.2 mm wall thickness for Type E grade A
139.7 mm OD, up to 3.6 mm wall thickness for Type E grade A only
168.3 mm OD, up to 4.5 mm wall thickness for Type E grade A only
219.1 mm OD, up to 6.3 mm wall thickness for Type E grade A
219.1 mm OD, up to 5.6 mm wall thickness for Type E grade B
273 mm OD, up to 8.8 mm wall thickness for Type E grade A
273 mm OD, up to 7.1 mm wall thickness for Type E grade B
323 mm OD, up to 10 mm wall thickness for Type E grade A
323 mm OD, up to 8 mm wall thickness for Type E grade B
355.6 mm OD, up to 11 mm wall thickness for Type E grade A
355.6 mm OD, up to 8.8 mm wall thickness for Type E grade B
406.4 mm OD, up to 14.2 mm wall thickness for Type E grade A
406.4 mm OD, up to 11 mm wall thickness for Type E grade B
457.2 mm OD, up to 14.2 mm wall thickness for Type E grade A
457.2 mm OD, up to 11 mm wall thickness for Type E grade B
508 mm OD, up to 12.5 mm wall thickness for Type E grades A and B
609.6 mm OD, up to 17.5 mm wall thickness for Type E grade A
609.6 mm OD, up to 14.2 mm wall thickness for Type E grade B
660.4 mm OD, up to 14.2 mm wall thickness for Type E grades A and B

For all other wall thicknesses in these outside diameters, the DIN pressure is 3% or more below the A53 requirement for either Type F or Type E pipe.

Nondestructive Test Requirements

The weld quality of ERW pipe 50 mm and larger outside diameter must be checked according to A53 by an ultrasonic or electromagnetic technique capable of detecting flaws in the weld with a sufficient sensitivity as contained in A53. Flaws that do not reduce the wall thickness by more than 12½% are allowed by A53.

Specification DIN 1626 Sheet 3 quality allows undefined nondestructive tests to be carried out on a spot check basis. Sheet 4 quality requires that all welds shall be totally inspected nondestructively to insure that no appreciable defects are present. The sensitivity of these nondestructive tests is not specified in DIN 1626.

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JIS G3456-78//ASTM A106-79

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to carbon steel pipe for high-temperature service. Specification ASTM A106-79 contains three grades of seamless pipe, hot and/or cold finished depending on diameter in nominal sizes from 6 mm to 660 mm diameter in a variety of wall thicknesses. Specification JIS G3456-78 contains three grades or classes, two of which can be hot or cold finished electric-resistance welded pipe or seamless pipe and one grade available as hot or cold finished seamless pipe, in nominal sizes from 6 mm to 500 mm diameter in a variety of wall thicknesses.

The major design criteria for the intended applications of these materials are the static strength properties, ultimate tensile strength and yield strength. In addition, qualitative tests for material soundness, pressure tightness, and weld ductility are also specified. These include hydrostatic tests, bend tests, flattening tests, and nondestructive tests. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the materials intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition, and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G3456 are considered equivalent to the requirements of ASTM A106 if the JIS values exceed or are within 5% of the A106 minimum value; (2) the percent elongation requirements of JIS G3456 are considered equivalent to the requirements of ASTM A106 if the JIS values exceed or are within 15% of the A106 minimum values; (3) JIS G3456 pipe to be equivalent must satisfy the qualitative test requirements of A53. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation ; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) JIS class 2 (STPT 38) from JIS G3458-78 is generally equivalent to ASTM A106-79 grade A based on the criteria discussed earlier, subject to the following limitations:

(a) All JIS cold-finished pipe must be heat treated at 650 C or higher to remove effects of cold work.

(b) The JIS percent elongation values for pipe less than 20 mm outside diameter must satisfy the A106 acceptance criteria.

(c) The flattening test on JIS pipe must be carried out to complete collapse of the pipe.

(d) To be acceptable, JIS schedule 10 pipe, schedule 30 pipe, schedule 40 pipe, schedule 120 pipe, and schedule 140 pipe in all diameters must satisfy the A530 hydrostatic requirements for grade A pipe.

(e) To be acceptable, JIS schedule 20 pipe less than 318 mm outside diameter must satisfy the A530 hydrostatic requirements for grade A pipe.

(f) To be acceptable, JIS schedule 60 pipe less than 508 mm outside diameter must satisfy the A530 hydrostatic requirements for grade A pipe.

(g) To be acceptable, JIS schedule 80 pipe less than 457 mm outside diameter must satisfy the A530 hydrostatic requirements for grade A pipe.

(h) To be acceptable, JIS schedule 160 pipe more than 114.3 mm outside diameter must satisfy the A530 hydrostatic requirements for grade A pipe.

(2) JIS class 3 (STPT 42) from JIS G3456-78 is generally equivalent to ASTM A106-79 grade B based on the criteria discussed earlier, subject to the following limitations:

(a) All JIS cold-finished pipe must be heat treated at 650 C or higher to remove effects of cold work.

(b) The JIS percent elongation values for pipe less than 20 mm outside diameter must satisfy the A106 acceptance criteria.

(c) The flattening test on JIS pipe must be carried out to complete collapse of the pipe.

(d) To be acceptable, JIS schedule 10 pipe, schedule 30 pipe, schedule 40 pipe, schedule 60 pipe, schedule 80 pipe, schedule 100 pipe, schedule 120 pipe, and schedule 140 pipe in all diameters must satisfy the A530 hydrostatic requirements for grade B pipe.

(e) To be acceptable, all JIS schedule 20 pipe except 457.2 mm outside diameter must satisfy the A530 hydrostatic requirements for grade B pipe.

(f) To be acceptable, JIS schedule 160 pipe greater than 114.3 mm outside diameter must satisfy the A530 hydrostatic requirements for grade B pipe.

(3) JIS class 4 (STPT 49) from JIS G3456-78 is generally equivalent to ASTM A106-79 grade C based on the criteria discussed earlier, subject to the following limitations:

(a) All JIS cold-finished pipe must be heat treated at 650 C or higher to remove effects of cold work.

(b) The JIS percent elongation values for pipe less than 20 mm outside diameter must satisfy the A106 acceptance criteria.

(c) The flattening test on JIS pipe must be carried out to complete collapse of the pipe.

(d) To be acceptable, JIS schedule 10 pipe, schedule 20 pipe, schedule 30 pipe, schedule 40 pipe, schedule 60 pipe, schedule 80 pipe, schedule 100 pipe, schedule 120 pipe, and schedule 140 pipe must satisfy the A530 hydrostatic requirements for grade C pipe.

(e) To be acceptable, JIS schedule 160 pipe greater than 114.3 mm outside diameter must satisfy the A530 hydrostatic requirements for grade C pipe.

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CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analyses for JIS class 2 (STPT 38) and class 3 (STPT 42) pipe satisfy the chemical limits for ASTM A106 grade A and grade B pipe, respectively.

The JIS maximum carbon levels are identical with the A106 requirements while the maximum JIS levels of the impurities phosphorus and sulfur are below the A106 permitted maximum levels. The JIS manganese range falls within the permitted A106 limits for both grades.

The chemical composition limits based on ladle analyses for JIS class 4 (STPT 49) pipe satisfy the chemical limits for ASTM A106 grade C pipe. The JIS carbon level is slightly below the maximum allowed by A106 while the maximum JIS levels of the impurities phosphorus and sulfur are below the A106 permitted maximum levels. The JIS manganese range falls within the permitted A106 limits.

The minimum of the JIS silicon range for all three grades satisfies the A106 minimum requirement and the JIS range is consistent with the A106 requirement for killed steel deoxidation practice.

MECHANICAL PROPERTIES

Heat Treatment

All cold finished pipe is required to be annealed at 650 C or higher by A106 while JIS G3456 requires only an undefined low temperature anneal. This requirement is necessary because of the strong effect of cold drawing on the resulting mechanical properties.

Strength Requirements

The ASTM test specimen requirements are taken from both A106 and A370, Sections S5 and S6. For pipe 200 mm or larger nominal diameter, either longitudinal or transverse tests are required while only longitudinal tests are required for pipes smaller than 200 mm nominal diameter. The preferred longitudinal specimen is rectangular with curved cross-section although the standard round 50 mm gage length specimen is allowed, while transverse specimens are to be taken from flattened ring sections.

Similarly, in JIS G3456, longitudinal or transverse tests are required for pipe 200 mm or larger in nominal diameter while only longitudinal tests are required for smaller diameter pipe. The preferred longitudinal specimen is rectangular with curved cross-section although a round 50 mm gage length specimen is allowed while transverse specimens are taken from flattened ring sections.

The minimum ultimate tensile strength and yield strength requirements specified for JIS G3456 class 2 (STPT 38), class 3 (STPT

42), and class 4 (STPT 49) exceed or are within 1% of the A106 minimum requirements for grade A, grade B, and grade C, respectively.

Ductility Requirements

These two specifications contain similar approaches to tensile ductility as measured by percent elongation. In JIS G3456, a minimum percent elongation is specified for longitudinal and transverse specimens of five different geometries for each class based on ultimate tensile strength independent of pipe wall thickness above 8 mm and independent of cross-sectional area. For wall thickness below 8 mm, a reduction in minimum percent elongation is allowed while pipe below 20 mm outside diameter need not guarantee the minimum percent elongation. In ASTM A106, a minimum percent elongation is specified for longitudinal and transverse specimens of two different geometries for each grade based on ultimate tensile strength independent of pipe wall thickness above 8 mm and independent of cross-sectional area. For wall thicknesses below 8 mm, a reduction in minimum percent elongation is allowed.

The preferred ASTM test specimens for longitudinal and transverse tests are strap type specimens of full wall thickness with curved cross-section between 50 mm gage marks and a fixed width of 38 mm. Where pipe wall thickness permits, the standard round 50 mm gage length specimen (L/D = 4) is also permitted for both longitudinal and transverse tests.

The preferred JIS specimens for longitudinal tests are also strap type specimens of full wall thickness with curved cross-sections, 50 mm gage length and standard widths of 19 mm, 25 mm, and 38 mm depending on pipe diameter. For transverse tests, the specimen is full wall thickness, 50 mm gage length and a width of 25 mm. For pipe of sufficient wall thickness, a standard round 50 mm gage length specimen (L/D = 3.54) is also allowed for both longitudinal and transverse tests.

The comparison of the elongation requirements was carried out in the following manner. For the longitudinal requirements, the preferred ASTM and JIS specimens are not always the same because the ASTM specimen has one geometry independent of pipe diameter while the JIS specimen has three geometries based on pipe diameter. However, if a comparison is made assuming all JIS tests are conducted on a 38 mm wide strap specimen, then the JIS class 2 minimum elongation requirement is 14% or less below the A106 grade A minimum requirement for all pipe diameters and wall thickness. The JIS class 3 and class 4 minimum elongation requirement is 16% or less below the A106 grade B and grade C minimum requirement for all pipe diameters and wall thickness. However, a comparison can be made using round specimens where the JIS specimen has a gage length 3.54 times the diameter and the ASTM specimen has a gage length four times the diameter. Using the relationship between percent elongation, gage length, and cross-sectional area, the equivalent ASTM elongation would be about 95% of the JIS value. Thus, based on round specimens, the JIS class 2, class 3, and class 4 minimum longitudinal elongation requirements exceed, respectively, the A106 grade A, grade B, and grade C minimum requirements for all pipe diameters.

The comparison of transverse requirements, an adjustment must be made because the cross-sectional area of the JIS flat specimen is only 66% of the ASTM specimen. Using the relationship between percent elongation, gage length, and cross-sectional area, the JIS equivalent elongation is 92% of the ASTM elongation value. Based on this adjustment, the JIS class 2, class 3, and class 4 minimum transverse elongation requirement exceeds, respectively, the A106 grade A, grade B, and grade C minimum requirements for all pipe diameters and wall thickness.

Bend Test Requirements

Bend tests of various types are typically used as qualitative measures of material ductility, especially with respect to forming operations. Generally, the material must be bent to some minimum angle around a mandrel, and passes the test if no cracking is observed and fails the test if cracks occur. For pipe or tubing, bend tests are usually required only for small outside diameter sizes and the lower range of wall thicknesses. For larger diameter pipe and thick walled pipe, a flattening test replaces the bend test as a measure of ductility and soundness. Thus, although the type of test required is strongly influenced by the pipe dimensions, both are a measure of the same qualitative behavior.

The bend test requirements in A106 for grade A, grade B, and grade C pipe for regular or close coiling usage, are required for pipe 50 mm or smaller in diameter. Specification JIS G3456 contains the identical requirements for class 2, class 3, and class 4 pipe 40 mm or smaller in diameter. For pipe larger than these two sizes, both A53 and G3456 require flattening tests. There appears to be no basis for concluding for this one size of pipe, i.e. JIS 50 mm that one test is more severe than the other because these tests are only qualitative "go/no go" tests.

Flattening Test Requirements

Specification A106 requires flattening tests on all pipe over 50 mm nominal outside diameter. The test is a two-part test which qualitatively measures both ductility and pipe soundness. Part 1, a measure of pipe ductility, requires a section of pipe to be flattened to a fraction of its original diameter without cracking. This critical height is a function of pipe diameter, wall thickness, and maximum allowed strain. The equation relating these parameters can be derived from theoretical analyses of bending of a curved section and can be written as:

$$e = \frac{1 - \frac{H}{D}}{\frac{H}{D} \cdot \frac{D}{t} - 1}$$

where H = distance between flattening plates
t = wall thickness
D = pipe outside diameter
e = maximum strain at outer pipe surface

Specification JIS G3456 requires flattening tests for all pipe over 40 mm nominal outside diameter and bases the test requirements on the identical equation. This equation does not account for the experimental observation that the actual maximum strain experienced in flattening pipe exceeds substantially the calculated value from the above equation. This effect, called 'peaking", is not important for this discussion since both ASTM and JIS use only the theoretical equation.

The maximum strain required by the test is 0.08 for A106 grade A and JIS class 2, while the maximum strain is 0.07 for A106 grade B and grade C and JIS class 3 and class 4. Thus, the ASTM and JIS test requirements are identical.

Finally, in part 2 of the A106 test, a measure of internal soundness, the pipe is totally collapsed to look for evidence of delamination. However, JIS G3456 is deficient because it does not contain this requirement.

Hydrostatic Test Requirements

Specification A106 requires all lengths of pipe to be hydrostatically tested without leaking at pressures calculated by the requirements of ASTM A530, General Requirements for Specialized Carbon and Alloy Steel Pipe. The maximum test pressures are 17.2 MPa for pipes with outside diameters 88.9 mm or less and 19.3 MPa for pipes over 88.9 mm. Specification JIS G3454 also requires a hydrostatic test at pressures determined by the pipe wall thickness independent of strength class.

The test pressures for all pipe sizes of JIS schedule 10 pipe in class 2, class 3, and class 4 are from 5% to 58% below the requirements for A106 grade A, grade B, and grade C. For JIS schedule 20 pipe only the 318.5 mm, 406.4 mm, 457.2 mm, and 508 mm sizes satisfy the A106 grade A requirements, while only the 457.2 mm size satisfies the A106 grade B requirement. None of the JIS sizes satisfy the A106 grade C requirements. For JIS schedule 30 pipe, the test pressures are from 16% to 54% below the A106 requirements for grade A, grade B, and grade C. For JIS schedule 40 pipe, the test pressures are from 7% to 60% below the A106 requirements for grade A, grade B, and grade C. For JIS schedule 60 pipe, only the 508 mm size satisfy the A106 grade A requirements, while for other pipe sizes the test pressures are from 4% to 37% below the A106 requirements for grade A, grade B, and grade C. For JIS schedule 80 pipe, only the 457.2 mm and 508 mm size satisfy the A106 grade A requirements, while for other pipe sizes the test pressures are from 3% to 34% below the A106 requirements for grade A, grade B, and grade C. For JIS schedule 100 pipe, all diameters satisfy the A106 grade A requirements, while the test pressures are from 10% to 14% below the A106 requirements for grade B and grade C for all pipe diameters. For all sizes of JIS schedule 120 pipe, the test pressures are from 5% to 9% below the A106 requirements for grade A, grade B, and grade C. For all sizes of JIS schedule 140 pipe, the test pressures are 9% below the A106 requirements for grade A, grade B, and grade C. For JIS schedule 160 pipe, only the 21.7 mm, 27.2 mm, 34 mm, 42.7 mm, 48.6 mm, 60.5 mm, 76 mm, and 89.1 mm sizes satisfy the A106 requirements for grade A, grade B, and grade C, while for other pipe sizes the test pressures are 9% below the A106 requirements for grade A, grade B, and grade C.

JIS G3459-78//ASTM A312-77

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to stainless steel pipe for high temperature service in corrosive environments. Specification ASTM A312-77 includes seamless and welded austenite stainless steel pipe in standard nominal diameters from 6 mm to 762 mm. The pipe can only be made by the seamless process or an automatic welding process without filler metal, and can be finished by either hot working or cold working. Specification JIS G3459-78 also includes seamless and welded austenitic stainless steel pipe in standard nominal diameters from 6 mm to 500 mm. One ferritic grade is also included. The JIS pipe, however, can be made by automatic arc welding as well as the electric-resistance welding process and the seamless process and can be hot finished or cold finished. The use of a filler during welding is not precluded.

The major design criteria for the intended applications of these materials are the static strength properties, ultimate tensile strength and yield strength. In addition, qualitative tests for material soundness, pressure tightness, and weld ductility are also specified. These include hydrostatic tests, bend tests, flattening tests, and nondestructive tests. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the materials intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition, and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G3459 are considered equivalent to the requirements of ASTM A312 if the JIS values exceed or are within 5% of the A312 minimum value; (2) the percent elongation requirements of JIS G3454 are considered equivalent to the requirements of ASTM A312 if the JIS values exceed or are within 15% of the A312 minimum values; (3) JIS G3459 pipe to be equivalent must satisfy the qualitative test requirements of A53. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) JIS SUS 329J1 TP from JIS G3459-78 is a ferritic stainless steel and outside of the scope of ASTM A312-77 and thus not equivalent to any A312 grade.

(2) JIS SUS 304L and SUS 316L from JIS G3459-78 are generally equivalent to ASTM A312-77 grade TP 304L and TP 316L based on the criteria discussed earlier, subject to the following limitations:

(a) For welded pipe, filler metal cannot be used.

(b) To be acceptable, the maximum silicon level should be limited to 0.75%.

(c) The JIS percent elongation values for pipe less than 20 mm outside diameter must satisfy the A312 acceptance criteria.

(d) The flattening test on JIS pipe must be carried out to complete pipe collapse.

(e) To be acceptable, JIS schedule 5S welded and seamless pipe less than 216 mm diameter or more than 319 mm diameter must satisfy the hydrostatic requirements of A530.

(f) To be acceptable, JIS schedule 10S welded and seamless pipe other than 318.5 mm diameter must satisfy the hydrostatic requirements of A530.

(g) To be acceptable, JIS schedule 20S welded pipe in all sizes and seamless pipe less than 267 mm and more than 319 mm diameter must satisfy the hydrostatic requirements of A530.

(h) To be acceptable, JIS schedule 40 welded pipe in all sizes and seamless pipe less than 216 mm diameter must satisfy the hydrostatic requirements of A530.

(i) To be acceptable, JIS schedule 80 welded pipe in all sizes and seamless pipe less than 114 mm diameter must satisfy the hydrostatic requirements of A530.

(j) To be acceptable, JIS schedule 120 welded pipe in all sizes must satisfy the hydrostatic requirements of A530.

(k) To be acceptable, JIS schedule 160 welded pipe in all sizes and seamless pipe above 90 mm diameter must satisfy the hydrostatic requirements of A530.

(3) JIS SUS 304 TP, SUS 304H TP, SUS 309S TP, SUS 310S TP, SUS 316 TP, SUS 316H TP, SUS 321 TP, SUS 321H TP, SUS 347 TP, and SUS 347H TP are generally equivalent to ASTM A312 grades TP 304, TP 304H, TP 309, TP 310, TP 316, TP 316H, TP 321, TP 321H, TP 347, and TP 347H, respectively, based on the criteria discussed earlier, subject to the following limitations:

(a) For welded pipe, filler metal cannot be used.

(b) To be acceptable, the maximum silicon level for SUS 304 TP, SUS 3095 TP, SUS 310S TP, SUS 316 TP, SUS 321 TP, SUS 347 TP, and SUS 347H TP should be limited to 0.75%.

(c) To be acceptable, the maximum titanium level in JIS SUS 321 TP and the maximum niobium plus tantalum level in JIS SUS 347 should be held to 0.7% and 1%, respectively.

(d) The JIS percent elongation values for pipe less than 20 mm outside diameter must satisfy the A312 acceptance criteria.

(e) The flattening test on JIS pipe must be carried out to complete pipe collapse.

(f) To be acceptable, JIS schedule 5S welded pipe less than 216 mm and more than 319 mm diameter and seamless pipe less than 267 mm diameter must satisfy the hydrostatic requirements of A530.

(g) To be acceptable, JIS schedule 10S welded pipe in all sizes and seamless pipe less than 406 mm diameter must satisfy the hydrostatic requirements of A530.

(h) To be acceptable, JIS schedule 20S welded pipe in all sizes and seamless pipe less than 267 mm or more than 319 mm diameter must satisfy the hydrostatic requirements of A530.

(i) To be acceptable, JIS schedule 40 welded pipe in all sizes and seamless pipe less than 318 mm must satisfy the hydrostatic requirements of A530.

(j) To be acceptable, JIS schedule 80 welded pipe in all sizes and seamless pipe less than 216 mm diameter must satisfy the hydrostatic requirements of A530.

(k) To be acceptable, JIS schedule 120 welded pipe in all sizes and seamless pipe less than 165 mm diameter must satisfy the hydrostatic requirements of A530.

(l) To be acceptable, JIS schedule 160 welded pipe in all sizes and seamless pipe above 90 mm diameter must satisfy the hydrostatic requirements of A530.

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JIS G3459-78//ASTM A312-77

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analyses for JIS stainless steel types SUS 304H, SUS 316H, and SUS 321H are essentially identical to the ASTM limits for grades TP 304H, TP 316H, and TP 321H, respectively.

The chemical composition limits based on ladle analyses for JIS stainless steel types SUS 304, SUS 304L, SUS 309S, SUS 310S, and SUS 347H satisfy the ASTM limits for grades TP 304, TP 304L, TP 309, TP 310S, and TP 347H, respectively. The A312 maximum carbon level for TP 304L is slightly above the JIS maximum for SUS 304L, but this difference should not be significant. A312 does allow a higher carbon level for tubes less than 12.7 mm outside diameter or tubes with a wall thickness less than 1.24 mm, and thus for JIS schedule 5S tubes of 10.5 mm diameter of type SUS 304L, an increase in the maximum carbon level from 0.3 to 0.04 would be appropriate.

The chemical composition limits based on ladle analyses for JIS stainless steel types SUS 316, SUS 316L, SUS 321, and SUS 347 satisfy the A312 limits for grades TP 316, TP 316L, TP 321, and TP 347, respectively. The slightly lower nickel minimum level for JIS SUS 316 and slightly higher nickel maximum for JIS SUS 316L compared to A312 grades TP 316 and TP 316L should have no significant impact. The A312 carbon maximum for TP 316L is slightly above the JIS maximum for SUS 316L, but this difference should not be significant. A312 does allow a higher carbon level for small diameter tubes and thin wall tubes where many drawing passes are needed, and thus for JIS schedule 5S tubes of 10.5 mm diameter of type SUS 304L, an increase in the maximum carbon level from 0.03 to 0.04 would be appropriate. For JIS SUS 321 and SUS 347, no upper limit on titanium (SUS 321) or niobium plus tantalum (SUS 347) is specified while A312 limits titanium to 0.7% for TP 321 and niobium plus tantalum to 1% for TP 347. The upper limits on titanium and niobium plus tantalum in A312 limit the residual levels of these elements which reduces the formation of their oxides and other phrases as inclusions which are undesirable in tube drawing operations. Further residual niobium in 347 stainless steel can lead to strain-induced precipitation at elevated temperatures and enhance the possibility of cracking.

The higher permitted silicon levels in JIS SUS 304, SUS 304L, SUS 309S, SUS 310S, SUS 316, SUS 316L, SUS 321, SUS 347, and SUS 347H compared to the same A312 types are undesirable in pipe alloys because of greater fluidity of the molten metal during welding which can result in poorer containment of the metal as well as increased oxide inclusion content and its effect on tube drawing.

JIS SUS 329J1 is a ferritic stainless steel and outside the scope of ASTM A312 and thus not part of this comparison.

MECHANICAL PROPERTIES

Fabrication and Heat Treatment

Specification A312 permits the pipe to be fabricated as seamless pipe on automatic welded pipe without the addition of filler metal. Specification JIS G3459 permits pipe to be made as seamless pipe, electric-resistance welded (ERW) pipe, or automatic arc welded pipe without a prohibition on the addition of filler metal to the weld.

All austenitic stainless steels require heat treatment to fully develop the desired level of mechanical properties and corrosion resistance. The primary purpose of the heat treatment is to dissolve any second phrases present. A comparison of the recommended solution annealing temperatures for the JIS and ASTM grades indicates good agreement. Although the minimum temperatures for JIS SUS 321 and SUS 347 are 60 C below the A312 recommended values, 980 C vs. 1040 C, the lower temperatures are still within or very close to accepted industry practice.

Strength Properties

The ASTM test specimen requirements are taken from both A312, A530 Section 16, and A370, Sections S5 and S6. For pipe 200 mm or larger nominal diameter, longitudinal and/or transverse specimen tests are required while only longitudinal tests are required for pipes smaller than 200 mm diameter. The preferred longitudinal specimens is a full pipe section with a 50 mm gage length although rectangular specimens with curved cross-sections located 90° from weld in welded pipe are permitted. For thick-walled pipe, the standard round 50 mm gage length specimen is also allowed. Transverse specimens are taken from flattened pipe ring sections.

Similarly, in JIS G3459, longitudinal and/or transverse specimen tests are required for pipe 200 mm or larger in nominal diameter while only longitudinal tests are required for smaller diameter pipe. Full pipe sections with 50 mm gage length is the preferred specimen although rectangular specimens with curved cross-section located away from weld are permitted. For thick-walled pipe, a round 50 mm gage length specimen is also allowed. Transverse specimens are taken from flattened pipe ring sections. Neither specification distinguishes between longitudinal or transverse strength properties.

The minimum ultimate tensile strength requirements for JIS SUS 304, SUS 304H, SUS 309S, SUS 310S, SUS 316, SUS 316H, SUS 321, SUS 321H, SUS 347, and SUS 347H exceed the A312 minimum requirements for TP 304, TP 304H, TP 309, TP 310, TP 316, TP 316H, TP321, TP 321H, TP 347, and TP 347H, respectively. The minimum ultimate tensile strength requirements for JIS SUS 304L and SUS 316L are within 1% of the A312 minimum requirements for TP 304L and TP 316L, respectively. The slightly lower strength is probably related to the slightly lower maximum permitted carbon level in the JIS grades. The minimum yield strength requirements for JIS SUS 304, SUS 304H, SUS 304L, SUS 309S, SUS 310S, SUS 316, SUS

316H, SUS 321, SUS 321H, SUS 347, and SUS 347H exceed the A312 minimum requirements for these alloy grades.

Ductility Requirements

These two specifications contain similar approaches to tensile ductility as measured by percent elongation. In JIS G3459, a minimum percent elongation is specified for longitudinal and transverse specimens of four different geometries for each grade of pipe with wall thicknesses 8 mm and above, independent of cross-sectional area. For wall thicknesses below 8 mm, a reduction in minimum percent elongation is allowed while for pipe below 20 mm outside diameter, a minimum percent elongation is not guaranteed.

In A312, a minimum percent elongation is specified for longitudinal and transverse specimens of three geometries for all alloys regardless of three geometries for all alloys regardless of strength requirements for pipe wall thicknesses 8 mm and above, independent of cross-sectional area. For wall thicknesses below 8 mm, a reduction in minimum percent elongation is allowed.

One of the preferred ASTM test specimens for longitudinal and transverse tests are strap type specimens of full wall thickness with curved cross-section between 50 mm gage marks and a fixed width of 38 mm. Where wall thickness permits the standard round 50 mm gage length specimen (L/D = 4) is also allowed for both longitudinal and transverse tests.

The preferred JIS specimen for longitudinal tests are also strap type specimens of full wall thickness with curved cross-sections, 50 mm gage length and standard widths of 19 mm, 25 mm, and 38 mm depending on pipe diameter. For transverse tests, the specimen is full wall thickness, 50 mm gage length and a fixed width of 25 mm. For pipe of sufficient wall thickness, a standard round 50 mm gage length specimen (L/D = 3.54) is also allowed for both longitudinal and transverse tests.

The comparison of the elongation requirements was carried out in the following manner. For the longitudinal requirements, the ASTM and JIS strap specimens are not always the same because the ASTM specimen has one geometry independent of pipe diameter while the JIS specimen has three geometries based on pipe diameter. However, JIS G3459 has a fixed elongation requirement independent of strap specimen geometry so a direct comparison can be made as if both specimens were always 38 mm wide. The minimum JIS longitudinal percent elongation requirement for strap specimens for all alloy grades is identical to the A312 minimum requirement for strap specimens.

A comparison can also be made based on the round specimens where the JIS specimen has a gage length 3.54 times the diameter and the ASTM specimen has a gage length 4 times the diameter. Using the relationship between percent elongation, gage length, and cross-sectional area, the equivalent ASTM elongation would be about 95% of the JIS value. Thus, for round specimens, the longitudinal JIS percent elongation requirement for all alloy grades is within 2% of the A312 minimum requirement for all alloy grades.

For comparison of transverse requirements based on strap specimens, an adjustment must be made because the cross-sectional area of the JIS specimen is only 66% of the ASTM specimen. Using the relationship between percent elongation, gage length, and cross-sectional area, the JIS equivalent elongation is 92% of the ASTM value. Based on this adjustment, the JIS G3459 minimum transverse elongation requirement for strap specimens of all alloy grades exceeds the A312 minimum requirements for all alloy grades. Making a comparison based on transverse round specimens, similar to the analysis for longitudinal round specimens, the JIS minimum transverse percent elongation requirement for all alloy grades exceeds the A312 minimum requirement for all grades.

Flattening Test Requirements

Specification A312 requires flattening tests on all pipe diameters for both seamless and welded pipe. The test is a two part test which qualitatively measures both ductility and soundness. Part 1, a measure of ductility, requires a section of pipe to be flattened to a fraction of its original diameter without cracking. For welded pipe, the weld is located 90° from direction of applied force. This critical height is a function of the original diameter, wall thickness, and maximum allowed strain. The equation relating these parameters can be derived from theoretical analyses of bending of a curved section and can be written as

$$e = \frac{1 - \frac{H}{D}}{\frac{H}{D} \cdot \frac{D}{t} - 1}$$

where H = distance between flattening plates
D = pipe outside diameter
t = wall thickness
e = maximum strain at outer pipe surface

Specification JIS G3459 also requires a flattening test for all pipe diameter and bases the test requirements on the identical equation. This equation does not account for the experimental observation that the actual maximum strain experienced in flattening pipe exceeds substantially the calculated value from the above equation. This effect, called "peaking" is not important for this discussion since both ASTM and JIS use only the theoretical equation. The maximum strain required by the test, e = 0.09, is the same for both ASTM and JIS and thus the part 1 flattening test requirements are identical.

In part 2 of the A312 test, a measure of internal soundness, the pipe is totally collapsed to look for evidence of delamination. However, JIS G3459 is deficient because it does not contain this requirement.

Hydrostatic Test Requirements

Specification A312 requires all lengths of pipe to be hydrostatically tested without leaking at pressures calculated by the requirements of ASTM A530, General Requirements for Specialized Carbon and Alloy Steel Pipe and the alloy yield strength. The maximum test pressures are 17.2 MPa for pipe with outside diameters 88.9 mm or less and 19.3 MPa for pipe over 88.9 mm diameter. Specification JIS G3459 requires a hydrostatic test on all lengths of pipe at pressures determined by the wall thickness independent of yield strength for seamless pipe and at a constant pressure for all welded pipe.

For welded schedule 5S pipe for JIS grades SUS 304L and SUS 316L, only the 216.3 mm, 267.4 mm, 318.5 mm diameter pipe satisfy the A312 test pressure requirements while the other sizes are from 14% to 85% below the A312 requirements for grades TP 304L and TP 316L. For welded schedule 10S pipe for JIS grades SUS 304L and SUS 316L, only the 318.5 mm diameter pipe satisfies the A312 test pressure requirements while the other sizes are from 7% to 86% below the A312 requirements for grades TP 304L and TP 316L. For welded schedule 20S pipe for JIS grades SUS 304L and SUS 316L, the test pressures are from 30% to 86% below the A312 requirements for grades TP 304L and TP 316L. For welded schedule 40 pipe for JIS grades SUS 304L and SUS 316L, the test pressures are from 52% to 86% below the A312 requirements for grades TP 304L and TP 316L. For welded schedule 80 pipe for JIS grades SUS 304L and SUS 316L, the test pressures are from 172% to 86% below the A312 requirements for grades TP 304L and TP 316L. For welded schedule 120 pipe for JIS grades SUS 304L and SUS 316L, the test pressures are from 81% to 85% below the A312 requirements for grades TP 304L and TP 316L. For welded schedule 160 pipe, the test pressures are from 86% to 87% below the A312 requirements for grades TP 304L and TP 316L.

For welded schedule 5S pipe for all the other JIS austenitic grades, only the 216.3 mm, 267.4 mm, 318.5 mm diameter pipe satisfy the A312 requirements while the other sizes are from 28% to 88% below the A312 requirements. For welded schedule 10S pipe for all other JIS austenitic grades, the test pressures are from 12% to 86% below the A312 requirements. For welded JIS schedule 20S pipe, the test pressures are from 42% to 86% below the A312 requirements. For welded JIS schedule 40 pipe, the test pressures are from 60% to 86% below the A312 requirements. For welded JIS schedule 80 pipe, the test pressures are from 77% to 86% below the A312 requirements. For welded JIS schedule 120 pipe, the test pressures are from 84% to 87% below the A312 requirements. For welded JIS schedule 160 pipe, the test pressures are from 86% to 87% below the A312 requirements.

For seamless schedule 5S pipe for JIS grades SUS 304L and SUS 316L, only the 216.3 mm, 267.4 mm, and 318.5 mm diameter pipe satisfy the A312 requirements while the other sizes are from 14% to 85% below the A312 requirements. For seamless JIS schedule 10S pipe, only the 318.5 mm diameter pipe satisfies the A312 requirements while the other sizes are from 7% to 86% below the A312 requirements. For seamless JIS schedule 20S pipe, only 267.4 mm and 318.5 mm diameter pipe satisfy the A312 requirements while the other sizes are from 5% to 72% below the A312 requirements. For seamless JIS schedule 40 pipe, only 216.3 mm through 508 mm diameter pipe satisfy the A312 requirements while the other sizes are from 6% to 60% below the A312 requirements. For seamless JIS schedule 80 pipe, only 114.3 mm through 508 mm diameter pipe satisfy the A312 requirements while the other sizes are from 7% to 26% below the

A312 requirements. For seamless JIS schedule 120 pipe, all diameter satisfy the requirements of A312. For seamless JIS schedule 160 pipe, only 21.7 mm through 89.1 mm and 318.5 mm through 508 mm diameter satisfy the A312 requirements while all other sizes are from 4% to 9% below the A312 requirements.

For seamless schedule 5S pipe for all other JIS austenitic grades, only the 267.4 mm through 508 mm diameter pipe satisfy the A312 requirements while the other sizes are from 28% to 88% below the A312 requirements. For seamless JIS schedule 10S pipe, only the 406.4 mm through 508 mm diameter pipe satisfy the A312 requirements while the other sizes are from 12% to 86% below the A312 requirements. For seamless JIS schedule 20S pipe, only the 267.4 mm and 318.5 mm diameter pipe satisfy the A312 requirements while the other sizes are from 21% to 72% below the A312 requirements. For seamless JIS schedule 40 pipe, only the 318.5 mm through 508 mm diameter pipe satisfy the A312 requirements while the other sizes are from 2% to 60% below the A312 requirements. For seamless JIS schedule 80 pipe, only the 216.3 mm through 508 mm diameter pipe satisfy the A312 requirements while the other sizes are from 6% to 26% below the A312 requirements. For seamless JIS schedule 120 pipe, only the 165.2 mm through 508 mm diameter pipe satisfy A312 requirements while the other sizes are from 6% to 12% below the A312 requirements. For seamless JIS schedule 160 pipe, only the 21.7 mm through 89.1 mm diameter pipe satisfy the A312 requirements while the other sizes are 9% below the A312 requirements.

DIN 17440-72//ASTM A312-77

INTRODUCTION

The scope statements for these two specifications are similar only in the reference to stainless steels. Specification ASTM A312-77 includes only austenitic stainless steel pipe, welded and seamless, for high temperature service in corrosive environments in standard nominal diameters from 6 mm to 762 mm.

Specification DIN 17440-72 however, includes all ordinary stainless steels as hot or cold rolled products. Ferritic grades, martensitic grades as well as austenitic grades of stainless steel in the form of sheet, strip, bar, wire, seamless and welded tubes, and forgings are covered.

The major design criteria for the intended applications of these materials are the static strength properties, ultimate tensile strength and yield strength. In addition, qualitative tests for material soundness, pressure tightness, and weld ductility are also specified. These include hydrostatic tests and flattening tests. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the materials intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition, and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17440 are considered equivalent to the requirements of ASTM A312 if the DIN values exceed or are within 5% of the A312 minimum values; (2) the percent elongation requirements of DIN 17440 are considered equivalent to the requirements of ASTM A312 if the DIN values exceed or are within 15% of the A312 minimum values; (3) DIN 17440 tubes to be equivalent must satisfy the qualitative test requirements of A312. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirements; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) DIN grades 1.4000, 1.4002, 1.4006, 1.4024, 1.4021, 1.4034, 1.1116, 1.4016, 1.4510, 1.4511, 1.4113, 1.4104, and 1.4057 from DIN 17440-72 are not equivalent to any grade in ASTM A312-77 because they are ferritic and martensitic stainless steels and outside the scope of A312.

(2) DIN austenitic stainless steel grades 1.4305, 1.4303, 1.4571, 1.4580, 1.4436, 1.4435, 1.4438, 1.4311, 1.4406, and 1.4429 are not generally equivalent to any grade in ASTM A312-77 based on chemical composition requirements.

(3) DIN grade X 5 CrNi 189 (1.4301) from DIN 17440-72 is generally equivalent to ASTM A312-77 grade TP304 based on the criteria discussed earlier, subject to the following limitations:

(a) Filler metal is not to be used during fabrication of welded tubes.

(b) To be acceptable, the maximum silicon level should be limited to 0.75%.

(c) To be acceptable, the minimum yield strength for this DIN grade must be shown to satisfy the strength acceptance criterion.

(d) To be acceptable, the following welded tube sizes must satisfy the A312 hydrostatic test requirement.

wall thickness, mm	outside diameter, mm
1	less than 25
1.2	less than 31.8
1.6	less than 40
2	less than 51
2.3	less than 60.3
2.6	less than 63.5
2.9	less than 76.1
3.2	less than 82.5
3.6	less than 88.9
4	139.7 and less than 101.6
4.5	168.3 and less than 114.3
5	less than 273
5.6	less than 323.9
6.3	less than 273
7.1	less than 323.9
8	less than 355.6
8.8	less than 355.6

(e) To be acceptable, the following seamless tube sizes must satisfy the A312 hydrostatic test requirement:

wall thickness, mm	outside diameter, mm
1	less than 25
1.2	less than 31.8
1.6	less than 40
2	less than 51
2.3	less than 60.3
2.6	less than 63.5
2.9	less than 76.1
3.2	less than 82.5

3.6	less than 88.9
4	less than 101.6
4.5	less than 114.3
5	less than 139.7
5.6	less than 139.7
6.3	all diameters
7.1	all diameters
8	less than 219.1
8.8	less than 219.1
10	less than 273
11	less than 355.6
12	less than 323.9
14.2	all diameters

(4) DIN grade X 2 CrNi 189 (1.4306 from DIN 17440-72 is generally equivalent to ASTM A312-77 grade TP304L based on the criteria discussed earlier, subject to the following limitations:

(a) Filler metal is not to be used during fabrication of welded tubes.

(b) To be acceptable, the maximum silicon level should be limited to 0.75%.

(c) To be acceptable, the minimum ultimate tensile strength for this DIN grade must be shown to satisfy the strength acceptance criterion.

(d) To be acceptable, the following welded tube sizes must satisfy the A312 hydrostatic test requirement:

wall thickness, mm	outside diameter, mm
1	less than 21.3
1.2	less than 25
1.6	less than 33.7
2	less than 42.4
2.3	less than 48.3
2.6	less than 54
2.9	less than 60.3
3.2	less than 82.5
3.6	less than 88.9
4	less than 88.9
4.5	less than 114.3
5	139.7 and less than 114.3
5.6	less than 323.9
6.3	less than 219.1
7.1	less than 323.9
8	less than 355.6
8.8	less than 355.6

(e) To be acceptable, the following seamless tube sizes must satisfy the A312 hydrostatic test requirement:

wall thickness, mm	outside diameter, mm
1	less than 21.3
1.2	less than 25
1.6	less than 33.7
2	less than 42.4
2.3	less than 48.3
2.6	less than 54
2.9	less than 60.3
3.2	less than 82.5
3.6	less than 76.1
4	less than 88.9
4.5	less than 114.3
5	less than 139.7
5.6	less than 139.7
6.3	less than 139.7
7.1	less than 168.3
8	less than 219.1
8.8	less than 219.1
10	less than 273
11	less than 355.6
12.5	less than 355.6
14.2	all diameters

(5) DIN grade X 5 CrNiMo 1810 (1.4401) from DIN 17440-72 is generally equivalent to ASTM A312-77 grade TP 316 based on the criteria discussed earlier, subject to the following limitations:

(a) Filler metal is not to be used during fabrication of welded tubes.

(b) To be acceptable, the maximum silicon level should be limited to 0.75%.

(c) To be acceptable, the welded tube sizes listed in Section (3)(d) must satisfy the A312 hydrostatic test requirement.

(d) To be acceptable, the seamless tube sizes listed in Section (3)(e) must satisfy the A312 hydrostatic test requirement.

(6) DIN grade X 2 CrNiMo 1810 (1.4404) from DIN 17440-72 is generally equivalent to ASTM A312-77 grade TP316L based on the criteria discussed earlier, subject to the following limitations:

(a) Filler metal is not to be used during fabrication of welded tubes.

(b) To be acceptable, the maximum silicon level should be limited to 0.75%.

(c) To be acceptable, the minimum ultimate tensile strength for this DIN grade must be shown to satisfy the strength acceptance criterion.

(d) To be acceptable, the welded tube sizes listed in Section (4)(d) must satisfy the A312 hydrostatic test requirement.

(e) To be acceptable, the seamless tube sizes listed in Section (4)(e) must satisfy the A312 hydrostatic requirement.

(7) DIN grade X 10 CrNiTi 189 (1.4541) from DIN 17440-72 is generally equivalent to ASTM A312-77 grade TP321 based on the criteria discussed earlier, subject to the following limitations:

(a) Filler metal is not to be used during fabrication of welded tubes.

(b) To be acceptable, the maximum silicon level should be limited to 0.75%.

(c) To be acceptable, the maximum carbon level should be limited to 0.08 weight percent to ensure good corrosion resistance.

(d) To be acceptable, the welded tube sizes listed in Section (3)(d) must satisfy the A312 hydrostatic test requirement.

(e) To be acceptable, the seamless tube sizes listed in Section (4)(e) must satisfy the A312 hydrostatic test requirement.

(8) DIN grade X 10 CrNiNb 189 (1.4550) from DIN 17440-72 is generally equivalent to ASTM A312-77 grade TP347 based on the criteria discussed earlier, subject to the following limitations:

(a) Filler metal is not be used during fabrication of welded tubes.

(b) To be acceptable, the maximum carbon level should be limited to 0.08 weight percent, and the minimum niobium level should be increased to 10 times the carbon content in order to maintain good corrosion resistance.

(c) To be acceptable, the welded tube sizes listed in Section (3)(c) must satisfy the A312 hydrostatic test requirement.

(d) To be acceptable, the seamless tube sizes listed in Section (4)(d) must satisfy the A312 hydrostatic test requirement.

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DIN 17440-72//ASTM A312-77

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analyses for DIN stainless steel grades X 5 CrNi 189 (1.4301) and X 2 CrNi 189 (1.4306) generally satisfy the A312 chemical limits for grades TP304 and TP304L, unstabilized 18 Cr-8 Ni alloys. The DIN maximum levels for carbon, manganese, and sulfur are identical with or slightly below the A312 requirements while the DIN range for nickel is within the A312 range. For chromium, the lower limit of the DIN range is slightly below the A312 minimum. The critical element for these A312 grades is the greatly enhanced corrosion resistance, especially in welded applications, over the basic general purpose 18 Cr-8 Ni alloy AISI type 302 due to the reduced maximum carbon level. Thus, the slightly lower minimum chromium limit for these DIN grades should not significantly affect their behavior compared to TP304 and TP304L.

The chemical composition limits based on ladle analyses for DIN X 5 CrNiMo 1810 (1.4401) and X 2 CrNiMo 1810 (1.4404) generally satisfy the A312 chemical limits for grades TP316 and TP316L. The DIN maximum levels for carbon, manganese, and sulfur are identical with or slightly below the A312 requirements while the DIN ranges for nickel and molybdenum are within the A312 ranges. The upper limit of the DIN chromium range is slightly above the A312 upper limit, but this should have no effect on behavior.

The chemical composition limits based on ladle analyses for DIN stainless steel grade X 10 CrNiTi 189 (1.4541) generally satisfy the A312 chemical limits for grade TP321, a stabilized 18 Cr-8 Ni alloy. The DIN maximum levels for manganese, and sulfur are identical with the A312 requirements while the DIN maximum titanium level can exceed the A312 limit. The DIN ranges for chromium and nickel are within the A312 ranges. The DIN upper limit for carbon exceeds the A312 maximum for the TP321 alloy and actually satisfies the requirements for the TP321H alloy, a higher carbon version of the standard TP321 alloy. In this alloy type, titanium is added as a carbon stabilizer to reduce the tendency for carbide precipitation in order to enhance the corrosion resistance, especially against grain boundary attack. The higher carbon level allowed in the DIN grade could result in a somewhat lower corrosion resistance if not fully stabilized by the titanium, particularly in weld applications, and should be avoided.

The chemical composition limits based on ladle analyses for DIN X10 CrNiNb 189 (1.4550) generally satisfy the A312 chemical limits for grade TP347, a stabilized 18 Cr-8 Ni alloy. The DIN maximum levels for manganese and sulfur are identical with the A312 requirements while the DIN ranges for chromium and nickel are within the A312 ranges. For carbon, the DIN upper limit exceeds the A312 maximum for TP347 (actually satisfies requirements for the type 347H alloy, a higher carbon version of the standard type 347 alloy) while the DIN lower limit for niobium (plus tantalum) is less than the A312 minimum requirement. In this alloy, niobium and/or tantalum are added to stabilize the carbon and reduce the tendency for carbide precipitation in order to enhance the corrosion resistance, especially of the grain boundaries. The combination in this DIN grade of possible higher carbon and lower niobium, tantalum levels compared to the A312 grade can be significant, and should be avoided.

The higher permitted silicon levels in the DIN grades are undesirable in tube alloys because of greater fluidity of the molten metal during welding which can result in poorer containment of the metal as well as increased oxide inclusion content and its affect on tube drawing.

The DIN austenitic grades 1.4305, 1.4303, 1.4571, 1.4580, 1.4436, 1.4435, 1.4438, 1.4311, 1.4406, and 1.4429 are not equivalent to any grade in A312 based on chemical composition.

The DIN grades 1.4000, 1.4002, 1.4006, 1.4024, 1.4021, 1.4034, 1.4116, 1.4016, 1.4510, 1.4511, 1.4113, 1.4104, and 1.4057 are ferritic and martensitic stainless steel and outside the scope of A312 and not part of this comparison.

MECHANICAL PROPERTIES

Fabrication and Heat Treatment

Specification A312 requires the pipe to be fabricated as seamless tube or automatic welded tube without the addition of filler metal and to be pickled free from scale or bright annealed. Specification DIN 17440 permits tube to be made as seamless tube, electric resistance welded (ERW) tube, or arc welded tube without a prohibition on the use of filler metal during welding.

All austenitic stainless steels included in A312 require heat treatment to fully develop the desired level of mechanical properties and corrosion resistance. The primary purpose is to dissolve any second phases present. A comparison of the recommended solution treatment temperatures for the DIN and ASTM grades indicates good agreement. Although the minimum temperatures for DIN 1.4301, 1.4306, 1.4541, and 1.4550 are 40 C and 20 C, respectively, below the A312 recommended value, the lower temperature is still within industry practice.

Specification DIN 17440 contains many heat treatment and surface condition descriptions because of the wide range of product forms included in the specification. Generally, seamless and welded tube in condition c2, d2, d3, h, k2, k3, L1, and L2 would satisfy the intent of A312.

Strength Requirements

The ASTM test requirements are taken from A312, A530-78, Section 16, and A370, Section S5 and S6. For tube 200 mm or larger nominal diameter, longitudinal and/or transverse specimen tests are required while only longitudinal tests are required for tube less than 200 mm diameter. The preferred longitudinal specimen is a full tube section with a 50 mm gage length although rectangular specimens with curved cross-sections, located 90° from weld in welded tube, are permitted. For thick-walled pipe, the standard ASTM round specimen (L/D = 4) is also allowed. The preferred transverse specimens are rectangular and taken from flattened tube ring sections although standard, round, 50 mm gage length specimens are permitted for thick wall tubes.

Similarly, DIN 17440 requires longitudinal and/or transverse specimen tests for tube 200 mm or larger in diameter, while only longitudinal tests are required for smaller diameter tube. Full tube section specimens, rectangular specimens, or round specimens, all with the ratio of gage length to cross-sectional area equal to 5.65, or the ratio of gage length to diameter equal to 5.0, are permitted for the longitudinal and transverse tests. Neither specification distinguishes between longitudinal or transverse strength properties.

The minimum ultimate tensile strength requirement and minimum yield strength requirement for DIN grade 1.4301 are 3% and 10%, respectively, below the A312 minimum requirements for grade TP304.

The minimum ultimate tensile strength requirements for DIN grades 1.4306, and 1.4404, are 7% below the A312 minimum requirements while the DIN minimum yield strength values satisfy A312 for grades TP304L and TP316L respectively.

The minimum ultimate tensile strength and yield strength requirements for DIN grade 1.4401, 1.4541, and 1.4550 are 3% below and satisfy, respectively the A312 minimum requirements for grades TP316, TP321, and TP347.

Ductility Requirements

These two specifications take somewhat different approaches to tensile ductility as measured by percent elongation. In DIN 17440, a minimum percent elongation is specified for longitudinal and transverse specimens as a function of tube diameter, for each grade of pipe. Permitted reductions in percent elongation for thin wall tubes is not specified.

In A312, a minimum percent elongation is specified for longitudinal and transverse specimens for all alloy grades regardless of strength requirements, for pipe wall thicknesses 8 mm and above, independent of cross-sectional area. For wall thicknesses below 8 mm, a reduction in minimum percent elongation is allowed.

The comparison of minimum percent elongation requirements for both longitudinal and transverse orientations was carried out on the basis of the round specimen criteria with L/D = 4 for the ASTM specimen and L/D = 5 for the DIN specimen. Using the relationship between percent elongation, gage length, and cross-sectional area, the equivalent DIN elongation would be about 92% of the ASTM value. Thus, for round specimens, the longitudinal and transverse DIN percent elongation requirement for grades 1.4301, 1.4306, 1.4401, 1.4404, 1.4541, and 1.4550 for all nominal tube diameters exceeds the A312 minimum requirement for alloys TP304, TP304L, TP316, TP316L, TP321 and TP347.

Flattening Test Requirements

Specification A312 requires flattening tests on all tube diameters for both seamless and welded tube. The test is in two parts and qualitatively measures both ductility and material soundness. Part 1, a measure of ductility, requires a section of tube to be flattened to a fraction of its original diameter without cracking. For welded pipe, the weld is located 90° from the direction of applied force. This critical height is a function of the original diameter, wall thickness, and maximum allowed strain. The equation relating these parameters can be derived from theoretical analyses of bending of a curved section and can be written as:

$$e = \frac{1 - \frac{H}{D}}{\frac{H}{D} \cdot \frac{D}{t} - 1}$$

where H = distance between flattening plates
D = tube outside diameter
t = wall thickness
e = maximum strain at outer tube surface

In Part 2 of the A312 test, a measure of internal soundness, the tube is totally collapsed to look for evidence of delamination.

Specification DIN 17440 also requires a flattening test for all tube diameters for both seamless and welded tube. However, for tube diameters 146 mm and smaller, a tube expansion test may be substituted. The DIN test requirements are also in two parts, and the first part is based on the identical equation as used in A312. This equation does not account for the experimental observation that the actual maximum tensile strain experienced in flattening tube exceeds substantially the calculated value from the above equation. This effect, called "peaking" is not important for this discussion since both ASTM and DIN use only the theoretical equation. In Part 2 of the DIN test, the tube is also totally collapsed.

The maximum strain required by the ASTM test is 0.09 while DIN test requires a higher strain, 0.10, and thus DIN 174440 has a more severe test.

Hydrostatic Test Requirements

Specification A312 requires all lengths of tube to be hydrostatically tested without leaking a pressures calculated by the requirements of ASTM A530 and the alloy yield strength. The maximum test pressure are 17.2 MPa for tube with outside diameters 88.9 mm or less, and 19.3 MPa for tube over 88.9 mm diameter. Specification DIN 17440 requires a hydrostatic test on all lengths of pipe at fixed pressures. For DIN seamless pipe, the test pressures of 5 MPa and 8 MPa are determined by the tube operating pressure, while for welded tube the test pressures are determined by the tube diameter, 8 MPa for tube 133 mm or less in diameter and 5 MPa for tubes greater than 133 mm in diameter.

For welded tube of DIN grades 1.4306 and 1.4404, the following standard sizes from DIN 2463-81 satisfy the A312 test pressure requirements for grades TP 304L and TP316L:

wall thickness, mm	outside diameter, mm
1	21.3 and above
1.2	25 and above
1.6	33.7 and above
2	42.4 and above
2.3	48.3 and above
2.6	54 and above
2.9	60.3 and above
3.2	82.5 and above
3.6	76.1 and above
4	88.9 and above
4.5	114.3 and above
5	114.3, 168.3 and above
5.6	323.9 and above
6.3	219.1 and above
7.1	323.9 and above
8	355.6 and above
8.8	355.6 and above

For all other diameters, the DIN test pressure is from 7% to 54% below the A312 requirement for these grades.

For welded tube of DIN grades 1.4301, 1.4401, 1.4541, and 1.4550, the following standard tube sizes from DIN 2463-81 satisfy the A312 test pressure requirements for grades TP304, TP316, TP321, and TP347:

wall thickness, mm	outside diameter, mm
1	25 and above
1.2	31.8 and above
1.6	40 and above
2	51 and above
2.3	60.3 and above
2.6	63.5 and above
2.9	76.1 and above
3.2	82.5 and above
3.6	88.9 and above
4	101.6, 168.3 and above
4.5	114.3, 273 and above
5	273 and above
5.6	323.9 and above
6.3	273 and above
7.1	323.9 and above
8	355.6 and above
8.8	355.6 and above

For all other diameters, the DIN test pressure is from 7% to 54% below the A312 requirement for these grades.

In this comparison only the DIN test pressure for the higher pressure service, 8 MPa, will be used. For seamless tube of DIN grades 1.4306 and 1.4404, the following standard tube sizes from DIN 2462-81 satisfy the A312 test pressure requirements for grades TP304L and TP316L:

wall thickness, mm	outside diameter, mm
1	21.3 and above
1.2	25 and above
1.6	33.7 and above
2	42.4 and above
2.3	48.3 and above
2.6	54 and above
2.9	60.3 and above
3.2	82.5 and above
3.6	76.1 and above
4	88.9 and above
4.5	114.3 and above
5	139.7 and above
5.6	139.7 and above
6.3	139.7 and above
7.1	168.3 and above
8	219.1 and above
8.8	219.1 and above
10	273 and above
11	355.6 and above
12.5	273 and above
14.2	None

For all other diameters, the DIN test pressure is from 7% to 54% below the A312 requirement for these grades.

For seamless tube of DIN grades 1.4301, 1.4401, 1.4541, and 1.4550, the following standard tube sizes from DIN 2462-81 satisfy the A312 test pressure requirements for grades TP304, TP316, TP321, and TP347:

wall thickness, mm	outside diameter, mm
1	25 and above
1.2	31.8 and above
1.6	40 and above
2	51 and above
2.3	60.3 and above
2.6	63.5 and above
2.9	76.1 and above
3.2	82.5 and above
3.6	88.9 and above
4	101.6 and above
4.5	114.3 and above
5	139.7 and above
5.6	139.7 and above
6.3	None
7.1	None

8	219.1 and above
8.8	219.1 and above
10	273 and above
11	355.6 and above
12.5	323.9 and above
14.2	None

For all other diameters, the DIN test pressure is from 7% to 54% below the A312 requirement for these grades.

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JIS G5202-78//ASTM A426-76

INTRODUCTION

The scope statements for these two specifications are very similar and refer to centrifugally cast steel pipe for high-temperature and high pressure service. Specification ASTM A426-76 is limited to ferritic alloy steels while JIS G5202-78 includes both ferritic carbon and alloy steel grades.

The major design criteria for the intended applications of these materials are the static strength properties, ultimate tensile strength and yield strength. In addition, qualitative tests for material soundness and pressure tightness are also specified. The additional requirements include hydrostatic tests and flattening tests. The percent elongation requirement characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the materials intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility. The percent reduction-in-area is also a measure of tensile ductility and is not as sensitive to specimen geometry as percent elongation. Percent reduction-in-area measures the ability of the material to deform locally and thus reflects the materials ability to relieve local stress concentrations as might be expected in pressurized components at elevated temperatures.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G5202 are considered equivalent to the requirements of ASTM A426 if the JIS values exceed or are within 5% of the A216 minimum value; (2) the minimum JIS reduction-in-area values are considered equivalent to the requirements of A426 if they exceed or are within 5% of the A426 minimum value; (3) the percent elongation requirements of JIS G5202 are considered equivalent to the requirements of A426 if the JIS values exceed or are within 15% of the A426 minimum values; (4) the hardness requirements of JIS G5202 are considered equivalent to the requirements of A426 if the JIS values if they are below or within 5% of the A426 maximum value; (5) JIS G5202 pipe to be equivalent must satisfy the qualitative test requirements of A426. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) JIS class 1 (SCPH 1-CF) and class 2 (SCPH 2-CF) from JIS G5202-78 are carbon steel grades and outside of the scope of ASTM A426-76 and thus not equivalent to any A426 grades.

(2) JIS class 11 (SCPH 11-CF) from JIS G5202-78 is generally equivalent to ASTM A426-76 grade CP1 based on the criteria discussed earlier, subject to the following limitations:

(a) For JIS pipe to be acceptable, the inner and outer pipe surfaces must be finished to the requirements of A426, Section 5.2.

(b) To be acceptable, the JIS pipe must be normalized and tempered at a minimum temperature of 649 C.

(c) To be acceptable, the longitudinal and transverse ultimate tensile strength and yield strength requirements for the JIS pipe in the proper heat treated condition must be shown to satisfy the strength acceptance criterion.

(d) To be acceptable, the JIS pipe must be shown to satisfy the hardness acceptance criterion.

(3) JIS class 21 (SCPH 21-CF) from JIS G5202-78 is generally equivalent to ASTM A426-76 grade CP11 based on the criteria discussed earlier, subject to the following limitations:

(a) For JIS pipe to be acceptable, the inner and outer pipe surfaces must be finished to the requirements of A426, Section 5.2.

(b) To be acceptable, the JIS pipe must be normalized and tempered at a minimum temperature of 649 C.

(c) To be acceptable, the longitudinal and transverse ultimate tensile strength and yield strength requirements for JIS pipe in the proper heat treated condition must be shown to satisfy the strength acceptance criterion.

(d) To be acceptable, the JIS pipe must be shown to satisfy the hardness acceptance criterion.

(4) JIS class 32 (SCPH 32-CF) from JIS G5202-78 is generally equivalent to ASTM A426-76 grade CP22 based on the criteria discussed earlier, subject to the following limitations:

(a) For JIS pipe to be acceptable, the inner and outer pipe surfaces must be finished to the requirements of A426, Setion 5.2.

(b) To be acceptable, the JIS pipe must be normalized and tempered at a minimum temperature of 677 C.

(c) To be acceptable, the longitudinal and transverse tensile strength and yield strength requirements for JIS pipe in the proper heat treated condition must be shown to satisfy the strength acceptance criterion.

(d) To be acceptable, the JIS pipe must be shown to satisfy the hardness acceptance criterion.

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STEELMAKING PRACTICE

Specification ASTM A426 requires the steel to be made by the electric-furnace steelmaking process because of the alloy content of these grades. The use of other steelmaking processes would lead to unacceptably high alloying element losses. Specification JIS G5202 does not specify how the steel is made because it includes carbon steel grades which can be made by any of the usual steelmaking processes. Thus, JIS G5202 is not inconsistent with the requirements of A426.

SURFACE FINISH

Specification ASTM A426 requires all pipe to have both the inner and outer surfaces mchined to a particular finish while JIS G5202 does not specify any surface finish. The surface finish requirement for the inner pipe surface insures the removal of debris which could become attached to the surface and disrupt the resulting fluid flow through the pipe. The surface finish requirement for the pipe outer surface insures that surface casting defects originating from the centrifugal casting process are exposed and/or removed. These surface finish requirements are important for this pipe in its intended applications.

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analyses for JIS class 1 and class 2 do not satisfy the ASTM limits for any grade because they are carbon steel compositions and outside the scope of A426.

The chemical composition limits based on ladle analyses for JIS class 11 satisfy the chemical limits for A426 grade CP1. The JIS maximum carbon level is below the A426 maximum level while the JIS manganese range and molybdenum ranges are within the A426 ranges. The lower JIS carbon limit could result in lower strength properties. The maximum JIS levels for the impurities sulfur and phosphorus are below the A426 levels. The upper limit for the JIS silicon range exceeds the A426 upper limit but is not inconsistent with the requirements of A426. The JIS limits on the residual elements copper, nickel, chromium, tungsten and total residuals are identical to the A426 limits.

The chemical composition limits based on ladle analyses for JIS class 21 satisfy the chemical limits for A426 grade CP11. The JIS maximum carbon level is below the A426 maximum level while the JIS manganese range, chromium range, and molybdenum range are within or identical to the A426 ranges. The lower JIS carbon limit could result in lower strength properties. The maximum JIS levels for silicon, the impurities sulfur and phosphorus, and the residual elements copper, nickel, tungsten and total residuals are identical to the A426 limits.

The chemical composition limits based on ladle analyses for JIS class 32 satisfy the chemical limits for A426 grade CP22. The JIS maximum carbon level is slightly below the A426 maximum level while the JIS manganese range and molybdenum range are within or identical to the

A426 ranges. The maximum JIS levels for silicon, the impurities sulfur and phosphorus, and the residual elements copper, nickel, tungsten and total residuals are identical to the A426 limits. The JIS lower limit for the chromium range is slightly below the lower limit of the A426 range klbut this is not inconsistent with the requirements of A426.

MECHANICAL PROPERTIES

Heat Treatment

Specification ASTM A426 requires the steel to be normalized and tempered at temperatures which depend on the chemical composition of the grade. The minimum tempering temperature for ASTM A426 grades CP1, CP2, CP11, CP12, and CP15 is 649 C while the minimum temperature for grades CP5, CP5b, CP7, CP9, CP21, CP22, and CPCA15 is 677 C. Specification JIS G5202 does not specify heat treatment temperatures but only that the pipe must be heat treated by either annealed, normalized, normalized and tempered, or quenched and tempered. The variety of heat treatments is due in part to the presence of both carbon and alloy steels. To be acceptable, the JIS pipe must be in the normalized and tempered condition with minimum tempering temperatures as required by A426.

Strength Properties

The ASTM test specimen requirements are taken from both A426, A530 Section 16, and A370. For pipe 200 mm or larger nominal diameter, longitudinal or transverse specimen tests are required while only longitudinal tests are required for pipe smaller than 200 mm diameter. The preferred longitudinal and transverse specimen is the standard round specimen with a 50 mm gage length and a gage length-to-diameter (L/D) ratio of 4. There is no difference between longitudinal and transverse requirements.

Specification JIS G5202 permits test specimens to be taken from either the pipe itself or from a separately cast coupon. Thus, the JIS requirements are for the longitudinal orientation only. The test specimen is a standard round type with a diameter of 14 mm and a gage length-to-diameter ratio of 5 and the strength requirements can be directly compared with A426.

The minimum ultimate tensile strength and yield strength requirements of JIS class 11 are both 15% below the A426 requirements for grade CP1 and related in part to the lower JIS maximum carbon level and unspecified heat treatment.

The minimum ultimate tensile strength and yield strength requirements of JIS class 21 and class 32 are 15% and 25%, respectively, below the A426 requirements for grade CP11 and grade CP22 and related in part to the lower JIS maximum carbon levels and unspecified heat treatment.

Hardness Requirements

Specification A426 contains a requirement of maximum hardness in addition to the minimum ultimate tensile strength requirements. Using a correlation between hardness and approximate tensile strength, the maximum hardness permitted for A426 grades CP1, CP11, and CP22 permit a maximum ultimate tensile strength of about 690 MPa which is consistent with the range of minimum ultimate tensile strength values of 448 MPa to 483 MPa for these three grades. Specification JIS G5202 does not contain a maximum hardness requirement but since the JIS minimum ultimate tensile strength requirements are below the A426 values, it would be expected that the JIS class 11, class 21, and class 32 would satisfy the A426 hardness requirements.

Ductility Requirements

The JIS minimum percent elongation requirement is based on a specimen with a gage length five times the diameter. The equivalent ASTM specimen has a gage length four times the diameter. Using the relationship between percent elongation, gage length, and cross-sectional area, the equivalent JIS percent elongation would be about 91% of the ASTM value.

The JIS minimum percent elongation requirement for class 11 is 14% below the A426 minimum requirement for grade CP1. The JIS minimum percent elongation requirement for class 21 and class 32 exceed the A426 minimum requirement for grade CP11 and CP22.

Specification A426 contains minimum reduction-in-area requirements because the pipe could receive additional fabrication operations, including, but not limited to swaging, expansion, upsetting in which the ability of the pipe to withstand local deformation would be important. However, specification JIS G5202 does not include reduction-in-area requirements. If the JIS alloy classes satisfied the other mechanical property requirements of A426, then the reduction-in-area requirements would probably also be satisfied. The substantially lower minimum strength values for the JIS classes combined with the marginal elongation minimum for JIS class 11 suggests that the ASTM reduction-in-area acceptance criteria should be satisfied.

Flattening Test Requirements

Specification A426 and JIS G5202 permit flattening tests on all pipe diameters. The ASTM test is in two parts which qualitatively measure both ductility and soundness. Part 1, a measure of ductility, requires a section of pipe top be flattended to a fraction of its original dliametr without cracking. This critical height is a function of the original diameter, wall thickness, and maximum allowed strain. The equation relating these parameters can be derived from theoretical analyses of bending of a curved section and can be written as:

$$e = \frac{1 - \frac{H}{D}}{\frac{H}{D} \cdot \frac{D}{t} - 1}$$

where H = distance between flattening plates
D = pipe outside diameter
t = wall thickness
e = maximum strain at outer pipe surface

Specification JIS G5202 also permits a flattening test for all pipe diameters based on the identical equation. This equation does not account for the experimental observation that the actual maximum strain experienced in flattening pipe exceeds substantially the calculated value from the above equation. This effect, called "peaking" is not important for this discussion since both ASTM and JIS use only the theoretical equation. The maximum strain required by JIS for class 11, class 21, and class 32, e = 0.08, is the same as required by A530.

In part 2 of the ASTM test, a measure of internal soundness, the pipe is totally collapsed to look for evidence of delamination. However, JIS G5202 is deficient because it does not contain this requirement.

Hydrostatic Test Requirements

Specification A426 requires all lengths of pipe to be hydrostatically tested without leaking at pressures calculated from A530 by:

$$P = \frac{2\ St}{D}$$

where P = hydrostatic test pressure
S = pipe wall stress equal to 0.6 of minimum specified yield strength
t = pipe wall thickness
D = pipe outside diameter

The minimum test pressure need not exceed 17.2 MPa for outside diameters 88.9 mm or less, nor 19.3 MPa for outside diameters over 88.9 mm. Specification JIS G5202 permits a hydrostatic test at pressures calculated from the identical equation specified in A530.

JIS G4051-65//ASTM A576-74

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to hot-rolled carbon steel bars suitable for forging, heat treating, machining and other structural uses, called special quality in ASTM A576. In addition, JIS G4051-65 contains three classes identified as case-hardening alloys.

The major design criterion for the intended applications of these materials is the chemical composition limits. The applications for these alloys are extensive and varied, and in many situations require additional processing such as heat treatment and surface preparation so that it is expected that alloys with identical or very similar chemistry limits will respond in the same manner to various thermo/mechanical treatments. However, JIS G4051 requires killed steel without limits on the austenite grain size while ASTM A576 permits rimmed, capped, semi-killed, or killed steel with optional designation of austenite grain size for killed steel. Thus, these differences in deoxidation practice may influence subsequent properties depending on further processing and ultimate use.

For purposes of this comparison and based on the previous discussion, the acceptance criterion for the determination of equivalence is a very high degree of agreement in chemistry for all elements. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) The following JIS classes from JIS G4051-65 are generally equivalent to the indicated grades from ASTM A576-74, based on the criterion discussed earlier:

JIS class	ASTM grade (AISI designation)
S10C	1010
S12C	1012
S15C	1015
S17C	1017
S20C	1020
S22C	1023
S25C	1025
S28C	1029
S30C	1030
S35C	1035
S38C	1038
S40C	1040
S43C	1042
S45C	1045
S48C	1049
S50C	1050
S53C	1053
S55C	1055
S58C	1060

(2) JIS classes S9CK, S15CK, and S20CK from JIS G4051-65 are generally equivalent to grades 1010, 1015, and 1020, respectively, from ASTM A576-74, based on the criterion discussed earlier.

(3) JIS class S33C from JIS G4051-65 is not equivalent to any grade in ASTM A576-74 because the JIS carbon range does not fall within a range for any ASTM grade.

CHEMICAL REQUIREMENTS

Two primary quality descriptors of hot-rolled steel bars, in order of increasing quality, are merchant quality and special quality (ASTM A576). Merchant quality bars are typically used in non-critical structural applications which do not require extensive bending or welding and are generally unsuited for forging or other processing where internal soundness and high surface quality are important. Merchant quality bars are produced to wider carbon and manganese ranges than for other quality steel. Special quality bars such as those covered by A576 are suited for forging, cold forming, and machining and are required to be free from visible pipe and excessive chemical segregation and have narrower carbon and manganese ranges than merchant quality. Further, special quality bars often are produced from billets which have been inspected and conditioned to reduce surface defects.

The chemical composition ranges for carbon and manganese, based on ladle analyses, for JIS classes S10C, S12C, S15C, S17C, S20C, S22C, S25C, S28C, S35C, S38C, S40C, S43C, S50C, S53C, S55C, S58C, S15CK, and S20CK are identical to or totally within the A576 ranges for grades 1010, 1012, 1015, 1017, 1020, 1023, 1025, 1029, 1035, 1038, 1040, 1042, 1049, 1053, 1055, 1060, 1015, and 1020, respectively. Although JIS G4051 specifies a range of silicon levels which is consistent with the required killed steel deoxidation practice, A576 does not specify a silicon content because a variety of deoxidation practices are permitted which would result in different residual silicon levels. Thus the JIS silicon requirements for these classes are consistent with the intent of A576 which allows killed steels. The maximum JIS levels of sulfur and phosphorus for these classes are below the A576 maximum levels and thus satisfy the ASTM requirements.

The chemical composition range for carbon, based on ladle analyses, for JIS classes S30C, S45C, S48C, and S9CK falls slightly below the A576 ranges for grades 1030, 1045, 1049, and 1010, respectively. The JIS minimum carbon value for these four classes is only 0.01% or one point of carbon below the ASTM minimum value and thus should not have a noticeable effect on subsequent properties or behavior. The manganese range for these JIS classes is identical to the A576 ranges while the maximum JIS levels for sulfur and phosphorus are below and thus satisfy the ASTM maximum levels. Silicon is not specified in A576 because of the variety of deoxidation practices allowed; therefore the JIS silicon range satisfies the intent of A576.

The carbon composition range, based on a ladle analysis, for JIS class S33C falls equally between A576 grades 1030 and 1035, and thus does not satisfy any grade from A576.

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DIN 17200-69//DIN 17210-69//ASTM A576-74

INTRODUCTION

The scope statement in ASTM A576--4 refers to hot-rolled, special quality, carbon steel bars suitable for additional processing, including forging, heat treating, cold drawing, and machining. The two DIN specifications, DIN 17200-69 and DIN 17210-69, however, describe two generic classes of steels, quenched and tempered carbon and alloy steels, and case hardening carbon and alloy steels, in a variety of forms including bar stock, flats, sheet, seamless tubes, and forgings. Further, DIN 17200 and DIN 17210 specify minimum mechanical properties which depend on the subsequent heat treatment received whereas A576 does not specify any mechanical property requirements for the hot-rolled condition since further thermo/mechanical processing is expected. Thus the comparison excludes consideration of mechanical properties.

The major design criterion for the intended applications of these alloys (as described in A576) is the chemical composition limits. The applications for these alloys are extensive, and in many situations require additional processing such as heat treatment so that it is expected that alloys with identical or very similar chemistry limits will respond in the same manner to various thermo/mechanical treatments.

For purposes of this comparison and based on the previous discussion, the acceptance criterion for the determination of equivalence is a very high degree of agreement in chemistry for all elements. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) DIN grade Ck10 (1.1121), grade Ck15 (1.1141), and grade Cm15 (1.1140) from DIN 17210-69 are generally equivalent to grades 1010, 1015, and 1015, respectively, from ASTM A576-74, based on the criterion discussed earlier.

(2) DIN grade C10 (1.0301) and grade C15 (1.0401) from DIN 17210-69 are not equivalent to ASTM A576-74 because they are lower quality grades of Ck10, Ck15, and Cm15 and are allowed a somewhat higher phosphorus level than that allowed by A576, greater inclusion content, and poorer surface quality.

(3) DIN grade Ck55 (1.1203), grade Cm55 (1.1209), grade Ck60 (1.1221), and Cm60 (1.1334) from DIN 17200-69 are generally equivalent to grades 1055, 1055, 1060, and 1060, respectively, from ASTM A576-74, based on the criterion discussed earlier.

(4) DIN grade C55 and grade C60 from DIN 17200-69 are not equivalent to ASTM A576-74 because they are lower quality grades of Ck55, Cm55, Ck60, and Cm60 and are allowed a somewhat higher phosphorus level than that allowed by A576, greater inclusion content, and poorer surface quality.

(5) DIN grade Ck35 (1.1181), grade Cm35 (1.1180), grade Ck45 (1.1191), and grade Cm45 (1.1201) from DIN 17200-69 are generally equivalent to ASTM A576-74, based on the criterion discussed earlier, subject to the following limitation:

(a) To be acceptable, the minimum manganese level (ladle analysis) for these DIN grades must be shown to exceed 0.60 weight percent in order to insure proper response to further thermal processing.

(6) DIN grades C35 (1.0501) and C45 (1.0503) from DIN 17200-69 are not equivalent to ASTM A576-74 because they are lower quality grades of Ck35, Cm35, Ck45, and Cm45 and are allowed a somewhat higher phosphorus level, greater inclusion content, and poorer surface quality in addition to having the maximum and minimum DIN manganese levels below the A576 requirements.

(7) DIN grades 15 Cr3, 16 MnCr5, 20 MnCr5, 20 MoCr4, 25 MoCr4, 15 CrNi6, 17 CrNiMo6 from DIN 17210-69, and DIN grades 28 Mn6, 38 Cr2, 46 Cr2, 34 Cr4, 37 Cr4, 41 Cr4, 25 CrMo4, 34 CrMo4, 42 CrMo4, 32 CrMo12, 36 CrNiMo4, 34 CrNiMo6, 30 CrNiMo8, and 50 CrV4 from DIN 12200-69 are alloy steel grades and are outside the scope of ASTM A576-74.

CHEMICAL REQUIREMENTS

Two primary quality descriptors of hot-rolled steel bars, in order of increasing quality, are merchant quality and specialty quality (ASTM A576). Merchant quality bars are typically used in non-critical structural applications which do not require extensive bending or welding and are generally unsuited for forging or other processing where internal soundness and high surface quality are important. Merchant quality bars are produced to wider carbon and manganese ranges than other quality steels. Special quality bars such as those covered by A576 are suited for forging, cold forming, and machining and are required to be free from visible pipe and excessive chemical segregation and have narrower carbon and manganese ranges than merchant quality. Further, special quality bars often are produced from billets which have been inspected and conditioned to reduce surface defects.

The chemical composition ranges for carbon, based on ladle analysis, for DIN grades Ck10, Ck15, and Cm15 falls slightly below the A576 ranges for grades 1010, 1015, and 1015, respectively. The DIN minimum carbon value for these three grades is only 0.01% or one point of carbon below the ASTM minimum value and thus should not have a noticeable effect on subsequent properties behavior. The manganese ranges for these DIN classes is identical to the A576 ranges while the maximum DIN values for sulfur and phosphorus are below the A576 values and thus satisfy A576. Although DIN 17210 specifies a range of silicon levels which suggests a killed steel deoxidation practice, A576 does not specify silicon because various deoxidation practices are permitted which result in different residual silicon levels. Thus, the DIN silicon requirement for these classes is consistent with the intent of A576 which allows killed steels. The maximum DIN levels of sulfur and phosphorus for these classes are below the A576 maximum level and thus satisfy the ASTM requirements.

The chemical composition ranges for all elements for DIN grades C10 and C15 are identical to those for the DIN Ck and Cm grades except higher levels of sulfur and phosphorus are permitted in C10 and C15. The maximum permitted phosphorus level for these two DIN grades exceeds slightly the maximum level allowed by A576. Further, DIN 17210 describes the grades C10 and C15 as having poorer homogeneity, greater number of inclusions, and poorer surface quality than the Ck and Cm grades, and thus less likely to satisfy the special quality requirements of A576.

The chemical composition ranges for carbon and manganese, based on ladle analysis, for DIN grades Ck55, Cm55, Ck60, and Cm60 are identical to or totally within the A576 ranges for grades 1055, 1055, 1060, and 1060, respectively. Although DIN 17200 specifies a range of silicon levels which suggests a killed steel deoxidation practice, A576 does not specify silicon because various deoxidation practices are permitted resulting in different residual silicon levels. Thus, the DIN silicon requirement for these classes is consistent with the intent of A576 which allows killed steels. The maximum DIN levels of sulfur and phosphorus for these grades are below the A576 maximum levels and thus satisfy the ASTM requirements.

The chemical composition ranges for carbon, based on ladle analysis, for DIN grades Ck35, Cm35, Ck45, and Cm45 fall slightly above or slightly below the A576 ranges for grades 1035, 1035, 1045, and 1045, respectively. The DIN maximum carbon value for grades Ck35 and Cm35 and the DIN maximum carbon value for grades Ck45 and Cm45 are only 0.01% or one point of carbon above or below the ASTM maximum or minimum values and thus should not have a noticeable effect on subsequent properties or behavior. The manganese range for these DIN grades, however, is substantially below the A576 range. The maximum and minimum DIN manganese levels are 0.1% below the A576 maximum and minimum levels and thus, at the low manganese end, properties could be affected. The maximum DIN levels of sulfur and phosphorus for these grades are below the A576 maximum levels and thus satisfy the ASTM requirements.

The chemical composition ranges for all elements for DIN grades C35, C45, C55, and C60 are identical to those for the DIN Ck and Cm grades except that higher levels of sulfur and phosphorus are permitted in all of these C grades. The maximum permitted phosphorus level for the C grade exceeds slightly the maximum level allowed by A576. Further, DIN 17200 describes the C grades as having poorer response to heat treating, greater number of inclusions, and poorer surface quality than the Ck and Cm grades, and thus less likely to satisfy the special quality requirements of A576.

JIS G3101-76//ASTM A307-78

INTRODUCTION

The scope statements of these two specifications do not have the same focus. Specification ASTM A307-78 covers only externally threaded fasteners in sizes 6.35 mm to 104 mm, plain and galvanized, while JIS G3101-76 includes all rolled steel products for general structural use, including sheet, plate, strip, flats, shapes, and bars. Specification JIS G3101-76 does not specifically cover finished products such as threaded fasteners, but rather, for example, the starting material for threaded fasteners.

However, A307 is the product specification for externally threaded fasteners based on the more general specification, A36. Specification A36 covers all forms of carbon structural steel, including shapes, plates, and bars in the unfinished condition, for general use, and in scope is very close to JIS G3101. (See the JIS G3101-76//ASTM A36-77a comparison).

The principal design criterion for the structural applications of these products is the ultimate tensile strength. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G3101 are considered equivalent to the requirements of ASTM A307 if the JIS values fall within the range from 5% above the A307 maximum value to 5% below the A307 minimum value; and (2) the percent elongation requirements of JIS G3101 are considered equivalent to the requirements of A307 if the JIS values exceed or are within 15% of the A307 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) JIS class 1 (SS 34) from JIS G3101-76 is not generally equivalent to ASTM A307-78 grade B because the maximum JIS ultimate tensile strength only slightly exceeds the A307 minimum requirement.

(2) JIS class 2 (SS 41) from JIS G3101-76 is generally equivalent to ASTM A307-78 grade B based on the criteria discussed earlier, subject to the following limitations:

(a) JIS tensile test specimens from bars over 38 mm to 65 mm in diameter must be located so that the specimen axis lies midway between the bar axis and the outer surface.

(b) To be acceptable, the minimum JIS percent elongation requirements for bars 25 mm or less in diameter must satisfy the elongation acceptance criterion.

(3) JIS class 3 (SS 50) from JIS G3101-76 grade B is generally equivalent to ASTM A307-78 based on the criteria discussed earlier, subject to the following limitations:

(a) JIS tensile test specimens from bars over 38 mm to 65 mm in diameter must be located so that the specimen axis lies midway between the bar axis and the outer surface.

(b) To be acceptable, the minimum JIS percent elongation requirement for bars 25 mm or less in diameter must satisfy the elongation acceptance criterion.

(4) JIS class 4 (SS 55) from JIS G3101-76 is not generally equivalent to ASTM A307-78 grade B because the minimum ultimate tensile strength is substantially greater than the A307 minimum, thus increasing the probability that the unspecified JIS maximum ultimate strength would exceed the A307 limit. This higher expected ultimate tensile strength is consistent with the JIS class 4 minimum percent elongation requirement for all bar sizes being less than the A307 minimum requirement.

CHEMICAL REQUIREMENTS

Specification ASTM A307-78 contains two strength grades with chemical composition limits for only sulfur and phosphorus. The carbon and manganese levels are not specified. One of the two grades, grade A, is a resulfurized steel for better machinability. Specification JIS G3101-76 contains four strength classes in which three of the four, class 1, class 2, and class 3, have chemical composition limits for only sulfur and phosphorus. Carbon and manganese levels are not specified for these three classes. The four classes do not cover resulfurized steels and thus none are equivalent to A307 grade A steel.

The absence of extensive chemical composition requirements allows wider chemistry limits on important elements such as carbon and manganese and thus reduces the cost of these products since both chemical requirements and mechanical property requirements do not have to be satisfied. When this steel is produced to mechanical property requirements, typical practice allows the carbon and manganese levels to vary in order to compensate for the effect of product thickness.

The chemical composition limits based on ladle analyses for JIS class 1, class 2, class 3, and class 4 satisfy the chemical limits for A307 grade B. The maximum phosphorus limit for JIS class 1, class 2, and class 3 material exceeds slightly the A307 grade B maximum limit but should not have an adverse effect on the mechanical properties. The maximum phosphorus limit for JIS class 4 material is identical to the A307 grade B maximum limit. The maximum sulfur limit for JIS class 1, class 2, class 3, and class 4 is identical to or below the A307 grade B maximum limit.

MECHANICAL PROPERTIES

Specification A307 calls for the mechanical tests to be carried out according to ASTM A370, Supplement III for threaded fasteners. The preferred specimen is the full-size threaded bolt tested to a minimum ultimate load which corresponds to a fixed ultimate tensile strength for the particular grade. Due to test equipment limitations, machined, round, 50 mm gage length specimens are permitted and ultimate tensile strength requirements are applied. Specific types of small bolts which cannot be directly tested can satisfy hardness requirements instead of ultimate tensile load or strength requirements. The hardness value limits correlate with the ultimate tensile strength limits applied to larger bolts. Machined specimens taken from bolts less than 38 mm in diameter shall have their axis concentric with bolt axis; the specimen axis in bolts 38 mm or more in diameter shall be midway between bolt axis and outer surface.

Specification JIS G3101 covers only the bar stock before it is converted into threaded fasteners and so does not contain threaded type specimens or hardness requirements. The preferred JIS specimens are full size sections of bar stock and located according to JIS G0303-72 class A. The test specimen taken from bars 65 mm or less in diameter has its axis concentric with the bar axis; the specimen axis for bars over 65 mm in diameter shall be midway between bar axis and outer surface. Thus for bar stock and threaded bolts 38 mm or less in diameter or greater than 65 mm in diameter, a direct comparison can be made between the requirements of JIS G3101 and ASTM A307. For sizes over 38 mm to 65 mm in diameter, the JIS specimen must be located as required by A370 in order for the same regions of the bar or bolt will be sampled by the test specimen.

Strength Requirements

The minimum ultimate tensile strength for JIS G3101 class 1 is 20% below the minimum A307 grade A and grade B value while the maximum class 1 value is only 4% above these A307 minimum values.

The minimum ultimate tensile strength for JIS G3101 class 2 is 3% below the A307 minimum value for grade A and grade B while the maximum class 2 value is within the allowed range for A307 grade B. For grade A fasteners, an upper limit on ultimate tensile strength is not specified.

The minimum ultimate tensile strength for JIS G3101 class 3 exceeds the A307 minimum value for grade A and grade B while the maximum class 3 value is within the allowed range for A307 grade B.

The minimum ultimate tensile strength for JIS G3101 class 4 substantially exceeds the A307 minimum value for grade A and grade B. The maximum ultimate tensile strength for JIS class 4 substantially exceeds the A307 minimum value for grade A and grade B. The maximum ultimate tensile strength for JIS class 4 is not specified.

Ductility Requirements

Using the preferred A307 test specimen, ductility requirements, such as percent elongation, are not specified. However, using the alternate machined specimen with the gage length-to-diameter ratio of 4, a minimum percent elongation is required.

The JIS test specimen for bars 25 mm or less in diameter has a gage length-to-diameter ratio (L/D) of 8. Using the relationship between gage length and cross-sectional area, the equivalent JIS elongation value would be smaller, about 76% of the ASTM value. The JIS test specimen for bars over 25 mm in diameter has a gage length-to-diameter ratio of 4, the same as the ASTM specimen. Thus, for specimens sampling the same region, the JIS and ASTM requirements can be directly compared.

The minimum elongation requirements for all sizes of JIS class 1 exceed the A307 minimum requirement for grade A and grade B. The minimum elongation requirements for JIS class 2 and class 3 bars over 25 mm diameter exceed the A307 minimum requirement for grade A and grade B. For JIS class 2 and class 3 bars 25 mm or less diameter, the JIS minimum requirements are 17% and 22%, respectively, below the A307 minimum value. The minimum elongation requirement for JIS class 4 bars over 25 mm diameter is 6% below the A307 minimum requirement while for bars 25 mm or less in diameter, the JIS requirement is 44% below the A307 value.

DIN 267-67//ASTM A307-78

INTRODUCTION

The scope statements for these two specifications are similar and refer to carbon steel externally threaded fasteners for general applications. Specification ASTM A307-78 is limited to headed bolts in sizes from 6.35 mm to 104 mm in diameter while specification DIN 267-67 includes nuts, screws, and other threaded forms in addition to headed bolts, up to 39 mm in diameter. Further, DIN 267 covers stainless steel and nonferrous fasteners as well as carbon steel fasteners.

The major design criteria for the intended applications of these materials is the static strength property, ultimate tensile strength, and hardness. The percent elongation requirement characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the materials intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition, and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 267 are considered equivalent to the requirements of ASTM A307 if the DIN values fall within the range from 5% above the A307 maximum value to 5% below the A307 minimum value; (2) the DIN hardness values are considered equivalent to the requirements of A307 if they fall within the range from 5% above the A307 maximum value to 5% below the A307 minimum value; (3) the percent elongation requirements of DIN 267 are considered equivalent to the requirements of A307 if the DIN values exceed or are within 15% of the A307 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) DIN grade 3.6 from DIN 267-67 is not generally equivalent to ASTM A307 Grade A or Grade B because the DIN minimum ultimate tensile strength and minimum hardness requirements are 20% and 26% below the A307 minimum requirements for Grade A or Grade B.

(2) Resulfurized DIN grade 4.6 from DIN 267-67 is generally equivalent to ASTM A307 Grade A (SAE grade 1) based on the criteria discussed earlier, subject to the following limitations:

(a) The DIN sulfur level should be held to 0.15% maximum.

(b) The DIN ultimate tensile strength and minimum hardness must satisfy the A307 acceptance criteria.

(3) Non-resulfurized DIN grade 4.6 from DIN 267-67 is generally equivalent to ASTM A307 Grade B (SAE grade 1) based on the criteria discussed earlier, subject to the following limitation:

(a) The DIN minimum ultimate tensile strength and minimum hardness must satisfy the A307 acceptance criteria.

(4) DIN grade 4.8 from DIN 267-67 is not generally equivalent to ASTM A307 Grade A or Grade B because this higher yield strength-to-tensile strength version of DIN grade 4.6 has a minimum percent elongation requirement 27% below the A307 minimum requirement.

(5) DIN grades 5.6 and 5.8 from DIN 267-67 are not generally equivalent to ASTM A307 Grade A or Grade B because their DIN minimum ultimate tensile strength values satisfy the SAE requirements for grade 2 bolts.

(6) DIN grades 6.6, 6.8, and 6.9 from DIN 276-67 are not generally equivalent to ASTM A307 Grade A or Grade B because their DIN minimum ultimate tensile strength values satisfy the SAE requirements for grade 3 bolts.

(7) DIN grades 8.8 and 10.9 from DIN 276-67 are not generally equivalent to ASTM A307 Grade A or Grade B because their DIN minimum ultimate tensile strength values satisfy the SAE requirements for grade 5 and grade 8 bolts, respectively.

(8) DIN grades 12.9 and 14.9 from DIN 276-67 are not generally equivalent to ASTM A307 Grade A or Grade B because their ultimate tensile strength and hardness ranges lie far outside the A307 allowed ranges.

DIN 267-67//ASTM A307-78

CHEMICAL REQUIREMENTS

Typically, threaded fasteners for service between -50 C and +200 C may be produced from a number of different grades of steel provided the finished fastener satisfies the specified strength requirements. These carbon and alloy steels are generally limited to 0.55% maximum carbon content. The fastener fabricator thus can choose among a number of steel compositions to satisfy the specified strength requirement. Consistent with this approach, A307 contains only the most minimal chemical requirements with only sulfur and phosphorus specified for the two steel grades. The free-machining grade, A307 Grade A permits up to 0.15% sulfur and 0.06% phosphorus, while the non-free machining grade, Grade B, limits sulfur to 0.05% and phosphorus to 0.04%. Steel grades containing lead, bismuth, selenium, or tellurium are not permitted for Grade B bolts.

Specification DIN 267 for strength categories or grades 4.6, 4.8, 5.6. 5.8, 6.6, 6.8, and 6.9 permits somewhat high sulfur and phosphorus limits of 0.07% and 0.06%, respectively, for the non-free machining types and 0.34% and 0.10% respectively, for the free-machining types. Typically, sulfur is limited to 0.13% in AISI-SAE resulfurized steel grades, although a few grades have maximum sulfur levels of 0.35%, similar to the DIN limit. However, in resulfurized steels, the manganese level must be high enough so that the sulfur is present only as manganese sulfide particles. Neither A307 or DIN 267 specify manganese levels and so to insure the absence of free-sulfur in the alloy, the DIN sulfur maximum should be held to the A307 limit of 0.15%. Phosphorus also improves machinability, especially for cutting threads and thus the higher maximum phosphorus levels in DIN 267 are not inconsistent with the intent of A307.

MECHANICAL PROPERTIES

Although not explicitly indicated, specification A307 applies to grade 1 bolts as defined by Society of Automotive Engineers (SAE) Standard J429, based on the minimum specified ultimate tensile strength. The SAE classifies bolts by strength grades with a minimum strength requirement for each grade. Variations in chemical composition and thermo/mechanical processing are allowed in order to achieve the particular minimum strength. The strength requirements of SAE grade 1 bolts can be met with hot rolled low-carbon steels.

Strength Requirements

Tensile testing of full-size bolts is preferred according to A307 although machined specimens are also permitted. For bolts less than 38 mm diameter, round 12.7 mm diameter, 50 mm gage length machined specimens concentric with the bolt axis are used, while for bolts 38 mm or more in diameter, the standard round specimen is located with its axis one-half the distance from the center to the surface of the bolt.

According to specification DIN 267, axial testing of full-size bolts or machined specimens concentric with the bolt axis are permitted. Thus, a direct comparison of strength requirements can be carried out.

Specification A307 distinguishes between the free-machining Grade A and the normal Grade B by allowing greater latitude in hardness for Grade A. In DIN 267, both normal and free-machining grades must satisfy the same strength requirements.

The minimum ultimate tensile strength for DIN grade 3.6 is 20% below the A307 minimum for Grade A or Grade B. The minimum ultimate tensile strength for DIN grades 4.6 and 4.8 are 4% below the SAE requirement for grade 1 bolts and 4% below the A307 requirement for Grade A or Grade B. The minimum ultimate tensile strength for DIN grades 5.6 and 5.8 are 2% below the SAE requirement for grade 2 bolts up to 19 mm diameter and 15% above the SAE requirements for grade 2 bolts over 19 mm diameter. The minimum ultimate tensile strength for DIN grades 6.6, 6.8, and 6.9 satisfy the SAE requirements for grade 3 bolts while the maximum ultimate tensile strength for DIN grades 6.6, 6.8, and 6.9 is 14% above the maximum A307 requirement for Grade B bolts. The minimum ultimate tensile strength for DIN grades 8.8 and 10.9 satisfy the SAE requirements for grade 5 and grade 8 bolts, respectively, and far exceed the maximum ultimate tensile strength for A307 Grade B bolts. The minimum ultimate tensile strength for DIN grades 12.9 and 14.9 far exceed the maximum values for A307 grade B bolts.

Hardness Requirements

The minimum Brinell hardness specified for DIN grade 3.6 is 26% below the minimum hardness for A307 Grade A or Grade B. The specified hardness range for DIN grades 4.6 and 4.8 lies from 8% below to within the allowed range for A307 Grade A or Grade B. The specified hardness range for DIN grades 5.6 and 5.8 lies within the allowed range for A307 Grade A and from within to 2% above the allowed range for A307 Grade B. The specified hardness range for DIN grades 6.6, 6.8, and 6.9 lie from within to 2% above the allowed range for A307 Grade A and from within to 16% above the allowed range for A307 Grade B. The specified hardness range for DIN grade 8.8 lies from within to 25% above the allowed range for A307 Grade A and from 6% to 42% the allowed range for A307 Grade B. The specified minimum hardness for DIN grade 10.9 is 16% and 32%, respectively, above the A307 maximum hardness value for Grade A and Grade B. The specified minimum hardness for DIN grades 12.9 and 14.9 are 37% or more above the maximum hardness specified for A307 Grade A or Grade B.

Ductility Requirements

Percent elongation requirements are specified only when machined specimens are tested. The machined DIN test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 5, independent of bolt diameter. Similarly, A307 through A370 permits a circular cross-section specimen with a constant gage length-to-diameter ratio of 4, independent of bolt diameter. Based on the relationship between percent elongation, gage length, and cross-sectional area, the equivalent DIN elongation would be 92% of the A307 value.

The minimum percent elongation requirements for DIN grades 3.6, 4.6, and 5.6 satisfy the A307 requirement for Grade A or Grade B bolts. The minimum percent elongation requirement for DIN grades 4.8, 5.8, and 6.6 are 27%, 50%, and 17%, respectively, below the A307 requirement for Grade A or Grade B. The minimum percent elongation requirement for DIN grades 6.8, 6.9, 8.8, 10.9, 12.9, and 14.9, are 59%, 39%, 39%, 54%, 59%, and 64%, respectively below the A307 requirement for Grade A or Grade B.

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DIN 17200-69//ASTM A307-78

INTRODUCTION

The scope statements for these two specifications are not closely related. Specification ASTM A307-78 covers threaded carbon steel bolts for general applications. Specification DIN 17200-69, however, includes quenched and tempered steels, both carbon and alloy steels in a variety of mill forms, including rolled or forged semi-finished products, wire, bars, plate, sheet, seamless tubes and forgings. For general applications, DIN 17240 refers to the steels in DIN 17200 as being suitable for bolts for general applications up to 350 C.

The major design criteria for the intended applications of these materials is the static strength property, ultimate tensile strength, and hardness. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the materials intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17200 are considered equivalent to the requirements of ASTM A307 if the DIN values fall within the range from 5% above the A307 maximum value to 5% below the A307 minimum value; (2) the DIN hardness values are considered equivalent to the requirements of A307 if they fall within the range from 5% above the A307 maximum to 5% below the A307 minimum value; and (3) the percent elongation requirements of DIN 17200 are considered equivalent to the requirements of A307 if the DIN values exceed or are within 15% of the A307 minimum values. Allowance of the larger differences for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) DIN grades C35 (1.0501), Ck35 (1.1181), and Cm35 (1.1180) from DIN 17200-69 are not generally equivalent to ASTM A307-78 Grade B (SAE grade 1) because the DIN minimum ultimate tensile strength satisfies the SAE requirement for grade 2 bolts.

(2) DIN grades C45 (1.0503), Ck45 (1.1191), and Cm45 (1.1201) from DIN 17200-69 are not generally equivalent to ASTM A307-78 Grade B (SAE grade

1) because the DIN minimum ultimate tensile strength satisfies the SAE requirement for grade 3 bolts.

(3) DIN grades C55 (1.0535), Ck55 (1.1203), Cm55 (1.1209), C60 (1.0601), Ck60 (1.1221), Cm60 (1.1223), and 28Mn6 from DIN 17200-69 are not generally equivalent to ASTM A307-78 Grade B because the DIN minimum ultimate tensile strength substantially exceeds the A307 minimum and in some cases also exceeds the A307 maximum ultimate tensile strength.

(4) DIN grades 38Cr2, 46Cr2, 34Cr4, 37Cr4, 41Cr4, 25CrMo4, 34CrMo4, 42CrMo4, 32CrMo12, 36CrNiMo4, 34CrNiMo6, 30CrNiMo8, 50CrV4, 34CrS4, 37CrS4, 41CrS4, 34CrMoS4, and 42CrMoS4 from DIN 17200-69 are alloy steels and outside of the scope of ASTM A307.

DIN 17200-69//ASTM A307-78

CHEMICAL REQUIREMENTS

Typically, threaded fasteners, including bolts, for service between -50C and +200C may be produced from a number of different grades of steel provided the finished fastener satisfies the specified strength requirements. These carbon and low alloy steels are generally limited to 0.55% maximum carbon content. The fastener fabricator thus can choose among a number of steel compositions to satisfy the specified strength requirement. Consistent with this approach, A307 contains only minimal chemical requirements with only sulfur and phosphorus specified for the two steel grades. The free-machining grade, A307, Grade A permits up to 0.15% sulfur and 0.06% phosphorus, while the non-free machining grade, Grade B, limits sulfur to 0.05% and phosphorus to 0.04%. Steel grades containing lead, bismuth, selenium, or tellurium are not permitted for Grade B bolts.

The chemical composition limits for carbon, manganese, sulfur, and phosphorus for DIN grades C35, Ck35, Cm35, C45, Ck45, Cm45, C55, Ck55, and Cm55 satisfy, are very close to, or are consistent with the intent of A307 for Grade B. Specification DIN 17200 does not contain free-machining grades. The chemical composition limits for manganese, sulfur, and phosphorus for DIN grades C60, Ck60, and Cm60 satisfy or are consistent with the intent of A307 for Grade B, while the minimum carbon level probably exceeds the A307 intended maximum level. The remaining DIN grades in DIN 17200 all contain one or more of the following alloying elements: chromium, molybdenum, nickel, and vanadium and thus are outside the scope of A307.

MECHANICAL PROPERTIES

Although not explicitly indicated, Specification A307 applies to grade 1 fasteners as defined by Society of Automotive Engineers (SAE) Standard J429, based on the minimum specified ultimate tensile strength. The SAE classifies bolts by strength grades with a minimum strength requirement for each grade. Variations in both chemical composition and thermo/mechanical processing are allowed to achieve the particular minimum strength. The strength requirements of SAE grade 1 bolts can be met with hot rolled low-carbon steels. Although not explicitly stated, A307 appears to cover non-heat treated steel. Quenched and tempered steels will, in general, satisfy the strength requirements for the lower strength bolts, e.g. grade 1 bolts, but because of their higher strength these steels will also satisfy the requirements of higher strength grades.

Strength and Hardness Requirements

Tensile testing of full-size bolts is preferred according to A307 although machined specimens are also permitted. For bolts less than 38 mm diameter, round 12.7 mm diameter, 50 mm gage length machined specimens concentric with the bolt axis are used, while for bolts 38 mm or more in diameter, the standard round specimen is located with its axis mid-way between the bolt center and its outer surface.

According to DIN 17200, round, machined specimens are used. For bars 25 mm or less in diameter, specimens concentric with the bar axis are used, while for bars over 25 mm diameter the specimen axis is to be located one third the distance in from the surface towards the bar center. In going through the range of diameters from 25 mm to 38 mm, the ASTM and the DIN specimens sample essentially the same volume, even with 38 mm bars, and thus a direct comparison can be carried out.

The minimum ultimate tensile strength for DIN grades C35, Ck35, and Cm35 is 8% above the SAE requirement for grade 2 bolts. The minimum ultimate tensile strength for DIN grades C45, Ck45, and Cm45 is 3% above the SAE requirement for grade 3 bolts. The minimum ultimate tensile strength for DIN grades C55, Ck55, Cm55, C60, Ck60, and Cm60 fall between the SAE requirements for grade 3 and grade 5 bolts.

Finally, specification DIN 17200 does not contain any hardness requirements for steels in the quenched and tempered condition.

Ductility Requirements

The machined DIN test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 5, independent of bolt diameter. Similarly, A307 through A370 permits a circular cross-section specimen with a constant gage length-to-diameter ratio of 4, independent of bolt diameter. Based on the relationship between percent elongation, gage length, and cross-sectional area, the equivalent DIN elongation would be 92% of the A307 value.

The minimum percent elongation requirements for DIN grades C35, Ck35, and Cm35 are 6% below the A307 Grade B minimum requirements. The minimum percent elongation requirements for DIN grades C45, Ck45, and Cm45 are 28% below the A307 Grade B minimum requirement.

DIN 17240-69//ASTM A307-78

INTRODUCTION

The scope statements for these two specifications are only similar in that both refer to bolts. Specification ASTM A307-78 covers threaded carbon steel bolts for general applications while DIN 17240-59 includes both carbon and alloy steel grades for bolts and nuts for elevated temperature surface. Further, A307 appears to be limited to hot or cold finished bar stock as the bolt starting material while DIN 17240-59 specifically calls for quenched and tempered material.

The major design criteria for the intended applications of these materials is the static strength property, ultimate tensile strength, and hardness. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the materials intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17240 are considered equivalent to the requirements of ASTM A307 if the DIN values fall within the range from 5% above the A307 maximum value to 5% below the A307 minimum value; (2) the DIN hardness values are considered equivalent to the requirements of A307 if they fall within the range from 5% above the A307 maximum to 5% below the A307 minimum value; and (3) the percent elongation requirements of DIN 17240 are considered equivalent to the requirements of A307 if the DIN values exceed or are within 15% of the A307 minimum values. Allowance of the larger differences for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) DIN grades C35 (1.0501), Ck35 (1.1181), and Cm35 (1.1180) from DIN 17240-59 are not generally equivalent to ASTM A307-78 Grade B (SAE grade 1) because the DIN minimum ultimate tensile strength satisfies the SAE requirement for grade 2 bolts.

(2) DIN grades C45 (1.0503) and Ck45 (1.1191) from DIN 17240-59 are not generally equivalent to ASTM A307-78 Grade B (SAE grade 1) because the DIN minimum ultimate tensile strength satisfies the SAE requirement for grade 3 bolts.

(3) -DIN grades 24CrMo5, 24CrMoV55, and 21CrMoV511, from DIN 17240-59 are alloy steels and outside of the scope of ASTM A307.

CHEMICAL REQUIREMENTS

Typically, threaded fasteners, including bolts, for service between -50C and +200C may be produced from a number of different grades of steel provided the finished fastener satisfies the specified strength requirements. These carbon and low alloy steels are generally limited to 0.55% maximum carbon content. The fastener fabricator thus can choose among a number of steel compositions to satisfy the specified strength requirement. Consistent with this approach, A307 contains only minimal chemical requirements with only sulfur and phosphorus specified for the two steel grades. The free-machining grade, A307 Grade A, permits up to 0.15% sulfur and 0.06% phosphorus, while the non-free machining grade, Grade B, limits sulfur to 0.05% and phosphorus to 0.04%. Steel grades containing lead, bismuth, selenium, or tellurium are not permitted for Grade B bolts.

The chemical composition limits for carbon, manganese, sulfur, and phosphorus for DIN grades C35, Ck35, C45, and Ck45 satisfy or are consistent with the intent of A307 for Grade B. The chemical composition limits for DIN grades 24 CrMo5, 24CrMoV55, and 21CrMoV511 contain vanadium, and/or chromium and molybdenum as alloying elements and thus are outside the scope of A307.

MECHANICAL PROPERTIES

Although not explicitly indicated, Specification A307 applies to grade 1 bolts as defined by Society of Automotive Engineers (SAE) Standard J429, based on the minimum specified ultimate tensile strength. The SAE classifies bolts by strength grades with a minimum strength requirement for each grade. Variations in both chemical composition and thermo/mechanical processing are allowed in order to achieve the particular minimum strength. The strength requirements of SAE grade 1 bolts can be met with hot rolled low-carbon steels.

Strength and Hardness Requirements

Tensile testing of full-size bolts is preferred according to A307 although machined specimens are also permitted. For bolts less than 38 mm diameter, round 12.7 mm diameter, 50 mm gage length machined specimens concentric with the bolt axis are used, while for bolts 38 mm or more in diameter, the standard round specimen is located with its axis one-half the distance from the center to the surface of the bolt.

According to specification DIN 17240, round, machined specimens are to be used for tensile testing. For bolts less than 40 mm diameter, specimens concentric with the bolt axis are used, while for bolts 40 mm or larger in diameter the specimen axis is to be located one third the distance from the outer surface towards the bolt axis. There requirements are close to those of A307 and so a direct comparison of strength requirements can be carried out.

The minimum ultimate tensile strength for DIN grades C35 and Ck35 is 2% below the SAE requirement for grade 2 bolts. The minimum ultimate tensile strength for DIN grades C45 and Ck45 is 2% below the SAE requirements for grade 3 bolts.

Specification DIN 17240 does not contain any hardness requirements.

Ductility Requirements

The machined DIN test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 5, independent of bolt diameter. Similarly, A307 through A370 permits a circular cross-section specimen with a constant gage length-to-diameter ratio of 4, independent of bolt diameter. Based on the relationship between percent elongation, gage length and cross-sectional area, the equivalent DIN elongation would be 92% of the A307 value.

The minimum percent elongation requirements for DIN grades C35 and Ck35 satisfy the A307 Grade B minimum requirement. The minimum percent elongation requirements for DIN grades C45 and Ck45 are 6% below the A307 Grade B requirement.

JIS G4107-74//ASTM A193-78a

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to steel bolting materials used with pressure components in high temperature service. The ASTM specification, A193-78a, contains a variety of both alloy steel and stainless steel grades while JIS G4107-74 is limited to only alloy steel grades. Both specifications define bolting material to include bars as well as finished or threaded bolts. The effect of threaded versus non-threaded can impact the type of tensile test specimen used. The alloy steel grades are heat treated and both A193 and JIS G4107 permit either the normalized and tempered or quenched and tempered condition.

The major design criteria for the intended applications of these materials are the static strength properties, ultimate tensile strength and yield strength. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition, and/or heat treatment on material ductility. The percent reduction-in-area measures the ability of the material to deform locally and thus reflects the materials ability to relieve local stresses such as those expected in pressurized components.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G4107 are considered equivalent to the requirements of ASTM A193 if the JIS values exceed or are within 5% of the A193 minimum value; (2) the minimum JIS reduction-in-area values are considered equivalent to the requirements of A193 if they exceed or are within 5% of the minimum A193 value; and (3) the percent elongation requirements of JIS G4107 are considered equivalent to the requirements of ASTM A193 if the JIS values exceed or are within 15% of the A193 minimum values. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) JIS class 1 (SNB 5) from JIS G4107-74 is generally equivalent to ASTM A193-78a, grade B5 based on the criteria discussed earlier.

(2) JIS class 2 (SNB 7) from JIS G4107-74 is generally equivalent to ASTM A193-78a, grade B7 based on the criteria discussed earlier.

(3) JIS class 3 (SNB 16) from JIS 4107-74 is generally equivalent to ASTM A193-78a, grade B16 based on the criteria discussed earlier.

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analyses for JIS class 1 satisfy the chemical limits for A193 grade B5 material. The JIS levels for all alloying elements are identical with the requirements of A193.

The chemical composition limits based on ladle analyses for JIS class 2 satisfy the chemical limits for A193 grade B7 material. The JIS levels for phosphorus, sulfur, and molybdenum are identical with the requirements of A193. The JIS ranges for carbon, manganese, silicon, and chromium fall within the A193 permitted ranges for grade B7.

The chemical composition limits based on ladle analyses for JIS class 3 satisfy the chemical limits for A193 grade B16 material. The JIS levels for carbon, manganese, phosphorus, sulfur, chromium, molybdenum, and vanadium are identical with the requirements of A193. The JIS range for silicon falls within the A193 permitted range for grade B16.

The JIS product analysis variations of classes 1, 2, and 3 for all of the alloying elements are identical with the product variations permitted by ASTM A193 for grades B5, B7, and B16, respectively.

MECHANICAL PROPERTIES

Heat Treatment

The ferritic alloy steel grades in A193 must be in the heat-treated condition, either normalized and tempered or quenched and tempered. In a similar manner, JIS G4107 specifies that the material should be supplied in either the normalized and tempered condition or the quenched and tempered condition. The minimum tempering temperatures for JIS class 1, class 2, and class 3 are identical to or within 1% of the A193 minimum tempering temperatures and thus a direct comparison in properties can be made.

Strength Requirements

The minimum ultimate tensile strength and yield strength requirements specified for JIS G4107 class 1 are within 1% of the A193 minimum requirements for grade B5.

The minimum ultimate tensile strength and yield strength requirements specified for all diameters of JIS G4107 class 2 satisfy or are within 1% of the A193 minimum requirements for all diameters of grade B7.

The minimum ultimate tensile strength and yield strength requirements specified for all diameters of JIS G4107 class 3 satisfy or are within 1% of the A193 minimum requirements for all diameters of grade B16.

Ductility Requirements

The JIS test specimen for both threaded and unthreaded forms has a circular cross-section with a constant gage length-to-diameter ratio of 4, independent of the bolting material diameter. In a similar manner, A193 recognizes both bar stock and finished bolts and by reference to A370, specifies a variety of test specimens. For threaded forms, A370, Section 11.1.7 permits circular cross-section test specimens of three diameters and constant gage length-to-diameter ratios of 4. For unthreaded forms, A370 Section S3 and Table 7 permit rectangular cross section test specimens with variable gage length-to-square root of area ratios or circular cross-section test specimens with constant gage length-to-diameter ratios of 4. Thus, the tensile ductility requirements for percent elongation and reduction in area can be directly compared.

The minimum percent elongation and reduction-in-area requirements for JIS class 1 satisfy the A193 minimum requirements for grade B5 up to the maximum JIS bolt diameter for this class.

The minimum percent elongation and reduction-in-area requirements for JIS class 2 satisfy the A193 minimum requirements for grade B7 up to the maximum JIS bolt diameter for this class.

The minimum percent elongation and reduction-in-area requirements for JIS class 3 satisfy the A193 minimum requirements for grade B16 up to the maximum JIS bolt diameter for this class.

DIN 17240-59//A193-78a

INTRODUCTION

The scope statements for these two specifications are similar and refer to steel bolting materials used in high temperature service. The ASTM specification, A193-78a, includes a variety of alloy steel and stainless steel grades while DIN 17240 is limited to unalloyed and alloyed structural steels. The alloy steel grades in A193-78a, B5, B6 and B6X, B7 and B7M, and B16, have a total alloy content range (including chromium, molybdenum, nickel, and vanadium) of about 1% to about 14%. The DIN grades have a total alloy content range of 0% to about 4%. The lower alloy grades in A193, B7, B7M, and B16, have medium carbon levels of 0.36% to 0.49% while the high alloy grades, B5, B6, and B6X, have low carbon levels of 0.1% to 0.15% maximum. The unalloyed grades in DIN 17240, C35, Ck35, C45, and Ck45, have medium carbon levels of 0.32% to 0.50% while the low alloy grades, 24 CrMo 5, 24 CrMoV 55, and 21 CrMovV 5 11, have lower carbon levels of 0.17% to 0.28%. The DIN unalloyed grades of C35, Ck35, C45, and Ck45 do not have comparable grades in A193 and are not considered further. The lower carbon, low alloy grades in DIN 17240 do not have equivalent grades in A193 based on chemical composition. Further, as a result of the lower carbon levels in these DIN grades, their minimum ultimate tensile strength and yield strength requirements fall about 15% below the A193 minimum requirements. For these reasons, the low alloy grades in DIN 17240 are not sufficiently close to the ASTM 193 low alloy grades in either chemistry or mechanical properties.

NOTE: Based only on chemical composition requirements, A193-78a grade B7, B7M appears to be equivalent to grade 42 CrMo 4 from DIN 17200-69. Also DIN 17240-59 has been revised and reissued in German only as DIN 17240-76. Based only on chemical composition requirements, A193-78a grade B16 appears to be equivalent to 40 CrMoV 47, a new grade appearing in the 1976 revision of DIN 17240.

CONCLUSIONS

(1) DIN grades C35 (1.0501), Ck35 (1.1181), C45 (1.0503), and Ck45 (1.1191) from DIN 17240-59 are not equivalent to any ASTM A193-78a grades because these DIN grades are unalloyed steels which are outside of the scope of A193-78a.

(2) DIN grades 24 CrMo 5 (1.7258), 24 CrMoV 55 (1.7733), and 21 CrMoV 5 11 (1.8070) from DIN 17240-59 are not equivalent to any ASTM A193-78a grades because both the chemical and mechanical property requirements of these DIN grades are sufficiently different.

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DIN 17440-72//ASTM A193-78a

INTRODUCTION

The scope statements for these two specifications contain areas of both similarity and dissimilarity. The ASTM specification, A193-78a, specifically covers only bolting materials, both bars and finished bolts of certain alloy steel and austenitic stainless steel grades for high temperature service. The DIN specification, DIN 17440-72, includes all common stainless steel grades, martensitic, ferritic, and austenitic, produced in the normal finished mill shapes of sheet, strip, bar, wire, tubes, and forgings. Both specifications include hot and cold formed bars in the appropriate heat treated condition. DIN 17440, however, does not include finished bolts. Thus this comparison will be limited to unfinished austenitic stainless steel bars.

The major design criteria for the intended applications of these materials are the static strength properties, ultimate tensile strength and yield strength. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition, and/or heat treatment on material ductility. The percent reduction-in-area is also a measure of tensile ductility and is not as sensitive to specimen geometry as the percent elongation. Percent reduction-in-area measures the ability of the material to deform locally and thus reflects the material's ability to relieve local stresses that would be expected in elevated temperature environments.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17440 are considered equivalent to the requirements of ASTM 193 if the DIN values exceed or are within 5% of the A193 minimum value; and (2) the percent elongation requirements of DIN 17440 are considered equivalent to the requirements of ASTM 193 if the DIN values exceed or are within 15% of the A193 minimum values. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) DIN X5 CrNi 189 (1.4301) bars from DIN 17440-72 in the solution-treated condition are generally equivalent to ASTM A193-78a, grade B8, class 1 based on the criteria discussed earlier, subject to the following limitation:

(a) To be acceptable, the minimum yield strength value for this DIN grade must be shown to satisfy the strength acceptance criterion.

(2) DIN X10 CrNiNb 189 (1.4550) bars from DIN 17440-72 in the solution-treated condition are generally equivalent to ASTM A193-78a, grade B8C, class 1 based on the criteria discussed earlier, subject to the following limitation:

(a) To be acceptable, the maximum carbon level should be limited to 0.08 weight percent and the minimum niobium level should be increased to 10 times the carbon content in order to maintain good corrosion resistance.

(3) DIN X5 CrNiMo 1810 (1.4401) bars from DIN 17440-72 in the solution-treated condition are generally equivalent to ASTM A193-78a, grade B8M, class 1 based on the criteria discussed earlier.

(4) DIN X10 CrNiTi 189 (1.4541) bars from DIN 17440-72 in the solution-treated condition are generally equivalent to ASTM A193-78a, grade B8T, class 1 based on the criteria discussed earlier, subject to the following limitation:

(a) To be acceptable, the maximum carbon level should be limited to 0.08 weight percent to ensure good corrosion resistance.

(5) DIN X5 CrNi 1911 (1.4303) bars from DIN 17440-72 in the solution-treated condition are generally equivalent to ASTM A193-78a, grade B8P, class 1 based on the criteria discussed earlier subject to the following limitation:

(a) To be acceptable, the minimum yield strength value for this DIN grade must be shown to satisfy the strength acceptance criterion.

(6) DIN X2 CrNiN 1810 (1.4311) and DIN X2 CrNiMoN (1.4406) bars from DIN 17440-72 in the solution-treated condition are generally equivalent to ASTM A193-78a, grade B8N class 1 and grade B8MN class 1, respectively, based on the criteria discussed earlier.

(7) DIN grades X12 CrNiS 18 8 (1.4305), X2 CrNi 189 (1.4306), X2 CrNiMo 1810 (1.4404), X10 CrNiMoTi 1810 (1.4571), X10 CrNiMoNb 1810 (1.4580), X5 CrNiMo 1812 (1.4436), X2 CrNiMo 1812 (1.4435), X2 CrNiMo 1816 (1.4438), and X2 CrNiMoN 1813 (1.4429) are not equivalent to any grade in ASTM A193-78a based on chemical composition requirements.

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analyses for DIN X5 CrNi 189 (1.4301) satisfy the chemical limits for A193 B8, B8A (AISi type 304) material, an unstabilized 18 Cr-8 Ni alloy. The DIN maximum levels for carbon, manganese, silicon, sulfur and phosphorus are slightly below or identical with the A193 B8, B8A requirements while the DIN range for nickel is within the A193 range. For chromium, the lower limit of the DIN range is 5% below the A193 minimum for the B8, B8A grade while the upper limits are identical. The critical element for this A193 grade is the greatly enhanced corrosion resistance, especially in welded applications, over the basic general purpose 18 Cr-8 Ni alloy A151 type 302) due to the reduced maximum carbon level. Thus, the slightly lower minimum chromium limit for this DIN grade should not significantly affect its behavior compared to A193 B8, B8A.

The chemical composition limits based on ladle analyses for DIN X10 CrNiNb 189 (1.4550) generally satisfy the chemical limits for A193 B8C, B8CA (A151 type 347), a stabilized 18 Cr-8 Ni alloy. The DIN maximum levels for manganese, silicon, sulfur, and phosphorus are identical with the A193 B8C, B8CA requirements while the DIN ranges for chromium and nickel are within or identical to the A193 ranges. For carbon, the DIN upper limit exceeds the A193 maximum for B8C, B8CA actually satisfies requirements for the type 347H alloy, a higher carbon version of the standard type 347 alloy) while the DIN lower limit for niobium (plus tantalum) is less than the A193 minimum requirement. In this alloy, niobium and/or tantalum are added to stabilize the carbon and reduce the tendency for carbide precipitation in order to enhance the corrosion resistance, especially of the grain boundaries. The combination in this DIN grade of possible higher carbon and lower niobium, tantalum levels compared to the A193 grade can be significant, and should be avoided.

The chemical composition limits based on ladle analyses for DIN X5 CrNiMo 1810 (1.4401) satisfy the chemical limits for A193 B8M, B8MA (A151 type 316). The DIN maximum levels for carbon, manganese, silicon, sulfur, and phosphorus are identical with or slightly below the A193 B8M, B8MA requirements while the DIN ranges for nickel and molybdenum are within the A193 ranges. The upper limit of the DIN chromium range is slightly above the A193 upper limit, about 3% above, but this should not have an effect on behavior compared to A193 B8M, B8MA.

The chemical composition limits for DIN X10 CrNiTi 189 (1.4541) generally satisfy the chemical limits for A193 B8T, B8TA (A151 type 321), a stabilized 18 Cr-8 Ni alloy. The DIN maximum levels for manganese, silicon, sulfur and phosphorus are identical with the A193 B8T, B8TA requirements while the DIN maximum titanium level can exceed the A193 minimum requirement. The DIN ranges for chromium and nickel are within or identical to the A193 ranges. The DIN upper limit for carbon exceeds the A193 maximum for the type 321 alloy and actually satisfies the requirements for the type 321H alloy, a higher carbon version of the standard type 321 alloy. In this alloy type, titanium is added as a carbon stabilizer to reduce the tendency for carbide precipitation in order to enhance the corrosion resistance, especially against grain boundary attack. The higher carbon level allowed in the DIN grade could result in a somewhat lower corrosion resistance if not fully stabilized by the titanium, particularly in weld applications, and should be avoided.

The chemical composition limits for DIN X5 CrNi 1911 (1.4303) generally satisfy the chemical limits for A193 B8P, B9PA (a low carbon version of AISI type 305), an unstabilized 18 Cr-8 Ni alloy. The DIN maximum levels for carbon, manganese, silicon, sulfur, and phosphorus are identical with or slightly below the A193 B8P, B8PA requirements while the DIN range for nickel is within the A193 range. The upper limit of the DIN chromium range is slightly above the A193 upper limit, about 5% above, but this should not have an effect on behavior compared to A193 B8P, B8PA.

The chemical composition limits for X2 CrNiN 1810 (1.4311) generally satisfy the chemical limits for A193 B8N, B8NA (AISI type 304N), a nitrogen bearing 18 Cr-8 Ni alloy. The DIN maximum levels for manganese, silicon, sulfur, and phosphorus are identical with the A193 B8N, B8NA requirements. The upper limit of the DIN ranges for nickel and nitrogen slightly exceed the A193 upper limits while the lower limit of the DIN range for chromium is below the A193 limit. The DIN upper limit for carbon is well below the A193 upper limit for the type 304N alloy and actually satisfies the requirements for the type 304LN alloy, the low carbon version of the standard 304N alloy. However, if the other requirements for A193 B8N, B8NA are satisfied, then these small variations in chemical limits for nickel, chromium, and nitrogen in this DIN alloy would not be expected to have an effect on its behavior compared to B8N, B8NA.

The chemical composition limits for DIN X2 CrNiMoN 1812 (1.4406) generally satisfy the chemical limits for A193 B8MN, B8MNA (AISI type 316N), a nitrogen bearing 18 Cr-8 Ni alloy. The DIN maximum limits for manganese, silicon, sulfur, and phosphorus are identical with A193 B8MN, B8MNA requirements while the DIN ranges for molybdenum and nickel are within the A193 ranges. The upper limit of the ranges for chromium and nitrogen slightly exceed the A193 upper limits. The DIN upper limit for carbon is well below the A193 upper limit for the type 316N alloy and actually satisfies the requirements for the type 316LN alloy, the low carbon version of the standard 316N grade. However, if the other requirements for A193 B8MN, B8MNA are satisfied, then the small variations in chemical limits for chromium and nitrogen for this DIN alloy would not be expected to have an effect on its behavior compared to B8MN, B8MNA.

MECHANICAL PROPERTIES

The austenitic stainless steel types in A193 based on chemical composition are further grouped by class depending on heat treatment and mechanical processing. The non-nitrogen bearing grades contain class 1, class 1A and class 2 and the nitrogen bearing grades contain class 1B. Class 1 refers to unfinished bars in the solution-treated condition and includes grades B8, B8C, B8M, B8P, and B8T. Class 1A refers to finished bolts in the solution-treated condition and includes grades B8A, B8CA, B8MA, B8PA, and B8TA. Class 2 refers to unfinished bars in the solution treated and strain-hardened condition and includes grades B8, B8C, B8M, B8P, and B8T. Class 1B unfinished bars in the solution-treated condition includes grades B8N and B8MN while class 1B finished bolts in the solution-treated condition includes grades B8NA and B8MNA. All comparisons are carried out for either unfinished bars in the solution-treated condition (class 1 and class 1B) for grades B8, B8C, B8M, B8N, B8MN, B8P, and B8T or for unfinished bars in the solution-treated and strain hardened condition (class 2) for grades B8, B8C, B8M, B8P, and B8T.

Strength and Hardness Requirements

The location within the unfinished bar from which longitudinal test specimens are taken are specified in both ASTM A193 and DIN 17440 depending on bar diameter. In A193, test specimens from bars up to 40 mm diameter are centered on the bar axis. For bars above 40 mm diameter, test specimens are centered midway between the bar axis and surface (1/4 position). In DIN 17440, test specimens from bars up to 25 mm diameter are centered on the bar axis. For bars above 25 mm diameter, test specimens are centered 12.5 mm from surface. In order to compare properties based on specimen location, the following analysis was followed. For bars up to 25 mm diameter, the bars are located identically. For bars between 25 mm and 40 mm diameter, the center of the DIN specimen moves away from the ASTM specimen so that at 40 mm diameter the common volume sampled has been reduced from 100% to about 40%. As a result of the solution treatment, significant differences in mechanical properties between these locations would not be expected. For bars between 40 mm diameter and 51 mm diameter, the centers of the DIN and ASTM specimens move together so that at 51 mm diameter they are again identical. For bars between 51 mm and 76 mm diameter, the center of the DIN specimen moves away from the ASTM specimen so that at 76 mm diameter, the common volume sampled again has been reduced from 100% to 40%. For the same arguments as above, differences in mechanical properties would not be expected. For bars between 76 mm and 102 mm diameter, the specimen centers continue to move apart until at 102 mm diameter the DIN and ASTM specimens are tangent and the common volume sampled is zero. Beyond 102 mm diameter to the maximum DIN diameter of 160 mm the DIN and ASTM specimens move further apart. However, as a result of the production of the bars, this region of the bar cross-section would be expected to exhibit the greatest chemical homogeneity and thus similar mechanical properties would also be expected. For these reasons, the effect of differing test specimen locations should not have a significant effect and so the strength properties can be directly compared.

Class 1 and Class 1B

The minimum ultimate tensile strength and the maximum hardness requirements for DIN X5 CrNi 189 and DIN X5 CrNi 1911 satisfy or are within 4% of the A193 requirements for grade B8 class 1 and grade B8P class 1 bars. The minimum DIN yield strength requirements are about 10% below the A193 requirements for these two grades.

The minimum ultimate tensile strength and yield strength requirements for DIN X10 CrNiNb 189, DIN X5 CrNiMo 1810, and DIN X10 CrNiTi 189 are within 4% and 1%, respectively, of the A193 requirements for grade B8C class 1, B8M class 1, respectively. The maximum DIN hardness requirements for these three grades satisfy the A193 requirements.

The minimum ultimate tensile strength and yield strength requirements for DIN X2 CrNiN 1810 and DIN X2 CrNiMoN 1812 satisfy the A193 requirements for grade B8N class 1B and grade B8MN class 1B, respectively. The maximum DIN hardness requirements for these two grades satisfy the A193 requirements.

Class 2

DIN 17440 contains reference data for a limited number of alloys in the solution-treated and work-hardened condition. These properties are not guaranteed because the final mechanical properties depend on the amount of strain or work hardening. As a result, a comparison with the class 2 requirements of A193 cannot be made. However, for those DIN grades found to be equivalent to certain A193 class 1 grades, the DIN grades should be able to satisfy A193 class 2 requirement after the appropriate amount of strain hardening, usually by cold drawing.

Ductility Requirements

The DIN test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 5, independent of bar diameter. Similarly, A193 through ASTM A370 permits a circular cross-section specimen with a constant gage length-to-diameter ratio of 4, independent of bar diameter. Based on the relationship between gage length and cross sectional area, the equivalent DIN elongation value would be 92% of the A193 minimum values.

The minimum percent elongation values for DIN grades X5 CrNi 189, X10 CrNiNb 189, X5 CrNi 1911, X5 CrNiMo 1810, and X10 CrNiTi 189 satisfy the class 1 requirements for A193 grades B8, B8C, B8P, B8M, and B8T, respectively. The minimum percent elongation values for DIN grades X2 CrNiN 1810 and X2 CrNiMoN 1812 satisfy the class 1B requirements for A193 grades B8N and B8MN, respectively.

Reduction-in-area requirements are not contained in DIN 17440, probably because of the wide variety of shapes, forms, and alloy conditions covered. However, for DIN grades which closely satisfy both the chemical and the other mechanical property requirements of A193 grades, there is no reason to believe the reduction-in-area requirements would not also be met.

INTRODUCTION

The scope statements for these two specifications are similar and refer to the same type of steel product, namely carbon steel forgings. ASTM A105 further states that these forgings are intended for both ambient- and higher-temperature service in pressure systems. Although JIS G3201 does not explicitly identify the type of service intended, nothing in the specification precludes service as described in ASTM A105.

Major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength. However, where heat treatment of the component is allowed in order to develop final properties, additional criteria such as hardness limits are important because of the correlation between chemistry, heat treatment, hardness, and the static strength properties. In the case of steel forgings, reduction-in-area requirements can be used as a qualitative measure of steel quality. Reduction-in-area behavior may be limiting in the design of the forged component. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry, gage length, and the material's intrinsic ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G3201 are considered equivalent to the requirements of ASTM A105 if the JIS values are higher than or within 5% of the A105 minimum value; (2) the JIS hardness values are considered equivalent to the requirements of A105 if they fall within the range from 5% above the A105 maximum value to 5% below the A105 minimum value; (3) the minimum JIS reduction-in-area values are considered equivalent to the requirements of A105 if they exceed or are within 5% of the A105 minimum value; (4) the percent elongation requirements of JIS G3201 are considered equivalent to the requirements of ASTM A105 if the JIS values exceed or are within 15% of the A105 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) JIS classes SF 35A and SF 40A from JIS G3201-78 are not equivalent to ASTM A105-77 because their maximum tensile strength requirement does not satisfy or barely satisfies the A105 minimum tensile strength requirement and the JIS minimum yield point value falls 20% to 30% belcw the A105 minimum requirement.

(2) JIS class SF45A is not generally equivalent to ASTM A105-77 because only the top 60% of the JIS tensile strength range satisfies A105 and the JIS minimum yield point is 9% below the A105 minimum requirement. Further, the minimum JIS hardness falls 12% below the A105 hardness minimum for small forgings.

(a) To be acceptable, JIS SF45A must be shown to satisfy both the strength acceptance criteria or satisfy the hardness acceptance criterion for small forgings.

(b) The maximum carbon level (ladle analysis) should be limited to 0.35 weight percent to insure adequate weldability while the minimum manganese level should be increased to 0.60 weight percent to compensate for the reduced carbon level.

(3) JIS classes SF50A and SF55A are generally equivalent to ASTM A105-77, based on the criteria discussed earlier subject to the following limitations:

(a) The maximum carbon level (ladle analysis) should be limited to 0.35 weight percent to insure adequate weldability while the minimum manganese level should be increased to 0.60 weight percent to compensate for the reduced carbon level.

(4) JIS class SF60A is generally equivalent to ASTM A105-77, based on the criteria discussed earlier, subject to the following limitations:

(a) For small forgings, JIS SF60A must be shown to fall within the hardness acceptance criteria.

(b) The maximum carbon level (ladle analysis) should be limited to 0.35 weight percent to insure adequate weldability while the minimum manganese level should be increased to 0.60 weight percent to compensate for the reduced carbon level.

(5) JIS class SF55B is not generally equivalent to ASTM A105-77 because only material in the lower half of the JIS tensile strength range would be expected to satisfy the A105 maximum hardness limit.

(a) To be acceptable, JIS SF55B must be shown to satisfy the hardness acceptance criteria.

(b) The maximum carbon level (ladle analysis) should be limited to 0.35 weight percent to insure adequate weldability while the minimum manganese level should be increased to 0.60 weight percent to compensate for the reduced carbon level.

(6) JIS classes SF60B and SF65B are not equivalent to ASTM A105-77 because the minimum JIS hardness values are within 11% (2% for SF65B) of the maximum hardness for quenched and tempered forgings permitted by A105.

(7) ASTM A105-77 contains the following general requirements which must be satisfied:

(a) Steels to which lead has been added cannot be used.

(b) All repair welds must be heat-treated and satisfy the mechanical requirements of A105.

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CHEMICAL REQUIREMENTS

The chemical requirements of A105 specify limits on the major elements carbon and manganese. Further, for carbon contents below the maximum allowed, a compensating increase in the manganese content is allowed in order to maintain the strength. In addition, steels within this carbon range generally can be easily welded by the commercial welding processes. Steels with higher carbon levels become increasingly susceptable to weld cracking and typically require both preheating and postheating treatments. The JIS chemical requirements permit both a much higher carbon content and a much lower manganese content than A105. Although this carbon-manganese combination may result in adequate strength properties to meet the requirements of A105, the high carbon level permitted raises questions as to the general suitability for welding, including repair welding permitted by A105. Based on this discussion, the JIS chemical requirements are equivalent to A105, based on ladle analyses, provided the maximum carbon content is limited to 0.35 percent and the minimum manganese level raised to 0.60 percent to compensate for the lowered maximum carbon level.

MECHANICAL PROPERTIES

Strength Requirements

The tensile strength range for JIS SF 35A does not meet the minimum tensile strength requirement for A105, and the minimum JIS yield point falls almost 30% below the A105 minimum requirement.

JIS class SF 40A will not in general satisfy the tensile strength requirements or the minimum yield point requirements of A105. Only the top 7% of the JIS tensile strength range exceeds the A105 minimum requirement while the JIS minimum yield point requirement is 21% below the A105 minimum requirement.

JIS class SF 45A will not consistently satisfy minimum tensile strength requirements of A105. However, material in the upper 60% of the JIS tensile strength range does satisfy A105 and the JIS minimum yield point is within 9% of the A105 minimum. Material at the high end of the JIS tensile strength range would probably have a sufficiently high yield point to satisfy A105.

JIS class SF 50A satisfies the minimum tensile strength requirements of A105 and the JIS minimum yield point value is within 2% of the A105 minimum value.

JIS classes SF 55A and SF 60A satisfy the minimum tensile strength and yield point requirement of A105. The JIS minimum tensile strengths exceed the A105 minimum requirement by 11% and 22% respectively for classes 55A and 60A. The JIS minimum yield points exceed the A105 minimum requirement by 11% and 18% respectively for classes 55A and 60A.

JIS classes SF 55B, SF 60B, and SF 65B satisfy the minimum tensile strength and yield point requirements of A105. The JIS minimum tensile strengths exceed the A105 minimum requirement by 12%, 22%, and 32% respectively for classes SF 55B, SF 60B, and SF 65B. The JIS minimum yield points exceed the A105 minimum requirement by amounts ranging from 18% to 34% for class 55B, 30% to 46% for class 60B, and 38% to 58% for class 65B, depending on diameter or thickness.

According to A105, the strength properties of forgings too small to permit preparation of subsize tension specimens can be accepted on the basis of Brinell hardness tests. This can be done because of the existence of established correlations between hardness and tensile strengths for constructional alloy and tool steels in the as-forged, annealed, normalized, and quenched and tempered conditions. JIS classes SF 35A and SF 40A will not in general satisfy the minimum Brinell hardness requirement of A105 for these small forgings. The minimum JIS hardness for class SF 45A, whose minimum tensile and yield point values are less than 10% below the A105 minimum values, lies 12% below the A105 minimum requirement. Material which satisfies the A105 strength requirements would be expected to satisfy the A105 minimum hardness requirements. The minimum JIS hardness for class SF 50A is within 3 percent of the A105 minimum while the minimum hardness for JIS classes SF 55A and SF 60A satisfies the A105 minimum requirement. Material in the upper half of the tensile strength range for class SF 60A probably would exceed the maximum hardness allowed by A105 for these small forgings, based on the hardness - tensile strength correlation.

For all quenched and tempered forgings, A105 limits the maximum hardness allowed, while JIS 3201 establishes only a minimum hardness. Using the approximate relation between hardness and tensile strength, the A105 maximum hardness of HB187 would correspond to a tensile strength of about 620 MPa (90 Ksi). Based on this correlation, only material in the lower half of the tensile strength range for JIS class SF 55B and near the minimum of the tensile strength range for JIS class SF 60B would probably satisfy the A105 maximum hardness limit. For JIS class SF 65B, the specified minimum hardness is within 2 percent of the maximum hardness allowed by A105.

Ductility Requirements

The JIS test specimen has a circular cross-section with a constant gage length to diameter ratio of 5. The ASTM circular cross-section specimen has a constant gage length to diameter ratio of 4. Based on the relationship between gage length and cross-sectional area, the equivalent JIS elongation value would be about 90 percent of the ASTM value.

For specimens with circular cross-sections, studies in the literature suggest that reduction-in-area measurements are not strongly related to specimen diameter and thus the JIS and ASTM specimen results are assumed to be comparable.

JIS classes, SF 35A, SF 40A, SF 45A, SF 50A, SF 55A (axial orientation) satisfy the A105 minimum percent elongation and minimum reduction-in-area values. Class SF 60A (axial orientation) satisfies the A105 minimum reduction-in-area requirement but its minimum elongation value is 10% below the A105 minimum value.

JIS classes SF 55B, SF 60B, and SF 65B satisfy the A105 minimum reduction-in-area requirement and class SF 55B satisfies the A105 minimum elongation value. The minimum percent elongation value for class SF 60B is within 5% of the A105 requirement for forgings less than 250 mm in diameter or thickness and 10 percent less for forgings from 250 mm to less than 400 mm in diameter or thickness. The JIS percent elongation minimum for class 65B is 20% below the A105 requirement for forgings less than 250 mm in diameter or thickness and 25% below for forgings from 250 to 400 mm in diameter or thickness.

Table 1 contains a summary of the comparison results for chemical and mechanical properties.

Table 1.

JIS G3201-78

Equivalent to A105

Grade	Chemistry	Strength	Hardness	Elongation and Reduction-In-Area
SF35A	Yes, provided carbon content limited to 0.35 percent and the minimum manganese level raised to 0.60 percent, based on ladle analyses.	No	No	Yes
SF40A		No, only at high end of JIS range.	No, except possibly material at highest end of tensile strength range.	Yes
SF45A		Yes, at upper end of JIS tensile strength range.	Yes, for material at upper end of tensile strength range.	Yes
SF50A		Yes	Yes	Yes
SF55A		Yes	Yes	Yes
SF60A		Yes	Yes, except material at upper end of tensile strength range probably exceeds the maximum allowed hardness for small forgings.	Yes
SF55B		Yes	Yes, for material in lower half of tensile strength range.	Yes
SF60B		Yes	No, except for material near the minimum of the tensile strength range.	Yes
SF65B		Yes	No	Yes, for reduction-in-area. No, for percent elongation.

DIN 17200-69//ASTM A105-77

INTRODUCTION

The scope of DIN 17200 is applicable to a variety of hot-rolled or hot-forged steel forms including semi-finished shapes, bars, flats, plate, and open die and drop forgings which are suitable for hardening based on their chemical composition. Further, DIN 17200 includes both carbon and alloy steels in various heat-treated conditions, including hot-worked, quenched and tempered, normalized, and soft annealed for service from 20 to 350 °C. In comparison, ASTM A105 has a more limited scope and specifically covers only forged carbon steel piping components, such as flanges, fittings, and values in either the hot-worked, annealed, normalized, or quenched and tempered condition for ambient or unspecified-higher temperature service.

In DIN 17200, the property requirements are grouped about specific guaranteed properties, i.e. chemistry and hardness, or chemistry and mechanical properties depending on the heat treatment condition. ASTM A105, although permitting the same heat treatment conditions, requires material in all conditions to satisfy the same chemistry, mechanical property, and under certain conditions hardness requirements. Thus, the comparison of DIN 17200 to ASTM A105 is based primarily on material described by DIN delivery modes 4, 4b, 4c, 4d, 4e, 5, and 10 and is limited to the DIN carbon steel grades C35, Ck35, Cm35, C45, Ck45, Cm45, C55, Ck55, Cm55, C60, Ck65, and Cm65.

Major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength. However, where heat treatment of the component is allowed in order to develop final properties, additional criteria such as hardness limits are important because of the correlation between chemistry, heat treatment, hardness, size, and the static strength properties. In the case of steel forgings, reduction-in-area requirements can be used as a qualitative measure of steel quality and thus may be limiting in the design of the forged component. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry, gage length, and the material's intrinsic ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17200 are considered equivalent to the requirements of ASTM A105 if the DIN values are higher than or within 5% of the A105 minimum value; (2) the DIN hardness values are considered equivalent to the requirements of A105 if they fall within the range from 5% above the A105 maximum value to 5% below the A105 minimum value; (3) the minimum DIN reduction-in-area values are considered equivalent to the requirements of A105 if they exceed or are within 5% of the A105 minimum value; (4) the percent elongation requirements of DIN 17200 are considered equivalent to the requirements of ASTM A105 if the DIN values exceed or are within 15% of the A105 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the DIN minimum requirement and thus approach the A105 value; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

1. The DIN grades, including the Cr series, the Mn series, the CrS series, the CrMo series, the CrMoS series, the CrNiMo series, and the CrV and CrMoV series, are not equivalent to ASTM A105-77 because they are alloy steels and are outside the scope of A105.

2. The DIN carbon steel grades C45, Ck45, Cm45, C55, Ck55, Cm55, C60, Ck60, and Cm60 and are not equivalent to ASTM A105-77 because their range of permitted carbon levels are significantly higher than the maximum carbon content permitted by A105, which greatly reduces their weldability.

3. DIN grades C35, Ck35, and Cm35 in the quenched and tempered condition are generally equivalent to ASTM A105-77, based on the criteria discussed earlier. Although probably as a result of the slightly higher maximum carbon level permitted by DIN, these grades could exceed the maximum hardness permitted by A105, based on the strength correlation. The DIN C35 grades are acceptable because (a) their minimum elongation values fall within the elongation acceptance criterion, and (b) their minimum reduction-in-area values exceed the A105 requirements.

4. DIN grades C35, Ck35, and Cm35 in the normalized condition are generally equivalent to ASTM A105-77, based on the criteria discussed earlier.

5. DIN grades C35, Ck35, and Cm35 in the annealed condition are generally equivalent to ASTM A105-77, based on the criteria discussed earlier, subject to the following limitations:

    a. The DIN minimum yield strength and ultimate tensile strength values are not specified. To be acceptable, the DIN C35 grades in the annealed condition must be shown to satisfy the A105 strength acceptance criterion.

    b. For small forgings, the DIN minimum hardness value is not specified. To be acceptable, small forgings of the DIN C35 grades in the annealed condition must be shown to satisfy the A105 hardness acceptance criterion.

6. ASTM A105-77 contains the following general requirements that must be satisfied:

   a. All steels shall be fully killed.

   b. All flanges with primary service ratings over 300 psi (2070 kPa) and any flanges where primary pressure rating is not referenced or known shall be heat-treated (i.e. no hot-worked or as-forged components permitted). All other piping components over 4 inch nominal pipe size and over 300 psi primary service pressure rating shall be heat-treated.

   c. Steels to which lead has been added shall not be used.

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DIN 17200-69//ASTM A105-77

CHEMICAL REQUIREMENTS

The DIN grades including the Cr series, the Mn series, the CrS series, the CrMo series, the CrMoS series, the CrNiMo series, and the CrV and CrMoV alloys are all classified as alloy steels falling outside the scope of A105. The special application DIN grades, C22, Ck22, and 40 Mn 4 are also omitted from this study.

The chemical requirements of A105 based on a ladle analysis specify limits on the principal strengthening alloying elements carbon and manganese. In addition, for carbon contents below the maximum allowed, an increase in the manganese content up to a maximum value is permitted. This balancing of the carbon and manganese levels assists in maintaining the necessary minimum strength level for this specification.

The minimum carbon content for DIN grades C35, Ck35, and Cm35 lies near the maximum carbon level allowed by A105 while the maximum carbon level for these DIN grades exceeds the A105 maximum allowed level. This higher allowed carbon content in these DIN grades is balanced in part by their reduced manganese level compared to A105. The silicon and sulfur levels in these DIN grades satisfy the requirements of A105 while the phosphorus limits in Ck35 and Cm35 also satisfy A105. The maximum allowed phosphorus level for C35 exceeds slightly the maximum allowed by A105 but is not considered inconsistent with the intended applications identified in A105.

The DIN carbon steel grades C45, Ck45, Cm45, C55, Ck55, Cm55, C60, Ck60, and Cm60 all exceed by wide margins the maximum carbon content permitted by A105. The range of manganese contents for these grades satisfy or are somewhat below the minimum manganese level required by A105. Thus, the major impact of these differences in carbon and manganese levels will be increased strength properties and decreased weldability for these DIN grades.

MECHANICAL PROPERTIES

Test specimen orientation is not explicitly specified in A105 but Section 9.3 implies the longitudinal orientation, i.e. specimen axis is in direction of greatest flow. Longitudinal test specimens are specifically called for in DIN 17200. The A105 minimum elongation value is based on a specimen with a gage length four times the diameter while the DIN specimens have a gage length five times the diameter (5.65 times the square root of the cross-sectional area). Using the relationship between percent elongation, gage length and cross-sectional area, the equivalent DIN elongation will be about 90 percent of the ASTM value. For specimens with circular cross-sections, studies in the literature suggest that reduction-in-area measurements are not strongly related to specimen diameter and thus the DIN and ASTM specimen results are assumed to be comparable.

Quenched and Tempered Condition (DIN code V)

Strength and Hardness Requirements

The strength requirements of A105 are specified only by minimum values of ultimate tensile strength and yield strength while the DIN grades are specified in terms of both minimum and maximum values. All of the DIN carbon steel grades satisfy the minimum strength requirements of A105 because the DIN minimum values all exceed the A105 minimum values by amounts ranging from about 32% to 132% in yield strength and 12% to 204% in ultimate tensile strength, respectively, for the DIN C35 grades, C45 grades, C55 grades, and C60 grades. However, according to A105, all quenched and tempered forgings must also satisfy a maximum hardness requirement while forgings too small for subsize tensile specimens may be accepted based only on hardness. Using an approximate hardness - tensile strength correlation for steel, either SAE J417b (May 1970) or DIN 50351, the maximum hardness specified by A105 would correspond to an ultimate tensile strength of about 65 Kg/mm^2 or for small forgings, an ultimate tensile strength range of about 46 Kg/mm^2 to 65 Kg/mm^2. The analysis in Table 1 is based on this tensile strength - hardness correlation.

Table 1. Satisfies A105 Maximum Hardness Requirement for both Quenched and Tempered Forgings and All Small Forgings[A]

DIN Grade	Up to 16 mm[B] diameter	Over 16 mm to[B] 40 mm diameter	Over 40 mm to[B] 100 mm diameter
C35, Ck35, Cm35	Yes or up to 20% above	Yes or up to 14% above	Yes or up to 8% above
C45, Ck45, Cm45	9% to 32% above	3% to 26% above	Yes or up to 20% above
C55, Ck55, Cm55	23% to 46% above	15% to 39% above	9% to 32% above
C60, Ck60, Cm60	31% to 54% above	23% to 46% above	15% to 39% above

[A] Small forgings defined by A105 as forgings too small to obtain subsize tensile specimen 0.25 inches in diameter or larger.

[B] DIN 17200 does not specify hardness for the quenched and tempered condition, code V, and thus comparison is made through tensile strength - hardness correlation.

Ductility Requirements

For material up to 100 mm in diameter, DIN grades C35, Ck35, and Cm35 satisfy or are within 15% of the minimum percent elongation requirement of A105.

For material up to 40 mm in diameter, the minimum percent elongation values of DIN grades C45, Ck45, and Cm45 are 20 percent or more below the A105 minimum value while for material over 40 mm to 100 mm in diameter, the DIN value is within 15% of the A105 minimum value. For material up to 100 mm in diameter for DIN grades C55, Ck55, Cm55, C60, Ck60, and Cm60, the minimum percent elongation values are 25% or more below the A105 minimum value.

For material up to 100 mm in diameter, DIN grades C35, Ck35, Cm35, C45, Ck45, and Cm45 satisfy the minimum reduction of area requirement of A105. For material up to 16 mm in diameter, the minimum reduction of area values for DIN grades C55, Ck55, Cm55, C60, Ck60, and Cm60 are from 17% to 33% below the A105 minimum value. For material over 16 mm to 100 mm in diameter, DIN grades C55, Ck55, Cm55, C60, Ck60, and Cm60 satisfy the minimum reduction of area requirements of A105.

Normalized Condition (DIN code N)

Strength and Hardness Requirements

The strength requirements of A105 are specified only by minimum values of ultimate tensile strength and yield strength while the DIN grades are specified in terms of both maximum and minimum values. All of the DIN carbon steel grades satisfy the minimum strength requirements of A105 since they exceed the A105 minimum yield strength value by amounts ranging from about 12% to 56% respectively, and exceed the A105 minimum ultimate tensile strength value by amounts ranging from about 2% to 33%, 22% to 53%, 36% to 74%, and 43% to 84%, respectively, for the C35 grades, C45 grades, C55 grades, and C60 grades.

For forgings too small for subsize tensile specimens, A105 allows acceptance based only on hardness. Using an approximate hardness-tensile strength correlation for steel, either Society of Automotive Engineers (SAE) J417b (May 1970) or DIN 50351, the allowable hardness range specified by A105 would correspond to an ultimate tensile strength range of about 46 Kg/mm^2 to 65 Kg/mm^2. The DIN C35 grades and the DIN C45 grades at the low end of their ultimate tensile strength range would satisfy the A105 hardness requirement. The tensile strength range of the DIN C55 grades and the DIN C60 grades would be expected to fall outside of the A105 allowable hardness range for small forgings.

Ductility Requirements

The DIN C35 grades and the C45 grades satisfy the minimum percent elongation requirement of A105. The minimum percent elongation requirements for the DIN C55 and C60 grades fall 25% and 30% respectively, below the minimum A105 requirement.

For material in the normalized condition, DIN 17200 does not specify reduction of area values. The DIN C35 grades, C45 grades, C55 grades and C60 grades in the quenched and tempered condition have higher strength values and lower elongation values than in the normalized condition. Since the reduction-in-area minimum values in the quenched and tempered condition for all of these grades satisfy the A105 minimum requirement, the normalized condition values would be expected to satisfy the A105 minimum requirement.

Annealed Condition (DIN code G)

Strength and Hardness Requirements

The DIN requirements for material in the annealed condition refer only to a maximum hardness value. Using an approximate hardness - tensile strength correlation for steel, either SAE J417b (May 1970) or DIN 50351, the minimum ultimate tensile strength permitted by A105 would correspond to a minimum hardness of about HB 137. Further, for forgings too small for subsize tensile specimens, A105 allows acceptance based only on hardness, provided the hardness falls between HB 137 and HB 187. Using this hardness range as a basis for comparison for any size forging, DIN C35 grades would not exceed the A105 maximum hardness limit for small forgings. However, with only a maximum hardness specified for the DIN C35 grades, it cannot be determined whether the minimum yield strength or ultimate tensile strength requirements of A105 would be satisfied.

The maximum hardness values allowed for DIN C45 grades, C55 grades, and C60 grades exceed the A105 small forging hardness limit by about 11%, 22%, and 29% respectively, although it is increasingly probable that the A105 minimum strength requirements would be satisfied going from the DIN C45 grades to the C60 grades.

Ductility Requirements

Although the DIN requirements do not include any ductility requirements, the DIN C35 grades, C45 grades, and C55 grades would be expected to satisfy both the percent elongation and percent reduction-in-area requirements of A105 based on the DIN maximum hardness limits. Similarly, the DIN C60 grades would probably not satisfy the A105 percent elongation requirement near the maximum hardness limit.

INTRODUCTION

The scope statements for these two specifications are similar and refer to the same type of steel products, namely rolled carbon steel plates for use in pressure vessels. Steel produced to JIS G3103 includes both carbon steel plates up to 200 mm thick and molybdenum alloy steel plates up to 150 mm thick for ambient and elevated temperature service while ASTM A285 is not intended for elevated temperature applications and is limited to normally as-rolled carbon steel plates up to 50 mm thick. The thickness limitation for A285 is necessary to insure adequate internal homogeneity and soundness since rimmed, capped, or semi-killed steels are also permitted in addition to the more uniform killed steels.

The major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G3103 are considered equivalent to the requirements of ASTM A285 if the JIS values fall within the range from 5% above the A285 maximum value to 5% below the A285 minimum value; (2) the percent elongation requirements of JIS G3103 are considered equivalent to the requirements of A285 if the JIS values are higher than or within 15% of the A285 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the JIS minimum requirement, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Material furnished under specification A285-78 must conform to the applicable requirements of ASTM A20-78, General Requirements for Steel Plates for Pressure Vessels. (The appropriate edition of A20 to use is that edition concurrent with the edition of A285 of interest). The relevant sections of A20 used in this comparison include: Section 3, Description of Terms; Section 6, Heat Treatment; Section 7, Chemical Analysis; Section 8, Metallurgical Structures; Section 10, Test Methods; Section 11, Tension Tests; Section 16, Retests, and Supplementary Requirements.

CONCLUSIONS

(1) JIS class 5 and class 6 from JIS G3103-77 are not equivalent to ASTM A285-78 because they are alloy steels and are outside of the scope of A285.

(2) JIS class 2 from JIS G3103-77 is generally equivalent to ASTM A285 grade C, based on the criteria discussed earlier. Although the maximum permitted ultimate tensile strength of this JIS class could exceed by 7% the maximum level permitted by A285 grade C, JIS class 2 is acceptable because (a) the minimum yield strength requirement for JIS class 2 is only 10% above the A285 grade C minimum requirement, and (b) the JIS class 2 minimum elongation values fall within the elongation acceptance criterion.

(3) JIS class 2 from JIS G3103-77 is not generally equivalent to ASTM A285 grade B because as a result of the higher carbon content allowed by JIS class 2, only the bottom 53% of the JIS tensile strength range falls within the A285 grade B range and the JIS class 2 minimum elongation requirement is 16% below the A285 grade B requirement.

(a) To be acceptable, JIS class 2 must be shown to fall within both the ultimate tensile strength acceptance criteria and the elongation acceptance criteria.

(4) JIS class 3 from JIS G3103-77 is not generally equivalent to ASTM A285 grade C because, as a result of the higher carbon content allowed by JIS class 3, only the bottom 47% of the JIS tensile strength range falls within the A285 grade C range and the JIS class 3 minimum elongation requirement is 17% below the A285 grade C requirement.

(a) To be acceptable, JIS class 2 must be shown to fall within both the ultimate tensile strength acceptance criteria and the elongation acceptance criteria.

(5) JIS class 4 from JIS G3103-77 is not equivalent to ASTM A285 because the JIS maximum carbon level is substantially above the maximum level for any grade of A285 and thus the maximum ultimate tensile strength values are much higher than the maximum A285 values and the minimum percent elongation values are much lower than the minimum A285 values.

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analysis for JIS class 2 (SB42) satisfy the chemical limits for A285 grade C plate. The maximum levels specified for manganese, sulfur, and phosphorus are identical with the requirements of A285 while the maximum carbon level for JIS class 2 is lower than the maximum carbon level for A285 grade C and higher than the maximum carbon levels allowed for A285 grades A and B.

Although the maximum levels specified for manganese, sulfur, and phosphorus for JIS classes 3 and 4 are identical with those of all grades of A285, the maximum carbon levels for JIS classes 3 and 4 exceed the maximum carbon levels for all grades of A285.

The silicon content of A285 is not specified because it depends on the deoxidation practice employed, i.e. killed, rimmed, capped, etc. The silicon range permitted by JIS G3103 is typical of that reported for killed steels and is not inconsistent with the requirements of ASTM A285.

MECHANICAL PROPERTIES

Strength Requirements

The specified ultimate tensile strength range of JIS class 2 plate lies from within to 22%, 13%, and 7% respectively, higher than the A285 ranges for grades A, B, and C while the minimum JIS class 2 yield strength value is 37%, 22%, and 10%, respectively above the A285 minimum values for grades A, B, and C.

The specified ultimate tensile strength ranges and minimum yield strength values for JIS class 3 and class 4 exceed the A285 requirements by increasing amounts. The tensile strength range for JIS class 3 plate lies from within to 31%, 21%, and 14% respectively, higher than the A285 ranges for grades A, B, and C while the minimum JIS class 3 yield strength value is 48%, 32%, and 20% respectively, above the A285 minimum values for grades A, B, and C. The tensile strength range for JIS class 4 plate lies from within to 37%, 27%, and 20% respectively, higher than the A285 ranges for grades A, B, and C while the minimum JIS class 4 yield strength value is 60%, 43%, and 29% respectively, above the A285 minimum values for grades A, B, and C.

Ductility Requirements

The dimensions, gage length, and type of tension test specimens permitted by ASTM A20-78 are controlled by the plate thickness. Although A285 specifies minimum percent elongation values for both 200 mm gage length and 50 mm gage length specimens, only the percent elongation value for the specimen and gage length appropriate for the plate thickness must be satisfied. For plate 50 mm and less in thickness, JIS G3103 requires a rectangular test specimen 38 mm wide, full plate thickness, and a 200 mm gage length. For plate up to 102 mm thick, A20 permits the identical test specimen and thus the following analysis is based on 200 mm gage length specimens.

The JIS class 2 minimum percent elongation value is within 15% of the A285 grade C requirement and 16% and 23% respectively, below the A285 grade B and grade A minimum requirement.

The JIS class 3 minimum percent elongation values are about 17%, 24%, and 30% respectively, below the A285 minimum values for grade C, grade B, and grade A.

The JIS class 4 minimum percent elongation values are about 20%, 32%, and 37% respectively, below the A285 minimum values for grade C, grade B, and grade A.

Supplementary Requirement S14 Bend Test

The bend test requirement is part of JIS G3103-77 although only one of several Supplementary Requirements in A285. The geometry of the ASTM and JIS bend test specimens are very similar and the specification requirements can be directly compared. For test specimens of equal thickness and with machined edges, the bend test requirements for JIS class 2 and class 3 plate up to 50 mm thick are identical or more severe than the A285 requirements. The bend-test requirements for JIS class 4 plate over 25 mm to 50 mm thick are identical or more severe than the A285 requirements. The bend-test requirement for JIS class 4 plate 25 mm or less in thickness is less severe than the A285 requirement.

DIN 17155-59//ASTM A285-78

INTRODUCTION

The scope statements for these two specifications are similar and refer to the same type of steel products, namely rolled carbon steel plates for use in pressure vessels. However, steel produced to DIN 17155 includes both carbon steel plates and alloy steel plates for both ambient and elevated-temperature service while ASTM A285 plate is not intended for elevated-temperature service and is limited to normally as-rolled carbon steel plates up to 50 mm thick. The thickness limitation for A285 is necessary to insure adequate internal homogeneity and soundness because rimmed, capped, or semi-killed steels are also permitted in addition to the more uniform killed steels. Rimmed steel or killed steel is permitted by DIN 17155 for the HI grade while the other grades must be produced in the killed condition.

The major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength. The percent elongation requirement, characterizing tensile ductility, is not usually used as a design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17155 are considered equivalent to the requirements of ASTM A285 if the DIN values fall within the range from 5% above the A285 maximum value to 5% below the A285 minimum value; (2) the percent elongation requirements of DIN 17155 are considered equivalent to the requirements of ASTM A285 if the DIN values are higher than or within 15% of the A285 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the DIN minimum requirement, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Material furnished under specification A285-78 must conform to the applicable requirements of ASTM A20-78, General Requirements for Steel Plates for Pressure Vessels. (The appropriate edition of A20 to use is that edition concurrent with the edition of A285 of interest.) The relevant sections of A20 used in this comparison include: Section

3, Description of Terms; Section 6, Heat Treatment; and Section 7, Chemical Analysis; Section 8, Metallurgical Structure; Section 10, Test Methods; Section 11, Tension Tests; Section 16, Retests, and Supplementary Requirements.

CONCLUSIONS

(1) DIN grades 15Mo3 and 13CrMo44 from DIN 17155-59 are not equivalent to ASTM A285-78 because they are alloy steels and outside of the scope of A285.

(2) DIN grade HI from DIN 17155-59 is generally equivalent to ASTM A286-78 grade B or grade C, based on the criteria discussed earlier, subject to the following limitations:

(a) The maximum sulfur and phosphorus levels (ladle or product analysis) should be limited to 0.04 percent and 0.035 percent by weight, respectively, to maintain notch toughness.

(b) The DIN minimum tensile strength is 10% below the A285 grade C minimum tensile strength requirement. To be acceptable for A285 grade C, DIN grade HI must be shown to fall within the strength acceptance criterion.

(3) DIN grade HII from DIN 17155-59 is generally equivalent to ASTM A285-78 grade C, based on the criteria discussed earlier, subject to the following limitations:

(a) The maximum sulfur and phosphorus levels (ladle or product analysis) should be limited to 0.04 percent and 0.035 percent by weight, respectively, to maintain notch toughness.

(b) Although the minimum percent elongation value within the DIN grade HII range, corresponding to the highest tensile strength, can be 20% below the A285 grade C minimum for some plate thickness ranges, the minimum percent elongation value corresponding to the lowest tensile strength satisfies or is within 2% of the A285 grade C requirement for most plates up to 50 mm thick. Thus, for intermediate tensile strength values, the DIN grade HII minimum percent elongation would be within 15% of the A285 grade C requirement. To be acceptable, DIN grade HII must be shown to fall within the elongation acceptance criterion for all plate thicknesses.

(4) DIN grade HIII from DIN 17155-59 is generally equivalent to ASTM A285-78 grade C, based on the criteria discussed earlier, subject to the following limitations:

(a) The maximum sulfur and phosphorus levels (ladle or product analysis) should be limited to 0.04 percent and 0.035 percent by weight, respectively, to maintain notch toughness.

(b) Although the minimum percent elongation value within the DIN grade HIII range, corresponding to the highest tensile strength, can be 26% below the A285 grade C minimum for some plate thicknesses, the minimum percent elongation value corresponding to the lowest tensile strength satisfies or is within 6% of the A285 grade C requirement for most plates up to 50 mm thick. Thus, for intermediate tensile strength values, the DIN grade HIII minimum percent elongation would be within 15% of the A285 grade C requirement to be acceptable, DIN grade HIII must be shown to fall within the elongation acceptance criterion for all plate thicknesses.

(5) DIN grade HIV and grade 17Mn4 from DIN 17155-59 are not generally equivalent to ASTM A285 because the minimum percent elongation corresponding to the lowest tensile strength (highest minimum value for the grade) is about 15% below the A285 grade C requirement (about 18% below A285 grade B, about 22% below A285 grade A) for most plates up to 50 mm thick. Thus, for intermediate tensile strength values, the DIN grade HIV and grade 17Mn4 minimum percent elongation would be more than 15% below the A285 grade C requirement.

(6) DIN grade 19Mn5 from DIN 17155-59 is not generally equivalent to ASTM A285 because 95% of the tensile strength range is higher than the maximum tensile strength permitted by A285 grade C (all of range for A285 grade B and grade A), and the minimum percent elongation corresponding to the lowest tensile strength (highest minimum value for the grade) is about 22% below the A285 grade C requirement (about 26% below A285 grade B, about 30% below A285 grade A) for most plates up to 50 mm thick.

(7) The application of the ASTM A285 Supplementary Bend test requirements reduces the range of equivalence for some DIN grades, as follows:

(a) The DIN grade HII and grade HIII bend requirements for plates 25 mm or less in thickness for specimens with machined edges do not satisfy A285.

For those thicknesses and grades where the DIN bend requirements do not satisfy A285, the DIN plate would be equivalent only if it met the A285 requirement.

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CHEMICAL REQUIREMENTS

Three primary quality descriptors of steel plate, listed in order of increasing quality, are regular quality, structural quality, and pressure vessel quality. Regular quality plates are normally produced to compositional ranges rather than mechanical property requirements and are typically used in non-critical applications. Further, regular quality plates are not expected to have the same level of chemical uniformity, internal soundness, or freedom from surface imperfections (i.e. inclusions) as found in structural quality or pressure vessel quality plate. Although structural quality and pressure vessel quality plate are normally produced to both chemical and mechanical property requirements, pressure vessel quality plate generally must satisfy more stringent limits on allowable surface and edge perfections and sometimes notch toughness requirements. Thus, pressure vessel quality specifications, such as ASTM A285, almost always require lower limits for phosphorus and sulfur than is required for structural quality or regular quality.

For rolled carbon pressure vessel steels, the mechanical properties and weldability are usually the important criteria. When this steel is produced to specific strength properties, usual practice allows the carbon and manganese levels to vary to achieve the necessary strength requirement and to compensate, if necessary, for the effect of plate thickness.

The chemical requirements of A285, based on ladle analyses, specify for each grade the same upper limit on the manganese content but allow the maximum carbon limit to increase to achieve increased strength levels. Following a somewhat different approach, the DIN chemical requirements for grades HI, HII, HIII, and HIV, based on ladle analyses, specify maximum carbon levels and minimum manganese levels which vary for each grade.

The maximum carbon level specified for DIN grade HI is below the maximum limits for A285 grades A, B, or C and the minimum manganese level is well below the A285 maximum level. The maximum carbon level specified for DIN grade HII is below the maximum limits for A285 grades B or C and the minimum manganese level is still below the A285 maximum level. The maximum carbon level specified for DIN grade HIII equals or is below the maximum limits for A285 grades B or C and the minimum manganese level is below the A285 maximum level. The maximum carbon level specified for DIN grade HIV is below the maximum limit for A285 grade C while the minimum manganese level is below the A285 maximum level.

The maximum carbon levels specified for DIN grades 17Mn4 and 19Mn5 are below the A285 maximum levels for grades B and C, respectively, while the DIN manganese requirements are compositional ranges with minimum values that are at or higher than the A285 maximum limit. The higher manganese levels compensate for a lower carbon level so that strength properties can be maintained without reducing notch toughness and so are considered to be consistent with the intent of A285. For example, DIN grade HIV allows higher carbon levels and lower manganese levels than DIN grade 17Mn4, yet both have identical specified strength.

The maximum phosphorus and sulfur levels of 0.050 percent permitted by DIN 17155 for DIN grades HI, HII, HIII, HIV, 17Mn4, and 19Mn5 exceed the allowed A285 maximum levels of 0.035 and 0.04 percent, respectively. Although phosphorus raises the strength level of steel, it reduces ductility and toughness. The presence of sulfur also has the effect of lowering the notch toughness. The additional quality requirements indicated for pressure vessel quality plate support the lower phosphorus and sulfur levels specified by A285. Thus, to be equivalent, the DIN grades must satisfy these lower limits for phosphorus and sulfur.

The silicon content of A285 is not specified because it depends on the deoxidation practice employed, i.e. killed, rimmed, capped, etc. The silicon range permitted by DIN 17155 is typical of that reported for killed steels and is not inconsistent with the requirement of A285.

MECHANICAL PROPERTIES

Strength Requirements

The specified tensile strength range of DIN grade HI is within the A285 ranges for grades A and B, and lies from 10% below to within the range for A285 grade C. The DIN minimum yield strength exceeds the A285 minimum requirements by 25% to 36%, 11% to 22%, and about 1% to 10%, depending on plate thickness, for grades A, B, or C.

The specified tensile strength range of DIN grade HII lies from within to 1% above the A285 ranges for grades B and C. The DIN minimum yield strength exceeds the A285 minimum requirements by 27% to 37% and 15% to 24%, depending on plate thickness, for grades B and C.

The specified tensile strength range of DIN grade HIII lies from within to 1% above the A285 range for grade C, and the minimum yield strength exceeds the A285 grade C requirement by 24% to 34%, depending on plate thickness.

The specified tensile strength range of DIN grade HIV and grade 17Mn4 lie from within to 7% above the A285 grade C range, and the minimum yield strength exceeds the A285 grade C requirement by 29% to 39%, depending on plate thickness.

The specified tensile strength range of DIN grade 19Mn5 lies from 1% below to 18% above the maximum specified tensile strength of A285 grade C, and the minimum yield strength exceeds the A285 grade C requirement by 53% to 58%, depending on plate thickness.

Ductility Requirements

Although A285 specifies minimum percent elongation values for both 200 mm gage length specimens and 50 mm gage length specimens, ASTM A20 requires only the percent elongation value for the specimen and gage length appropriate for the plate thickness to be satisfied. ASTM A20 also permits a reduction in the required minimum percent elongation values for plates under 8 mm thick. The dimensions, gage length, and specimen type permitted by A20 are controlled by the plate thickness. The minimum percent elongation requirement for each grade in DIN 17155 is a function of the tensile strength range for that grade and thus the minimum elongation values for each DIN grade vary inversely as the tensile strength range.

The dimensions of the DIN standard tensile test specimens are scaled so as to maintain a constant ratio of gage length to diameter equal to 5 for round specimens or the equivalent ratio of gage length to the square root of the cross-sectional area equal to 5.65 for rectangular specimens. For plate greater than 19 mm thick, ASTM A20 permits a round specimen with a ratio of gage length to diameter equal to 4 with a 50 mm gage length. Based on the relationship between gage length, percent elongation, and cross-section area, the equivalent DIN elongation value would be 91% of the A285 minimum values for 50 mm gage length.

For plate 19 mm and under in thickness, ASTM A20 requires full plate thickness rectangular test specimens either 38 mm wide with a 200 mm gage length or 13 mm wide with a 50 mm gage length. As the plate thickness changes, the ratio of the gage length to the square root of the cross-sectional area changes which results in an equivalent DIN elongation value which varies with the plate thickness. The following analysis, based on 50 mm gage length specimens, takes into account the effect of plate thickness and the ratio of gage length to the square root of the cross-sectional area on the percent elongation.

The minimum percent elongation value within the DIN grade HI range satisfies or is within 15% of both the A285 grade B and grade C requirements, and satisfies or is within 27% of the A285 grade A requirement.

The minimum percent elongation value within the DIN grade HII range satisfies or is within 20% of the A285 grade C requirement. Plate between 8 mm and 6 mm thick have minimum elongation values 20% below while other plate thicknessses have minimum elongation values which satisfy or are within 18% of the A285 grade C requirement. The minimum percent elongation value within the DIN grade HII range satisfies or is within 25% of the A285 grade B requirement and satisfies or is within 30% of the A285 grade A requirement.

The minimum percent elongation value within the DIN grade HIII range satisfies or is within 26% of the A285 grade C requirement; satisfies or is within 28% of the A285 grade B requirement; and is from 4% to 33% below the A285 grade A requirement.

The minimum percent elongation value within the DIN grade HIV and grade 17Mn4 range is from 16% to 30% below the A285 grade C requirement; from 18% to 32% below the A285 grade B requirement; and from 13% to 37% below the A285 grade A requirement.

The minimum percent elongation value within the DIN grade 19Mn5 range is from 26% to 38% below the A285 grade C requirement.

Supplementary Requirement S14 Bend Test

The bend test requirement is part of DIN 17155-59 although it is only one of several Supplementary Requirements in A285-78. The geometry of the ASTM and DIN bend-test specimens are similar and the specification requirements can be directly compared. For test specimens of equal thickness and with machined edges, the bend-test requirements for DIN grade HI are more severe than the A285 requirements. For DIN grade HII, the bend-test requirement is less severe than the A285 requirement for plate 25 mm or less thick and more severe than the A285 requirement for plate over 25 mm to 50 mm thick. For DIN grade HIII, the bend-test requirement is identical to or more severe than the A285 requirement for plate over 25 mm to 50 mm thick and less severe for plate 25 mm or less thick. For DIN grades HIV and 17Mn4, the bend-test requirement is less severe than the A285 requirement for plate 38 mm or less thick and more severe for plate over 38 mm to 50 mm thick. For DIN grade 19Mn5, the bend-test requirement is less severe than the A285 requirement for all plates up to 50 mm thick.

JIS G3103-77//ASTM A515-78

INTRODUCTION

The scope statements for these two specifications are very similar and refer to the same type of steel products, namely rolled carbon steel plates for use in boilers and pressure vessels in the as-rolled stress-relieved, or normalized condition, depending on plate thickness. Further, JIS G3103 includes both carbon steels and molybdenum alloy steels.

The intended use for ASTM A515 material is for intermediate and higher temperature service in welded boilers and other pressure vessels and thus requires the steel to be made to a coarse-grain practice. In comparison, JIS G3103 does not specifically refer to steel-making practice or grain-size requirements for the same intended uses.

The major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G3103 are considered equivalent to the requirements of ASTM A515 if the JIS values fall within the range from 5% above the A515 maximum value to 5% below the A515 minimum value; (2) the percent elongation requirements of JIS G3103 are considered equivalent to the requirements of ASTM A515 if the JIS values are higher than or within 15% of the A515 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the JIS minimum requirement, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Material furnished under specification A515-78 must conform to the applicable requirements of ASTM A20-78, General Requirements for Steel Plates for Pressure Vessels. (The appropriate edition of A20 to use is that edition concurrent with the edition of A515 of interest.) The relevant sections of A20 used in this comparison include: Section 3, Description of Terms; Section 6, Heat Treatment; Section 7, Chemical Analysis; Section 8, Metallurgical Structure; Section 10, Test Methods; Section 11, Tension Tests; Section 16, Retests, and Supplementary Requirements.

CONCLUSIONS

(1) JIS Class 2 is generally equivalent to ASTM A515-78, Grade 60 based on the criteria discussed earlier.

(2) JIS Class 3 and JIS Class 5 are generally equivalent to ASTM A515-78, Grade 65 based on the criteria discussed earlier.

(3) JIS Class 4 and JIS Class 6 are generally equivalent to ASTM A515-78, Grade 70 based on the criteria discussed earlier.

(4) Steel produced to JIS G3103-78 must be made to coarse-grain practice or have a carburized austenitic grain size of 1 to 5.

JIS G3103-77//ASTM A515-78

STEELMAKING PROCESS

ASTM A515-78 requires the steel to be made to a coarse-grain practice and as a supplementary requirement specifies the austenite grain size. The final grain size of the plate, which is important in determining such properties as yield strength and creep resistance, is strongly influenced not only by the austenite grain size but by the cooling rate through the transformation temperature and is therefore affected by deoxidation practice, plate finishing temperature, and subsequent heat treatment. However, the coarse-grain practice requirement of A515 is consistent with the intended use in intermediate- and higher-temperature service because of the generally higher creep resistance of coarse-grained microstructures compared to fine-grained microstructures of the same material. Although JIS G3103 is specified for the same applications, steelmaking practice and austenite grain size requirements are not specified.

CHEMICAL REQUIREMENTS

The chemical composition limits for JIS Class 2 (SB42) satisfy the chemical limits specified by A515 for Grade 60 plate. The maximum carbon limits for plates up to 50 mm thick, the maximum limits for manganese, phosphorus, and sulfur and the silicon content range are identical with the requirements of A515. The maximum carbon limit of 0.30 percent for plates between 50 mm to 200 mm thick falls between the A515 maximum limits of 0.29 percent and 0.31 percent, respectively, for plates 50 mm to 100 mm thick and 100 mm to 200 mm thick.

The chemical composition limits for JIS Class 3 (SB46) satisfy the chemical requirements specified by A515 for Grade 65 plate. The maximum carbon limits for plates up to 200 mm thick; the maximum limits for manganese, phosphorus, and sulfur; and the silicon content range are identical with the requirements of A515.

The chemical composition limits for JIS Class 4 (SB49) satisfy the chemical requirements specified by A515 for Grade 70 plate. The maximum carbon limits for plates up to 200 mm thick; the maximum limits for manganese, phosphorus, and sulfur; and the silicon content range are identical with the requirements of A515.

The chemical composition limits of JIS Class 5 (SS46M) and Class 6 (SS49M) for carbon, manganese, phosphorus, sulfur and the silicon content range satisfy the chemical requirements specified by A515 for Grades 60, 65, and 70. The minimum molybdenum content specified for JIS Classes 4 and 5 but not specified in A515 qualifies these two classes as alloy steels. The addition of the carbide-forming element molybdenum strengthens the ferrite in these hot-rolled pearlitic steels, increases resistance to temper embrittlement, and increases the elevated temperature strength. The maximum carbon levels for these two classes have been lowered to insure that non-pearlitic transformation products do not form during cooling after rolling or subsequent heat treatment.

MECHANICAL PROPERTIES

Strength Requirements

The specified tensile strength ranges of JIS Class 2, Class 3, and Class 4 plate overlap within one percent the specified ranges for A515 Grade 60, Grade 65, and Grade 70, respectively, and the minimum yield point value for each of these JIS classes exceeds slightly the respective minimum requirement for each of these three A515 grades.

The specified tensile strength ranges of JIS Class 5 and Class 6 plate overlap within one percent the specified ranges for A515 Grade 65 and Grade 70, respectively. The minimum yield points for JIS Class 5 and Class 6 are about six percent higher than the respective minimum requirements for A515 Grade 65 and Grade 70. The addition of the strengthening alloying element molybdenum and the reduction in the maximum carbon levels for JIS Classes 5 and 6 result in specified tensile strength properties identical to JIS Classes 3 and 4 but with minimum yield strength values about four percent higher than those specified in JIS Classes 3 and 4.

Ductility Requirements

The dimensions, gage length, and type of tension test specimens permitted by ASTM A20-78 are controlled by the plate thickness. Although A515 specifies minimum percent elongation values for both 200 mm gage length and 50 mm gage length specimens, only the percent elongation value for the specimen and gage length appropriate for the plate thickness must be satisfied. The two tension test specimens permitted by JIS G3103-77, a 200 mm gage length, 38 mm wide rectangular specimen and a 50 mm gage length, 12.7 mm diameter round specimen are identical to two of the permitted ASTM specimens. Thus, the percent elongation requirements of A515 and JIS G3103 can be directly compared.

The minimum percent elongation values specified for JIS Class 2, Class 3, and Class 4, regardless of test specimen, are identical to the minimum percent elongation values for A515 Grade 60, Grade 65, and Grade 70, respectively. The minimum percent elongation values specified for JIS Class 5 and Class 6, regardless of test specimen, are identical to the minimum percent elongation values for A515 Grade 65 and Grade 70, respectively.

Supplementary Requirement S14 Bend Test

The bend-test requirement is part of JIS G3103-77 although it is only one of a number of Supplementary Requirements in A515. The geometry of the ASTM and JIS bend-test specimens is very similar and the specification requirements can be directly compared. For test specimens of equal thickness, the bend-test requirements for JIS Class 2, JIS Classes 3 and 5, and JIS Classes 4 and 6 are identical or more severe than the requirements of A515 Grade 60, Grade 65, and Grade 70, respectively.

INTRODUCTION

The scope statements for these two specifications are very similar and refer to the same type of steel products, namely rolled carbon steel plates for use in boilers and other pressure vessels in the as-rolled, stress-relieved, or normalized conditions. Further, DIN 17155 includes both carbon steels and alloy steels.

The intended use for ASTM A515 material is for intermediate and higher temperature service in welded boilers and other pressure vessels and thus specifies the steel to be made to a coarse-grain practice. In comparison, DIN 17155 does not specifically refer to steel-making practice or grain size requirements for the same intended uses.

The major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength. The percent elongation requirement, characterizing tensile ductility, is not usually used as a design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17155 are considered equivalent to the requirements of ASTM A515 if the DIN values fall within the range from 5% above the A515 maximum value to 5% below the A515 minimum value; (2) the percent elongation requirements of DIN 17155 are considered equivalent to the requirements of ASTM A515 if the DIN values are higher than or within 15% of the A515 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the DIN minimum requirement, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

The ultimate strength ranges for the DIN grades overlap the ASTM A515 ranges to such an extent that the strength properties of each DIN grade can often satisfy the requirements of more than one A515 grade. Generally upper limits on product dimensions are not specified since the dimensions are usually only limited by the ability of the composition to satisfy the specified mechanical property requirements. However, A515 does identify by grade current practice limits on plate thickness. The comparison presented here includes the DIN grades up to these nominal thickness limits.

Material furnished under specification A515-78 must conform to the applicable requirements of ASTM A20-78, General Requirements for Steel Plates for Pressure Vessels. (The appropriate edition of A20 to use is that edition concurrent with the edition of A515 of interest. The relevant sections of A20 used in this comparison include: Section 3, Description of Terms; Section 6, Heat Treatment; and Section 7, Chemical Analysis; Section 8, Metallurgical Structure; Section 10, Test Methods; Section 11, Tension Tests; Section 16, Retests, and Supplementary Requirements.

CONCLUSIONS

(1) DIN Grade 13 Cr Mo 44 from DIN 17155-59 is not equivalent to ASTM A515-78 because it is an air-hardening and tempered alloy steel and outside of the scope of A515.

(2) DIN Grade HI from DIN 17155-59 is generally equivalent to ASTM A515-78, Grade 55, based on the criteria discussed earlier, subject to the following limitations:

(a) The DIN minimum ultimate tensile strength requirement falls 10% below the A515 minimum requirement. The DIN minimum yield strength requirement for plate more than 90 mm thick falls 5% or more below the A515 minimum requirement. The strength requirements are the principal design parameters and thus to be acceptable, DIN Grade HI plate must be shown to fall within the strength acceptance criteria.

(b) The maximum sulfur and phosphorus levels (ladle or product analysis) should be limited to 0.04 percent and 0.035 percent by weight, respectively, to maintain notch toughness and resistance to temper embrittlement.

(3) DIN Grade HII from DIN 17155-59 is generally equivalent to ASTM A515-78, Grade 60, based on the criteria discussed earlier, subject to the following limitations:

(a) The DIN minimum yield strength requirement for plate more than 115 mm thick falls 5% or more below the A515 minimum requirement. To be acceptable, DIN Grade HII plate in this size range must be shown to fall within the strength acceptance criterion.

(b) The maximum sulfur and phosphorus levels (ladle or product analysis) should be limited to 0.04 percent and 0.035 percent by weight, respectively, to maintain notch toughness and resistance to temper embrittlement.

(4) DIN Grade HIII from DIN 17155-59 is generally equivalent to ASTM A515-78, Grade 60 or Grade 65, based on the criteria discussed earlier, subject to the following limitations:

(a) The DIN minimum yield strength requirement for plate more than 150 mm thick falls 5% or more below the A515, Grade 60 minimum requirement while the DIN minimum yield strength requirement for plate more than 110 mm thick falls 5% or more below the A515, Grade 65 minimum requirement. To be acceptable, DIN Grade HIII plate in these ranges must be shown to fall within the strength acceptance criterion.

(b) The maximum sulfur and phosphorus levels (ladle or product analysis) should be limited to 0.04 percent and 0.035 percent by weight, respectively, to maintain notch toughness and resistance to temper embrittlement.

(5) DIN Grade HIV from DIN 17155-59 is generally equivalent to ASTM A515, Grade 65 or Grade 70, based on the criteria discussed earlier, subject to the following limitations:

(a) The DIN minimum yield strength requirement for plate more than 130 mm thick falls 5% or more below the A515, Grade 65 minimum requirement while the DIN minimum yield strength requirement for plate more than 95 mm thick falls 5% or more below the A515, Grade 70 minimum requirement. To be acceptable, DIN Grade HIV plate in these size ranges must be shown to fall within the strength acceptance criterion.

(b) The maximum sulfur and phosphorus levels (ladle or product analysis) should be limited to 0.04 percent and 0.035 percent by weight, respectively, to maintain notch toughness and resistance to temper embrittlement.

(6) DIN Grade 17 Mn 4 from DIN 17155-59 is generally equivalent to ASTM A515, Grade 65 or Grade 70, based on the criteria discussed earlier, subject to the following limitations:

(a) The DIN minimum yield strength requirement for plate more than 145 mm thick falls 5% or more below the A515, Grade 65 minimum requirement while the DIN minimum yield requirement for plate more than 110 mm thick falls 5% or more below the A515, Grade 70 minimum requirement. To be acceptable, DIN Grade 17 Mn 4 in these size ranges must be shown to fall within the strength acceptance criterion.

(b) The maximum sulfur and phosphorus levels (ladle or product analysis) should be limited to 0.04 percent and 0.035 percent by weight, respectively, to maintain notch toughness and resistance to temper embrittlement.

(7) DIN Grade 19 Mn 5 from DIN 17155-59 is generally equivalent to ASTM A515, Grade 70, based on the criteria discussed earlier, subject to the following limitations:

(a) The DIN minimum yield strength requirement for plate more than 165 mm thick falls 5% or more below the A515, Grade 70 minimum requirement. To be acceptable, DIN Grade 19 Mn 5 in this size range must be shown to fall within the strength acceptance criterion.

(b) The maximum sulfur and phosphorus levels (ladle or product analysis) should be limited to 0.04 percent and 0.035 percent by weight, respectively, to maintain notch toughness and resistance to temper embrittlement.

(8) DIN Grade 15 Mo 3 from DIN 17155-59 is generally equivalent to ASTM A515, Grade 60 or Grade 65, based on the criteria discussed earlier, subject to the following limitations:

(a) The DIN minimum yield strength requirement for plate more than 165 mm thick falls 5% or more below the A515, Grade 60 minimum requirement while the DIN minimum yield strength requirement for plate more than 130 mm thick falls 5% or more below the A515, Grade 65 minimum requirement. To be acceptable, DIN Grade 15 Mo 3 in these size ranges must be shown to fall within the strength acceptance criterion.

(9) Steel produced to DIN 17155-59 must be made to coarse-grain practice or have a carburized austenite grain size of 1 to 5.

(10) The application of the ASTM A515 Supplementary bend test requirements reduces the range of equivalence for some DIN grades as follows:

(a) The DIN grade HII bend requirement is less severe than the A515 grade 60 requirement for plates less than 50 mm thick.

(b) The DIN grade HIII bend requirement is less severe than the A515 grade 60 or grade 65 requirement for plates less than 100 mm thick.

(c) The DIN grades HIV and 17 Mn 4 bend requirements are less severe than the A515 grade 70 requirement for plates less than 100 mm thick and are less severe than the A515 grade 65 requirement for plate of any thickness.

(d) The DIN grade 19 Mn 5 bend requirement is less severe than the A515 grade 70 requirement for plate of any thickness.

(e) The DIN grade 15 Mo 3 bend requirement is less severe than the A515 grade 60 or grade 65 requirements for plate of any thickness.

For those thicknesses and grades where the DIN bend requirement is less severe, the DIN plate would be equivalent only if it met the A515 requirements for that generally equivalent grade.

STEELMAKING PROCESS

ASTM A515-78 requires the steel to be made to a coarse-grain practice and as a supplementary requirement specifies the austenite grain size. The final grain size of the plate, which is important in determining such properties as yield strength and elevated temperature creep resistance, is strongly influenced not only by the austenite grain size but also by the cooling rate through the transformation temperature and is therefore affected by deoxidation practice, plate finishing temperature, and subsequent heat treatment. However, the coarse-grain practice requirement of A515 is consistent with the intended use in intermediate- and higher-temperature service because of the generally higher creep resistance of coarse-grained microstructures compared to fine-grained microstructures of the same material.

Although DIN 17155-59 is specified for the same applications, steelmaking practice and austenite grain size requirements are not specified. However, DIN 17155 does include non-guaranteed elevated-temperature creep-rupture and creep-strain data which can be compared with other tabulated elevated-temperature data (ASTM Data Series DS 1151) for wrought carbon steels including data from the coarse-grained ASTM A515 and its fine-grained equivalent, ASTM A516. The reported average 10,000 hour and 100,000 hour creep-rupture strengths from 430 C to 520 C of DIN Grades HI, HII, HIII, HIV, 17Mn4, and 19Mn5 range from about 10% above to 30% below the average values for coarse-grain wrought carbon steels, including those covered by A515. Over this temperature range, the fine-grained wrought carbon steels, including those covered by A516, average up to 24% lower creep-rupture strength than the coarse-grain carbon steels. This grain size effect is reduced at the highest temperatures and longest rupture times due to several factors, including thermal effects on the steel microstructure.

CHEMICAL REQUIREMENTS

Three primary quality descriptors of steel plate, listed in order of increasing quality, are regular quality, structural quality, and pressure vessel quality. Regular quality plates are normally produced to compositional ranges rather than mechanical property requirements and are typically used in non-critical applications. Further, regular quality plates are not expected to have the same level of chemical uniformity, internal soundness, or freedom from surface imperfections (i.e. inclusions) as that found in structural quality or pressure vessel quality plate. Although structural quality and pressure vessel quality plate are normally produced to both chemical and mechanical property requirements, pressure vessel quality generally must satisfy more stringent limits on allowable surface and edge perfections and sometimes notch toughness requirements. Thus, pressure vessel quality specifications, such as ASTM A515, almost always require lower limits for phosphorus and sulfur than are required for structural quality or regular quality.

For rolled carbon pressure vessel steels, the mechanical properties and weldability are usually the important criteria. When this steel is produced to mechanical property values, usual practice allows the carbon and manganese levels to vary to compensate for the effect of plate thickness. Typically in these steels, strength properties decrease and tensile ductility (often measured by percent elongation) increases as the plate thickness increases.

The chemical requirements of A515 specify for each grade the same upper limit on the manganese content independent of plate thickness but allow the maximum carbon limit to increase with increase in plate thickness in order to maintain the necessary minimum strength for that particular grade. Following a different approach, the DIN chemical requirements for grades HI, HII, HIII and HIV specify maximum carbon levels and minimum manganese levels which are different for each grade but independent of plate thickness. Specifically, the DIN maximum carbon levels for these grades are all well below the A515 maximum levels for nominally equivalent grades, i.e. DIN HI below A515 Grade 55, DIN HII below A515 Grade 60, DIN HIII below A515 Grades 60 and 65, and DIN HIV below A515 Grades 65 and 70. However, the greater flexibility of the DIN carbon and manganese levels for these grades is consistent with the ASTM requirements.

Although the DIN maximum carbon levels for grades 17Mn4 and 19Mn5 are also well below the A515 maximum levels for nominally equivalent grades, i.e. DIN 17Mn4 below A515 Grades 65 and 70, and DIN 19Mn5 below A515 Grade 70, the DIN manganese requirements are compositional ranges whose minimum values are at or higher than the A515 maximum limit. The higher manganese levels compensate for the lower carbon levels so that strength properties are maintained without reducing notch toughness and are considered to be consistent with the intent of A515.

The maximum phosphorus and sulfur levels of 0.050 percent permitted by DIN 17155-59 for DIN grades HI, HII, HIII, HIV, 17Mn4, and 19Mn5 exceed the permitted A515 maximum levels of 0.035 and 0.04 percent respectively. Although phosphorus raises the strength level of steel, it reduces ductility and toughness and increases the susceptibility to temper embrittlement after exposure to temperatures above 700 F. The presence of sulfur has the effect of lowering the notch toughness. The additional quality requirements indicated for pressure vessel quality plate combined with the anticipated elevated temperature service environment supports the importance of the lower phosphorus and sulfur levels specified by A515. Thus, to be equivalent, the DIN grades must satisfy these lower limits for phosphorus and sulfur.

The chemical composition limits of DIN 15Mo3 for carbon, silicon, manganese, and sulfur satisfy the chemical requirements of A515 for grades 60 and 65. The maximum phosphorus level of 0.040 percent slightly exceeds the A515 requirement of 0.035 percent but this difference is not considered significant due to the presence of molybdenum. The minimum molybdenum content specified for DIN grade 15Mo3 qualifies this steel as an alloy steel. The addition of the carbide-forming element molybdenum strengthens the ferrite phase in this steel, increases resistance to temper embrittlement, and increases the elevated temperature strength. However, the maximum carbon level and the maximum manganese level have been lowered and/or specified in order to reduce the hardenability and insure that non-pearlitic transformation products do not form during cooling after rolling or subsequent heat treatment. As a result, the chemical requirements of DIN 15Mo3 are equivalent to the A515 requirements.

DIN grade 13 CrMo44, containing both chromium and molybdenum, has a sufficiently high alloy content that it is supplied in the hardened and tempered condition. The higher alloy content together with the substantially different thermal processing of this material places this DIN grade outside of the scope of A515.

MECHANICAL PROPERTIES

The specified ultimate tensile strength ranges and minimum percent elongation values for the DIN grades often overlap the A515 ultimate tensile strength ranges and satisfy the minimum elongation requirements for more than one A515 grade. The DIN minimum yield strength requirements, however, are thickness dependent while the A515 requirements are not and thus if a DIN grade satisfies the other requirements of more than one A515 grade, the final selection of equivalent grades could be determined by the plate thickness.

Strength Requirements

The specified tensile strength range of DIN grade HI lie from 10% below to within the A515 grade 55 strength range. The DIN minimum yield strength satisfies or is within 5% of the A515 grade 55 minimum requirement for plates up to 90 mm thick. Above 90 mm, the DIN minimum specified value lies between 7% below the A515 minimum value for plates 95 mm thick to 48% below for plates 300 mm thick.

The specified tensile strength range of DIN grade HII is from 3% below to within the A515 grade 60 strength range. The DIN minimum yield strength satisfies or is within 5% of the A515 grade 60 minimum value for plates up to 115 mm thick. Above 115 mm thick, the DIN minimum value lies between 6% below the A515 minimum requirement for plates 120 mm thick to 23% below for plate 200 mm thick.

The specified tensile strength range of DIN grade HIII is within the A515 grade 60 strength range, and from 4% below to within the A515 grade 65 strength range. The DIN minimum yield strength requirement satisfies or is within 5% of the A515 grade 60 requirement for plates up to 150 mm thick, and satisfies or is within 5% of the A515 grade 65 requirement for plates up to 110 mm thick. Above 150 mm thick for A515 grade 60, the DIN minimum value lies between 6% below the A515 minimum specified value for plate 155 mm thick to 17% below for plate 200 mm thick. Above 110 mm thick for A515 grade 65, the DIN minimum value lies between 6% below the A515 minimum specified value for plates 115 mm thick to 24% below for plates 200 mm thick.

The specified tensile strength range of DIN grade HIV is within the A515 grade 65 strength range, and from 5% below to within the A515 grade 70 range. The DIN minimum yield strength requirement satisfies or is within 5% of the A515 grade 65 requirement for plate up to 130 mm thick, and satisfies or is within 5% of the A515 grade 70 requirement for plate up to 95 mm thick. Above 130 mm thick for A515 grade 65 plate, the DIN minimum value lies between 6% below the A515 minimum specified value for plates 135 mm thick to 20% below for plates 200 mm thick. Above 95 mm thick, for A515 grade 70 plate, the DIN minimum value lies between 6% below the A515 minimum specified value for plates 100 mm thick to 27% below for plate 200 mm thick.

The specified tensile strength range of DIN grade 17Mn4 is within the A515 grade 65 strength range, and from 5% below to within the A515 grade 70 range. The DIN minimum yield strength requirement satisfies or is within 5% of the A515 grade 65 requirement for plate up to 145 mm thick, and satisfies or within 5% of the A515 grade 70 requirement for plate up to 110 mm thick. Above 145 mm thick, for A515 grade 65 plate, the DIN minimum value lies between 6% below the A515 minimum for plates 150 mm thick to 18% below for plate 200 mm thick. Above 110 mm thick, for A515 grade 70 plate, the DIN minimum value lies between 6% below the A515 minimum for plates 115 mm thick to 24% below for plate 200 mm thick.

The specified tensile strength range of DIN grade 19Mn5 is within the A515 grade 70 strength range. The DIN minimum yield strength requirement satisfies or is within 5% of the A515 grade 70 requirement for plate up to 165 mm thick. Above 165 mm thick, for A515 grade 70 plate, the DIN minimum value lies between 6% below the A515 minimum for plates 170 mm thick to 13% below for plates 200 mm thick.

The specified tensile strength range of DIN grade 15Mo3 is within the A515 grade 60 strength range, and from 4% below to within the A515 grade 65 strength range. The DIN minimum yield strength requirement satisfies or is within 5% of the A515 grade 60 requirement for plate up to 165 mm thick, and satisfies or within 5% of the A515 grade 65 requirement for plate up to 130 mm thick. Above 165 mm thick for A515 grade 60 plate, the DIN minimum value lies between 6% below the A515 minimum for plates 170 mm thick to 13% below for plates 200 mm thick. Above 130 mm thick for A515 grade 65 plate, the DIN minimum value lies between 6% below the A515 minimum for plates 135 mm thick to 20% below for plate 200 mm thick.

Ductility Requirements

Although A515 specifies minimum percent elongation values for both 200 mm gage length specimens and 50 mm gage length specimens, ASTM A20 requires only the percent elongation value for the specimen and gage length appropriate for the plate thickness to be satisfied. ASTM A20 also permits a reduction in the required minimum percent elongation values for plates under 8 mm thick or over 89 mm thick. The dimensions, gage length, and specimen type permitted by A20 are controlled by the plate thickness.

values for plates under 8 mm thick or over 89 mm thick. The dimensions, gage length, and specimen type permitted by A20 are controlled by the plate thickness.

The dimensions of the DIN standard tensile test specimens are scaled so as to maintain a constant ratio of gage length to diameter equal to 5 for round specimens or the equivalent ratio of gage length to the square root of the cross-sectional area equal to 5.65 for rectangular specimens. For plate greater than 19 mm thick, ASTM A20 permits a round specimen with a ratio of gage length to diameter equal to 4 with a 50 mm gage length. Based on the relationship between gage length and cross-section area, the equivalent DIN elongation value would be 91% of the A515 minimum values for 50 mm gage length.

For plate 19 mm and under in thickness, ASTM A20 requires full plate thickness rectangular test specimens either 38 mm wide with a 200 mm gage length or 13 mm wide with a 50 mm gage length. As the plate thickness changes, the ratio of the gage length to the square root of the cross-sectional area changes which results in an equivalent DIN elongation value which varies with the plate thickness. The following analysis, based on 50 mm gage length specimens, takes into account the effect of thickness and the ratio of gage length to the square root of the cross-sectional area on the percent elongation.

The minimum percent elongation for DIN grade HI satisfies or is within 15% of the A515 grade 55 requirement for plate up to 300 mm thick. The minimum percent elongation for DIN grade HII satisfies or is within 15% of the A515 grade 60 requirement for plate up to 200 mm thick.

The minimum percent elongation for DIN grades HIII and 15Mo3 satisfies or is within 15% of the A515 grade 60 or grade 65 requirements for plate up to 200 mm thick. However, the best agreement is with the requirements of A515 grade 65.

The minimum percent elongation for DIN grades IV and 17Mn4 satisfies or is within 15% of the A515 grade 65 or grade 70 requirements for plate up to 200 mm thick. However, the best agreement is with the requirements of A515 grade 70.

The minimum percent elongation for DIN grade 19Mn5 is within 15% of the A515 grade 70 requirement for plate up to 200 mm thick.

A515 Supplementary Requirement S14 Bend Test
See A20-78 for Requirements

The ratio of specimen width to thickness is assumed to be equal and constant for both the DIN and ASTM specimens.

DIN Grade	Equivalent to A515 (A20)
HI	Yes for grade 55 plate up to 300 mm thick.
HII	Yes for grade 60 plate 50 mm to 200 mm thick. No for grade 60 plate below 50 mm thick.
HIII	Yes for grade 60 or grade 65 plate 100 mm to 200 mm thick. No for grade 60 or grade 65 plate below 100 mm thick.
HIV	Yes for grade 70 plate 100 mm to 200 mm thick. No for grade 70 plate below 100 mm thick. No for grade 65 plate for any thickness.
17Mn4	Yes for grade 70 plate 100 mm to 200 mm thick. No for grade 70 plate below 100 mm thick. No for grade 65 plate for any thickness.
19Mn5	No
15Mo3	Yes for grade 70 plate 100 mm to 200 mm thick. No for grade 70 plate below 100 mm thick. No for grade 60 or 65 plate for any thickness.

JIS G5151-78//ASTM A216-77

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to ferritic steel castings for pressure environments at elevated temperatures. Although ASTM A216-77 is limited to plain carbon grades, JIS G5151-78 includes both plain carbon and alloy steel grades. All castings produced under A216 must be heat treated and can be furnished in the annealed, normalized, or normalized and tempered condition, while JIS G5151 allows in addition the quenched and tempered condition.

The major design criteria for the intended applications of these castings are the static strength properties, ultimate tensile strength and yield strength, and pressure tightness. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter depending on specimen geometry and gage length as well as the materials intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility. The percent reduction-in-area is also a measure of tensile ductility and is not as sensitive to specimen geometry as percent elongation. Percent reduction-in-area measures the ability of the material to deform locally and thus reflects the materials ability to relieve local stress concentrations such as expected in pressurized components.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G5151 are considered equivalent to the requirements of ASTM A216 if the JIS values fall within the range from 5% below the A216 minimum value to 5% above the A216 maximum value; (2) the minimum JIS reduction-in-area values are considered equivalent to the requirements of A216 if they exceed or are within 5% of the A216 minimum value; (3) the percent elongation requirements of JIS G5151 are considered equivalent to the requirements of A216 if the JIS values exceed or are within 15% of the A216 minimum values. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Material furnished under specification A216-77 must conform to the applicable requirements of ASTM A703-79b, General Requirements Applicable to Steel Castings for Pressure-Containing Parts. (The appropriate edition of A703 to use is that edition concurrent with the edition of

A216 of interest.) The relevant sections of A703 used in this comparison include: Section 6, Tensile Requirements; Section 7, Retests; and Section 8, Hydrostatic Tests.

CONCLUSIONS

(1) JIS class 1 (SCPH 1) from JIS G5151-78 is generally equivalent to ASTM A216-77, grade WCA based on the criteria discussed earlier.

(2) JIS class 2 (SCPH 2) from JIS G5151-78 is generally equivalent to ASTM A216-77, grade WCB based on the criteria discussed earlier.

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analyses for JIS class 1 and class 2 materials satisfy the chemical limits for ASTM A216 grades WCA and WCB, respectively. The maximum JIS levels for the major alloying elements carbon, manganese, silicon, and phosphorus and the impurities copper, nickel, and molybdenum are identical to the ASTM requirements, while the JIS maximum levels for sulfur and chromium are below the ASTM maximum allowable limits.

MECHANICAL REQUIREMENTS

The determination of mechanical properties of castings requires careful control over the preparation of the test specimen. The solidification behavior of castings is very important in determining mechanical properties because the cooling rate strongly affects the resultant casting grain size, the type and amount of the metallurgical phases present, and the extent and location of chemical segregation, shrinkage and porosity. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties than the component casting poured at the same time from the same heat of metal due to exaggerated differences in size.

For steel castings, test specimens may be taken from coupons cast as part of the casting, from separately cast coupons, or from specified areas of the casting itself. Even though the test specimens from the two types of coupons are heat-treated with the casting, differences in mechanical properties can result.

Specification JIS G5151 permits separately cast test specimens on test coupons cast as part of the casting. Specification ASTM A216 (through A703) generally requires separately cast test specimens although under certain conditions test specimens machined from coupons cast as part of the casting or taken from specified areas of the casting can be used. The separately cast JIS test bar has an initial diameter of 32 mm and a final specimen diameter of 14 mm, while the ASTM separately cast test bar has an initial diameter of about 26 mm and a final specimen diameter of about 13 mm, thus allowing a direct comparison of the mechanical properties.

Strength Requirements

The minimum ultimate tensile strength specified for JIS G5151 class 1 is within 1% of the A216 specified minimum while the JIS minimum yield strength slightly exceeds the A216 minimum requirement value for grade WCA. A maximum JIS ultimate tensile strength is not specified.

The minimum ultimate tensile strength specified by JIS G5151 class 2 is within 1% of the A216 grade WCB specified minimum while the JIS minimum yield strength is within 2% of the grade WCB minimum requirement. A maximum JIS ultimate tensile strength is not specified.

Ductility Requirements

The JIS test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 5 while the ASTM test specimen (see ASTM A703-79b) has a circular cross-section with a gage length-to-diameter ratio of 4. Using the relationship between gage length and cross-sectional area, the equivalent JIS elongation value would be smaller, about 91% of the ASTM value.

The minimum percent elongation requirement for JIS classes 1 and 2 is within 5% of the A216 minimum requirements for grades WCA and WCB, respectively. The minimum JIS reduction-in-area requirements for classes 1 and 2 satisfy the A216 minimum requirement for grades WCA and WCB.

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to ferritic steel castings for elevated temperature service. Although ASTM A216-77 is limited to plain carbon steel grades, DIN 17245-67 includes both plain carbon and alloy steel grades. All castings produced under A216 must be heat-treated and can be furnished in either the annealed, normalized, or normalized and tempered condition while under DIN 17245, all castings are supplied in either the normalized condition for the plain carbon grade or quenched and tempered for the alloy steel grades.

The major design criteria for the intended applications of these castings are the static strength properties, ultimate tensile strength and yield strength, and pressure tightness. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility. The percent reduction-in-area is also a measure of tensile ductility and is not as sensitive to specimen geometry as percent elongation. Percent reduction-in-area measures the ability of the material to deform locally and thus reflects the materials ability to relieve local stress concentrations such as expected in pressurized components.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17245 are considered equivalent to the requirements of ASTM A216 if the DIN values fall within the range from 5% below the A216 minimum value to 5% above the A216 maximum value; (2) the minimum DIN reduction-in-area values are considered equivalent to the requirements of A216 if they exceed or are within 5% of the A216 minimum value; (3) the percent elongation requirements of DIN 17245 are considered equivalent to the requirements of A216 if the DIN values exceed or are within 15% of the A216 minimum values. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Material furnished under specification A216-77 must conform to the applicable requirements of ASTM A703-796, General Requirements Applicable to Steel Castings for Pressure-Containing Parts. (The appropriate edition of A703 to use is that edition concurrent with the edition of A216 of interest.) The relevant sections of A703 used in this comparision include: Section 6, Tensile Requirements; Section 7, Retests; and Section 8, Hydrostatic Tests.

CONCLUSIONS

(1) DIN grade GS-C25 (1.0619) from DIN 17245-67 is generally equivalent to ASTM A216-77, grade WCA based on the criteria discussed earlier, subject to the following limitation:

(a) To be acceptable, DIN grade GS-25C must be shown to satisfy the reduction-in-area requirement.

(2) DIN grades GS-22Mo4 (1.5419), GS-17CrMo55 (1.7357), GS-17CrMoV511 (1.7706), G-X22CeMoV121 (1.4931), and G-X22CrMoWV121 (1.4932) from DIN 17245-67 are not equivalent to ASTM A216-77 because they are alloy steel grades and are thus beyond the scope of A216.

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analyses for DIN grade GS-C25 satisfy the chemical limits for ASTM A216 grade WCA. The maximum DIN levels specified for carbon, manganese, silicon, and chromium are very close to the requirements of grade WCA while the maximum sulfur and phosphorus levels only slightly exceed the A216 limits.

MECHANICAL REQUIREMENTS

The determination of mechanical properties of castings requires careful control over the preparation of the test specimen. The solidification behavior of castings is very important in determining mechanical properties because the cooling rate strongly affects the resultant casting grain size, the type and amount of the metallurgical phases present, and the extent and location of chemical segregation, shrinkage and porosity. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties than the component casting poured at the same time from the same heat of metal due to exaggerated differences in size.

For steel castings, test specimens may be taken from coupons cast as part of the casting, from separately cast coupons, or from specified areas of the casting itself. Even though the test specimens from the two types of coupons are heat-treated with the casting, differences in mechanical properties can result.

Specification DIN 17245 generally requires test specimens machined from coupons cast as part of the casting although separately cast test specimens are permitted when the former is not possible. Specification ASTM A216 (through A703) also allows the test specimens to be taken from casting coupons or separately cast test specimens. Although the ASTM test bar, whether from a casting coupon or a separately cast piece, has an initial diameter of about 26 mm and a final diameter of about 13 mm, the dimensions of the DIN test bars are not defined. Thus, the following comparison is based on the assumption that a DIN test piece similar in size to the ASTM values would be used.

Strength Requirements

The ultimate tensile strength range for DIN grade GS-C25 falls within the maximum-minimum range for A216 grade WCA and the GS-C25 minimum yield strength requirement exceeds the A216 grade WCA minimum requirement.

Ductility Requirements

The DIN test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 5 while the ASTM test specimen (see ASTM A703-79b) has a circular cross-section with a gage length-to-diameter ratio of 4. Using the relationship between gage length and cross-sectional area, the equivalent DIN elongation value would be smaller, about 91% of the ASTM value.

The minimum percent elongation requirement for DIN grade GS-C25 satisfies the minimum A216 requirement for grade WCA. Specification DIN 17245 does not contain reduction-in-area requirements although based on the comparison of the other mechanical properties, it is expected that DIN grade GS-C25 would satisfy the A216 grade WCA requirements.

JIS G5151-78//ASTM A217-77a

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to steel castings for pressure environments at elevated temperatures. Specification ASTM A217-77a includes a martensitic stainless steel grade as well as ferrite alloy steel grades while JIS G5151 contains both plain carbon and ferritic alloy steel grades. All castings produced under A217 must be heat-treated and furnished in the normalized and tempered condition while JIS G5151 permits casting to be furnished in the annealed, normalized, normalized and tempered, and quenched and tempered condition depending in part on the particular alloy grade. Generally, the lowest strength properties are found for the annealed condition while the quenched and tempered condition produces the highest tensile strength and most improved toughnesss compared to the normalized and tempered condition for similar tempering temperatures. The choice of heat treatment depends on the desired properties for particular compositional grades; thus, the heat requirements for JIS G5151 are not inconsistent with the requirements of A217.

The major design criteria for the intended applications of these castings are the static strength properties, ultimate tensile strength and yield strength, and pressure tightness. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, but depends on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility. The percent reduction-in-area is also a measure of tensile ductility and is not as sensitive to specimen geometry as the percent elongation. Reduction-in-area measures the ability of the material to deform locally and thus reflects the materials ability to relieve local stress concentrations such as expected in pressurized components.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS G5151 are considered equivalent to the requirements of ASTM A217 if the JIS values fall within the range from 5% below the A217 minimum value to 5% above the A217 maximum value; (2) the minimum JIS reduction-in-area values are considered equivalent to the requirements of A217 if they exceed or are within 5% of the A217 minimum values; and (3) the percent elongation requirements of JIS G5151 are considered equivalent to the requirements of A217 if the JIS values exceed or are within 15% of the A217 minimum values. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Material furnished under specification A217-77a must conform to the applicable requirements of ASTM A703-796, General Requirements Applicable to Steel Castings for Pressure-Containing Parts. (The appropriate edition of A703 to use is that edition concurrent with the edition of A217 of interest.) The relevant sections of A703 used in this comparision include: Section 6, Tensile Requirements; Section 7, Retests; Section 8, Hydrostatic Tests.

CONCLUSIONS

(1) JIS class 11 (SCPH 11) from JIS G5151-78 is generally equivalent to ASTM A217-77a, grade WC1 based on the criteria discussed earlier.

(2) JIS class 21 (SCPH 21) from JIS G5151-78 is generally equivalent to ASTM A217-77a, grade WC6 based on the criteria discussed earlier.

(3) JIS class 32 (SCPH 32) from JIS G5151-78 is generally equivalent to ASTM A217-77a, grade C5 based on the criteria discussed earlier.

(4) JIS class 22 (SCPH 22) and class 23 (SCPH 23) are not equivalent to any grade in ASTM A217-77a because the chemical ranges for chromium, molybdenum and vanadium do not satisfy the requirements in A217.

(5) JIS class 1 (SCPH 1) and class 2 (SCPH 2) are not equivalent to ASTM A217-77a because they are plain carbon grades and thus are outside the scope of A217.

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analyses for JIS class 11 and class 21 satisfy the chemical limits for ASTM A217 grade WC1 and grade WC6, respectively. The JIS limits for carbon, manganese, silicon, phosphorus, and molybdenum are the same as the ASTM limits while the JIS maximum sulfur level is slightly below the ASTM value.

The chemical composition limits based on ladle analyses for JIS class 32 and class 61 satisfy the chemical limits for ASTM A217 grade WC9 and grade C5, respectively. The JIS limits for carbon (class 61), silicon, phosphorus, chromium, and molybdenum in both JIS classes are identical to the ASTM requirements while the JIS maximum levels for sulfur and carbon (class 32) are slightly below the ASTM maximum values. The JIS permitted manganese range overlaps the ASTM range at the high end. Manganese, acting primarily as a deoxidizer in these alloys, contributes to the soundness of the casting and thus the small overlap is not inconsistent with the requirements of A217.

MECHANICAL REQUIREMENTS

The determination of mechanical properties of castings requires careful control over the preparation of the test specimen. The solidification behavior of castings is very important in determining mechanical properties because the cooling rate strongly affects the resultant casting grain size, the type and amount of the metallurgical phases present, and the extent and location of chemical segregation, shrinkage and porosity. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties than the component casting poured at the same time from the same heat of metal due to exaggerated differences in size.

For steel castings, test specimens may be taken from coupons cast as part of the casting, from separately cast coupons, or from specified areas of the casting itself. Even though the test specimens from the two types of coupons are heat-treated with the casting, difference in mechanical properties can result.

Specification JIS G5151 permits separately cast test specimens or test coupons cast as part of the casting. Specification ASTM A217 (through A703) generally requires separately cast test specimens although under certain conditions test specimens machined from coupons cast as part of the casting or taken from specified areas of the casting can be used. The separately cast JIS test bar has an initial diameter of 32 mm and a final specimen diameter of 14 mm, while the ASTM separately cast test bar has an initial diameter of about 26 mm and a final specimen diameter of about 13 mm, thus allowing a direct comparison of the mechanical properties.

Strength Requirements

The minimum ultimate tensile strength and yield strength requirements specified for JIS G5151 class 11 exceed the A217 minimum requirements for grade WC1. A maximum JIS ultimate tensile strength is not specified.

The minimum ultimate tensile strengths specified for JIS G5151 class 21, class 32, and class 61 are within 1% of the A217 minimum values for grades WC6, WC9, and C5, respectively while the minimum JIS yield strength requirements satisfy the A217 minimum values for grades WC6 and WC9. The JIS minimum yield strength value for class 61 is within 1% of the A217 minimum value for grade C5.

Ductility Requirements

The JIS test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 5 while the ASTM test specimen (see ASTM A703-796) has a circular cross-section with a gage length-to-diameter ratio of 4. Using the relationship between gage length and cross-sectional area, the equivalent JIS elongation value would be smaller, about 91% of the ASTM value.

The minimum percent elongation requirements for JIS class 11 and class 61 satisfy the A217 requirements for grade WC1 and grade C5. The minimum percent elongation requirements for JIS class 21 and class 32 are within 5% of the A217 minimum requirements for grades WC6 and WC9, respectively. The minimum JIS reduction-in-area requirements for class 11, class 21, class 32, and class 61 satisfy the A217 minimum requirements for grades WC1, WC6, WC9, and C5, respectively.

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to steel castings for pressure environments at elevated temperatures. Specification ASTM A217-77a includes a martensitic stainless steel grade as well as ferritic alloy steel grades while DIN 17245-67 is limited to plain carbon and ferritic alloy steel grades. All castings produced under A217 must be heat-treated and furnished in the normalized and tempered condition. All alloy castings in DIN 17245 are supplied in either the quenched and tempered condition or normalized condition. Generally, for similar tempering temperatures, the quenched and tempered condition results in higher tensile strength and better impact toughness than for the normalized and tempered condition. Thus the heat treatment requirement for DIN 17245 satisfies ASTM A217.

The major design criteria for the intended applications of these castings are the static strength properties, ultimate tensile strength and yield strength, and pressure tightness. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, but depends on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility. The percent reduction-in-area is also a measure of tensile ductility and is not as sensitive to specimen geometry as the percent elongation. Reduction-in-area measures the ability of the material to deform locally and thus reflects the materials ability to relieve local stress concentrations such as expected in pressurized components.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17245 are considered equivalent to the requirements of ASTM A217 if the DIN values fall within the range from 5% below the A217 minimum value to 5% above the A217 maximum value; (2) the minimum DIN reduction-in-area values are considered equivalent to the requirements of A217 if they exceed or are within 5% of the A217 minimum values; and (3) the percent elongation requirements of DIN 17245 are considered equivalent to the requirements of A217 if the DIN values exceed or are within 15% of the A217 minimum values. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the minimum requirement; (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation; and (3) the unknown precision in the relationship between gage length, cross-sectional area, and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

Material furnished under specification A217-77a must conform to the applicable requirements of ASTM A703-796, General Requirements Applicable to Steel Castings for Pressure Containing Parts. (The appropriate edition of A703 to use is that edition concurrent with the edition of A217 of interest.) The relevant sections of A703 used in this comparison include: Section 6, Tensile Requirements; Section 7, Retests; Section 8, Hydrostatic Tests.

CONCLUSIONS

(1) DIN grade GS-22Mo4 (1.5419) from DIN 17245-67 is generally equivalent to ASTM A217-77a, grade WC1 based on the criteria discussed earlier, subject to the following limitation:

(a) To be acceptable, DIN grade GS-22Mo4 must be shown to satisfy the reduction-in-area requirement.

(2) DIN grade GS-17CrMo55 (1.7357) from DIN 17245-67 is generally equivalent to ASTM A217-77a, grade WC6 based on the criteria discussed earlier, subject to the following limitation:

(a) To be acceptable, DIN grade GS-17CrMo55 must be shown to satisfy the reduction-in-area requirement.

(3) The DIN grades GS-17CrMoV11 (1.7706), G-X22CrMoV121 (1.4931), and G-X22CrMoWV121 (1.4932) from DIN 17245-67 are not equivalent to any grade in ASTM A217-77a because the chemical composition ranges for the alloying elements vanadium, nickel, and tungsten do not satisfy the requirements in A217.

(4) DIN grade GS-C25 (1.0619) from DIN 17245-67 is not equivalent to any grade in ASTM A217-77a because it is a plain carbon grade and thus is beyond the scope of A217.

CHEMICAL REQUIREMENTS

The chemical composition limits based on ladle analysis for DIN grade GS-22Mo4 satisfy the chemical limits for ASTM A217 grade WC1. The maximum DIN levels specified for carbon, manganese, sulfur, phosphorus, silicon, and chromium are the same or very close to the maximum limits of grade WC1. The maximum molybdenum level in DIN grade GS-22Mo4 just satisfies the minimum requirement for A217 grade WC1. Molybdenum acts as a ferrite strengthener and increases the elevated temperature strength of the alloy so that the elevated temperature mechanical properties of the two grades should be compared even though ASTM A217 does not include elevated temperature requirements.

The chemical composition limits based on ladle analysis for DIN grade GS-17CrMo55 satisfy the chemical limits for ASTM A217 grade WC6. The maximum DIN levels specified for carbon, manganese, silicon, sulfur, phosphorus, chromium and molybdenum are the same or very close to the maximum limits of grade WC6.

MECHANICAL REQUIREMENTS

The determination of mechanical properties of castings requires careful control over preparation of the test specimens. The solidification behavior of castings is very important in determining mechanical properties because the cooling rate strongly affects the resultant casting grain size, the type and amount of the metallurgical phases present, and the extent and location of chemical segregation, shrinkage and porosity. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties than the component casting poured at the same time from the same heat of metal due to exaggerated differences in size.

For steel castings, test specimens may be taken from compounds cast as part of the casting, from separately cast coupons, or from specified areas of the casting itself. Even though the test specimens from the two types of coupons are heat-treated with the casting, differences in mechanical properties can result.

Specification DIN 17245 generally requires test specimens machined from coupons cast as part of the casting although separately cast test specimens are permitted when the former is not possible. Specification ASTM A217 (through A703) also allows the test specimens to be taken from casting coupons or separately cast test specimens, thus the mechanical properties of these two specifications can be directly compared.

Strength Requirements

The ultimate tensile strength range for DIN grade GS-22Mo4 is from 2% below to within the minimum-maximum range for A217 grade WC1 and the GS-22Mo4 minimum yield strength requirement exceeds the A217 grade WC1 minimum requirement.

The ultimate tensile strength range for DIN grade GS-17CrMo55 falls within the minimum-maximum range for A217 grade WC6 and the GS-17CrMo55 minimum yield strength requirement exceeds the A217 grade WC6 minimum requirement.

Ductility Requirements

The DIN test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 5 while the ASTM test specimen (see A703-79b) has a circular cross-section with a gage length-to-diameter ratio of 4. Using the relationship between gage length and cross-sectional area, the equivalent DIN elongation value would be smaller, about 91% of the ASTM value.

The minimum percent elongation requirements for DIN grades GS-22Mo4 and GS-17CrMo55 satisfy the minimum A217 requirements for grades WC1 and WC6, respectively.

Specification DIN 17245 does not contain reduction-in-area requirements although based on the comparison of the other mechanical properties, it is expected that DIN grades GS-22Mo4 and GS-17CrMo55 would satisfy the A217 grade WC1 and WC6 requirements, respectively.

JIS G5501-76//ASTM A48-76

INTRODUCTION

The scope statements for these two specifications are very similar and refer to gray iron castings, that is, cast iron in which the graphite is present in the form of flakes. In both specifications, chemical composition is not specified except indirectly through the required presence of free or uncombined carbon as graphite.

The major design criterion for the intended applications of these products is the tensile strength. Each specification ranks the classes of gray cast iron by a minimum tensile strength value and permits the chemical composition to vary in order to produce the desired strength. In addition, the generalized strength classes identified in JIS G5501 are further subdivided based on the size of the as-cast test piece from which the test specimen is taken, with each sub-class having an individual minimum tensile strength. In ASTM A48, however, a different approach was followed. In A48, each strength class has the same minimum tensile strength requirement regardless of the size of the as-cast test piece.

For purposes of this comparison, the acceptance criterion for the determination of equivalence is: the tensile strength requirements of JIS G5501 are considered equivalent to the requirements of ASTM A48 if the JIS value is higher or within 5% of the A48 minimum value. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

1. JIS class 1 (FC10) from JIS G5501-76 is not equivalent to any grade in ASTM A48-76 because its minimum tensile strength is 29% below the lowest A48 minimum value.

2. JIS class 2 (FC15) from JIS G5501-76 is generally equivalent in part to ASTM A48-76, classes 20 and 25 based on the criterion discussed earlier and subject to the following limitations depending on the size of the as-cast test piece as follows:

    a. Class 2 material with test-piece diameters of 13 mm, 20 mm, and 30 mm are equivalent, respectively, to A48 classes 25S, 25A, and 20B.

    b. The minimum tensile strength for JIS class 2 determined from a 45 mm diameter as-cast test piece is 8% below the lowest strength class in A48, class 20. Thus, to be acceptable, any casting of JIS class 2 material for which the JIS 45 mm as-cast test piece is appropriate must be shown to satisfy class 20C.

3. JIS class 3 (FC20) from JIS G5501-76 is generally equivalent in part to ASTM A48-76, classes 25, 30, and 35 based on the criterion discussed earlier, depending on the size of the as-cast test piece as follows:

   a. Class 3 material with test-piece diameters of 13 mm, 20 mm, 30 mm, and 45 mm are equivalent, respectively, to A48 classes 35S, 30A, 25B, and 25C.

4. JIS class 4 (FC25) from JIS G5501-76 is generally equivalent in part to ASTM A48-76, classes 30, 35, and 40 based on the criterion discussed earlier, depending on the size of the as-cast test piece as follows:

   a. Class 4 material with test-piece diameters of 13 mm, 20 mm, 30 mm, and 45 mm are equivalent, respectively, to A48 classes 40S, 35A, 35B, and 30C.

5. JIS class 5 (FC30) from JIS G5501-76 is generally equivalent in part to ASTM A48-76, classes 35, 40, and 45 based on the criterion discussed earlier, depending on the size of the as-cast test piece as follows:

   a. Class 5 material with test-piece diameters of 20 mm, 30 mm, and 45 mm are equivalent, respectively, to A48 classes 45A, 40B, and 35C.

6. JIS class 6 (FC35) from JIS G5501-76 is generally equivalent in part to ASTM A48-76, classes 45 and 50 based on the criterion discussed earlier, depending on the size of the as-cast test piece as follows:

   a. Class 6 material with test-piece diameters of 30 mm and 45 mm are equivalent, respectively, to A48 classes 50B and 45C.

7. The separately cast test pieces for cast iron produced to JIS G5501-76 must be cast in dried or baked molds made primarily of an aggregate of siliceous sand with appropriate binders.

   a. Test pieces shall not be cast into molds of metal, graphite, zircon, or other materials that would significantly affect the cooling rate and thus significantly change the tensile strength of the test piece.

JIS G5501-76
Equivalent to A48-76

JIS Class	JIS Diameter of As-Cast Test Piece mm	Equivalent to Individual ASTM A48 Class
2	13	25S
2	20	25A
2	30	20B
2	45	8% below 20C
3	13	35S
3	20	30A
3	30	25B
3	45	25C
4	13	40S
4	20	35A
4	30	35B
4	45	30C
5	20	45A
5	30	40B
5	45	35C
6	30	50B
6	45	45C

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MECHANICAL PROPERTIES

The determination of mechanical properties of castings requires careful control over the preparation of the test specimen. The solidification behavior of cast iron is very important because the cooling rate strongly affects the resultant casting grain size, the type and amount of the metallurgical phases present, and the extent and location of chemical segregation, shrinkage and porosity. These factors dominate the final mechanical properties of the casting in the absence of further heat treatment. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties than the component casting poured at the same time from the same heat of metal due to exaggerated differences in size.

Both ASTM A48 and JIS G5501 require the determination of mechanical properties from separately cast test bars, and thus the requirements in these two specifications do not necessarily correlate directly with expected properties of the component casting. Depending on the casting size and geometry, the properties may be higher or lower than properties measured on test bars.

Most castings have critical areas where the resultant mechanical properties control the subsequent behavior of the component. Specifications ASTM A48 and JIS G5501 provide a series of as-cast test piece sizes allowing selection of a test piece which approximates the cooling rate in the critical section of the casting in an effort to reduce the effect of the cooling rate on mechanical properties. Specification A48 recognizes as-cast specimen diameters of 22.4 mm, 30.5 mm, and 50.8 mm for a critical section thickness range of 6 mm to 50 mm while G5501 requires specimen diameters of 20 mm, 30 mm, and 45 mm for a critical section thickness range of 8 mm to 50 mm. Thus, these specimen diameters are almost the same or are within 10% while the critical thickness ranges for each test-piece closely overlap and so the requirements based on these specimens can be directly compared. A test-piece diameter of 13 mm is also required by G5501 for critical thickness of 4 mm to 8 mm while A48 does not specify a size for sections less than 6 mm thick, but requires the dimensions to be negotiated.

Finally, G5501 specifies minimum ultimate tensile strength values for each size of as-cast test-piece for each gray cast iron class while A48 has one minimum tensile strength value for each gray cast iron class independent of the test-piece diameter. Thus, the comparisons must be based on test specimen size and a given JIS class can satisfy the strength requirements for several different A48 classes.

Specification JIS G5501-76 also contains hardness and deflection test requirements. ASTM A48 no longer includes deflection test requirements but permits such properties to be negotiated.

Strength Requirements

The minimum ultimate tensile strength requirement for JIS class 1 is about 29% below the minimum value for the lowest A48 strength class, class 20.

The minimum ultimate tensile strength requirements for JIS class 2 cast iron for as-cast specimen diameters of 13 mm, 20 mm, and 30 mm satisfy the A48 requirements for classes 25S, 25A, and 20B, respectively. The JIS class 2 strength requirement for 45 mm diameter test specimens is about 8% below the minimum requirements for A48 class 20C cast iron.

The minimum ultimate tensile strength requirements for JIS class 3 cast iron for specimen diameters of 13 mm, 20 mm, 30 mm, and 45 mm satisfy or are within 5% of the A48 requirements for classes 35S, 30A, 25B, and 25C, respectively.

The minimum ultimate tensile strength requirements for JIS class 4 cast iron for specimen diameters of 13 mm, 20 mm, 30 mm, and 45 mm satisfy the A48 requirements for classes 40S, 35A, 35B, and 30C, respectively.

The minimum ultimate tensile strength requirements for JIS class 5 cast iron for specimen diameters of 20 mm, 30 mm, and 45 mm satisfy the A48 requirements for classes 45A, 40B, and 40C, respectively.

The minimum ultimate tensile strength requirements for JIS class 6 cast iron for specimen diameters of 30 mm, and 45 mm satisfy the A48 requirements for classes 50B, and 45C, respectively.

DIN 1691-64//ASTM A48-76

INTRODUCTION

The scope statements for these two specifications are very similar and refer to gray iron castings, that is, cast iron in which the graphite is present in the form of flakes. In both specifications, chemical composition is not specified except indirectly through the required presence of free or uncombined carbon as graphite.

The major design criterion for the intended applications of these products is the tensile strength. Each specification ranks the grades or classes of gray cast iron by a minimum tensile strength value and permits the chemical composition to vary in order to produce the desired strength. In addition, the generalized strength grades identified in DIN 1691 are further subdivided based on the size of the as-cast test piece from which the test specimen is taken, with each sub-grade having an individual guaranteed minimum tensile strength. In ASTM A48, however, a different approach was followed. In A48, each strength class has the same minimum tensile strength requirement regardless of the size of the as-cast test piece.

For purposes of this comparison, the acceptance criterion for the determination of equivalence is: the tensile strength requirements of DIN 1691 are considered equivalent to the requirements of ASTM A48 if the DIN value is higher than or within 5% of the A48 minimum value. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

1. DIN grade GG-10 containing materials 0.6010 and 0.6012 from DIN 1691-64 is not equivalent to any class in ASTM A48-76 because the GG-10 minimum tensile strength values are 15% or more below the lowest A48 minimum value.

2. DIN grade GG-15 from DIN 1691-64 containing materials 0.6014 and 0.6015 is generally equivalent in part to ASTM A48-76, classes 20, 25, and 30 based on the criterion discussed earlier, depending on the size of the as-cast test-piece as follows:

   a. Material 0.6014 with-test piece diameter of 30 mm is equivalent to A48 class 20B.

   b. Material 0.6015 with test-piece diameters of 13 mm, 20 mm, and 30 mm are equivalent, respectively, to A48 classes 30S, 25A, and 20B.

c. The minimum tensile strength for material 0.6015 determined from a 45 mm diameter as-cast test piece is 22% below the lowest strength class in A48, class 20. Thus, any casting of 0.6015 material for which the DIN 45 mm as-cast test-piece is appropriate would not be equivalent to A48.

3. DIN grade GG-20 from DIN 1691-64 containing materials 0.6018, 0.6020, and 0.6022 is generally equivalent in part to ASTM A48-76, classes 20, 25, 30, and 40 based on the criterion discussed earlier, depending on the size of the as-cast test-piece as follows:

   a. Material 0.6018 with a test-piece diameter of 30 mm is equivalent to A48 class 25B.

   b. Material 0.6020 with test-piece diameters of 13 mm, 20 mm, 30 mm, and 45 mm is equivalent, respectively, to A48 classes 40S, 30A, 25B, and 20C.

   c. Material 0.6022 with a test-piece diameter of 30 mm is equivalent to A48 class 30B.

4. DIN grade GG-25 from DIN 1691-64 containing materials 0.6025 and 0.6026 is generally equivalent in part to ASTM A48-76, classes 30, 35, 40, and 45 based on the criterion discussed earlier, depending on the size of the as-cast test-piece as follows:

   a. Material 0.6025 with test-piece diameters of 13 mm, 20 mm, 30 mm, and 45 mm is equivalent, respectively, to A48 classes 45S, 40A, 35B, and 30C.

   b. Material 0.6026 with a test-piece diameter of 30 mm is equivalent to A48 class 35B.

5. DIN grade GG-30 from DIN 1691-64 is generally equivalent in part to ASTM A48-76, classes 35, 40, and 45 based on the criterion discussed earlier, depending on the size of the as-cast test-piece as follows:

   a. Material with test-piece diameters of 20 mm, 30 mm, and 45 mm is equivalent, respectively, to A48 classes 45A, 40B, and 35C.

6. DIN grade GG-35 from DIN 1691-64 is generally equivalent in part to ASTM A48-76, classes 45, 50, and 55 based on the criterion discussed earlier depending on the size of the as-cast test-piece as follows:

   a. Material with test-piece diameters of 20 mm, 30 mm, and 45 mm is equivalent, respectively, to A48 classes 55A, 50B, and 45C.

7. DIN grade GG-40 from DIN 1691-64 is generally equivalent in part to ASTM A48-76, classes 50 and 55 based on the criterion discussed earlier, depending on the size of the as-cast test-piece as follows:

   a. Material with test-piece diameters of 30 mm and 45 mm is equivalent, respectively, to A48 classes 55B and 50C.

8. The separately cast test-pieces for cast iron produced to DIN 1691-64 must be cast in dried or baked molds made primarily of an aggregate of siliceous sand with appropriate binders. Test pieces shall not be cast into molds of metal, graphite, zircon, or other materials that would significantly affect the cooling rate and thus significantly change the tensile strength of the test piece.

DIN 1691-64

Equivalent to A48-76

DIN Grade	DIN Material Number	DIN Diameter of As-Cast Test Piece mm	Equivalent to Individual ASTM A48 Class
GG15	0.6014	30	20B
GG15	0.6015	13	30S
GG15	0.6015	20	25A
GG15	0.6015	30	20B
GG15	0.6015	45	None
GG20	0.6018	30	25B
GG20	0.6020	13	40S
GG20	0.6020	20	30A
GG20	0.6020	30	25B
GG20	0.6020	45	20C
GG20	0.6022	30	30B
GG25	0.6025	13	45S
GG25	0.6025	20	40A
GG25	0.6025	30	35B
GG25	0.6025	45	30C
GG25	0.6026	30	35B
GG30	0.6030	20	45A
GG30	0.6030	30	40B
GG30	0.6030	45	35C
GG35	0.6035	20	55A
GG35	0.6035	30	50B
GG35	0.6035	45	45C
GG40	0.6040	30	55B
GG40	0.6040	45	50C

MECHANICAL REQUIREMENTS

The determination of mechanical properties of castings requires careful control over the preparation of the test specimens. The solidification behavior of cast iron is very important because the cooling rate strongly affects the resultant casting grain size, the type and amount of the metallurgical phases present, and the extent and location of chemical segregation, shrinkage and porosity. These factors dominate the final mechanical properties of the casting in the absence of further heat treatment. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties than the component casting poured at the same time from the same heat of metal due to exaggerated differences in size.

Both ASTM A48 and DIN 1691 require the determination of mechanical properties from separately cast test bars, and thus the requirements in these two specifications do not necessarily correlate directly with expected properties of the component casting. Depending on the casting size and geometry, the properties may be higher or lower than properties measured on test bars.

Most castings have critical areas where the resultant mechanical properties control the subsequent behavior of the component. Specifications ASTM A48 and DIN 1691 provide a series of as-cast test-piece sizes allowing selection of a test piece which approximates the cooling rate in the critical section of the casting in an effort to reduce the effect of cooling rate on mechanical properties. Specification A48 recognizes as-cast specimen diameters of 22.4 mm, 30.5 mm, and 50.8 mm while DIN 1691 requires similar specimen diameters of 20 mm, 30 mm, and 45 mm. Thus, these specimen diameters are almost the same or within 10% of each other and so the requirements based on these specimens can be directly compared. A test-piece diameter of 13 mm is also permitted by DIN 1691 while A48 does not specify this size but allows dimensions to be negotiated for thin section thickness less than 6 mm.

Finally, DIN 1691 specifies minimum ultimate tensile strength values for each size of as-cast test piece for each gray cast iron grade while A48 has one minimum tensile strength value for each gray cast iron class independent of the test-piece diameter. Thus, the comparisons must be made based on test specimen size and a given DIN class can satisfy the strength requirements for several different A48 classes.

Specification DIN 1691 also contains deflection test requirements. ASTM A48 no longer includes deflection test requirements but permits such properties to be negotiated.

Strength Requirements

The minimum ultimate tensile strength requirement for DIN grade GG-10 is 15% or more below the minimum value for the lowest A48 strength class, class 20.

The minimum ultimate tensile strength requirements for DIN grade GG-15 cast iron for as-cast specimens diameters of 30mm (material 0.6014), 13 mm, 20 mm, and 30 mm satisfy the A48 requirements for classes 20B (material 0.6014), 30S, 25A, and 20B, respectively. The DIN grade GG-15 strength requirement for 45 mm diameter test specimens is about 22% below the minimum requirement for the lowest A48 strength class, class 20.

The minimum ultimate tensile strength requirements for DIN grade GG-20 cast iron for specimen diameters of 30 mm (material 0.6018), 13 mm, 20 mm, 30 mm, 45 mm, and 30 mm (material 0.6022) satisfy the A48 requirements for classes 25B (material 0.6018), 40S, 30A, 25B, 20C, and 30B (material 0.6022), respectively.

The minimum ultimate tensile strength requirements for DIN grade GG-25 cast iron specimen diameters of 13 mm, 20 mm, 30 mm, 45 mm, and 30 mm (material 0.6026) satisfy the A48 requirements for classes 45S, 40A, 35B, 30C, and 35B (material 0.6026), respectively.

The minimum ultimate tensile strength requirements for DIN grade GG-30 cast iron for specimen diameters of 20 mm, 30 mm, and 45 mm satisfy the A48 requirements for classes 45A, 40B, and 35C, respectively.

The minimum ultimate tensile strength requirements for DIN grade GG-35 cast iron for specimen diameters of 20 mm, 30 mm, and 45 mm satisfy the A48 requirements for classes 55A, 50B, and 45C, respectively.

The minimum ultimate tensile strength requirements for DIN grade GG-40 cast iron for specimen diameters of 30 mm and 45 mm satisfy the A48 requirements for classes 55B and 50C, respectively.

JIS H5111-76//ASTM B584-79

INTRODUCTION

The scope statements for these two specifications are similar and refer to copper casting alloys. Specification ASTM B584-79 applies only to copper alloys suitable for sand castings while JIS H5111-76 covers bronze castings for general use without regard to casting method. However, comparisons are not carried out based on descriptive words such as bronze, brass, tin bronze, semi-red brass, etc. which do not always have precise meanings. All of the alloy types specified in B584 are further referenced in ASTM B30-79 as copper-base alloys in ingot form. As a result of the complex alloy designations for copper alloys, the ASTM specifications identify each grade or type by a UNS number (Unified Numbering System) and these UNS numbers will generally be referred to in this analysis. The UNS number for copper alloys is designated by a "C" prefix followed by a five-digit number.

The major design criteria for the intended applications of these products are the static strength properties, and because these products are castings, the associated criteria of pressure tightness and surface quality. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique material parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS H5111 are considered equivalent to the requirements of ASTM B584 if the JIS values are higher than or within 5% of the B584 minimum value; (2) the percent elongation requirements of JIS H5111 are considered equivalent to the requirements of ASTM B584 if the JIS values are higher than or within 15% of the B584 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the JIS minimum requirement, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

There are many copper alloy casting grades which are distinguished primarily by small differences in chemical composition. In carrying out this comparison, a high level of agreement in chemical composition is required before further determinations of equivalence are made.

CONCLUSIONS

(1) JIS class 3 alloy from JIS H5111-76 is not equivalent to any grade in ASTM B584-79 because the JIS chemical composition ranges for all of the major alloying elements do not satisfy the requirements in B584. This JIS class, based on chemical composition, is equivalent to a Copper Development Association grade C92400, a leaded tin bronze.

(2) JIS class 2 alloy from JIS H5111-76 is generally equivalent to alloy C90300 in ASTM B584-79, based on the criteria discussed earlier, subject to the following limitations:

  (a) The maximum aluminum and silicon levels should each be limited to 0.005 percent to enhance pressure tightness and surface quality.

  (b) The minimum JIS ultimate tensile strength is slightly more than 10% below the B584 minimum. The use of a JIS specimen that is somewhat larger than the ASTM specimen combined with the strong influence of test specimen size on strength and ductility would tend to reduce this difference. To be acceptable, JIS class 2 must be shown to fall within the ultimate tensile strength acceptance criterion.

(3) JIS class 6 alloy from JIS H5111-76 is generally equivalent to alloy C83600 in ASTM B584-79, based on the criteria discussed earlier, subject to the following limitations:

  (a) The maximum aluminum and silicon levels should each be limited to 0.005 percent to enhance pressure tightness and surface quality.

  (b) The JIS minimum percent elongation requirement is about 26% below the B584 minimum requirement. However, specimen size and chemical composition, especially impurity levels, have a major influence on measured mechanical properties of casting alloys. To be acceptable, JIS class 6 must be shown to fall within the percent elongation acceptance criterion.

(4) JIS class 7 alloy from JIS H5111-76 is not generally equivalent to alloy C92200 in ASTM B584-79 because the JIS minimum ultimate tensile strength and minimum percent elongation values are about 8% and 27%, respectively below the B584 minimum requirements. However, as a result of the major influence of both specimen size and chemical composition, especially impurity levels, on measured mechanical properties of casting alloys, mechanical property comparisons are less exact: To be acceptable based on the criteria discussed earlier, JIS class 7 must satisfy the following limitations:

(a) The maximum aluminum and silicon levels should each be limited to 0.005 percent to enhance pressure tightness and surface quality.

(b) Class 7 material must satisfy the ultimate tensile strength acceptance criterion and the elongation acceptance criterion.

(5) JIS class 1 alloy from JIS H5111-76 is not generally equivalent to alloy C84400 in ASTM B584-79 because the JIS minimum ultimate tensile strength and minimum percent elongation values are about 16% and 21%, respectively, below the B584 minimum requirements. However, as a result of the major influence of both specimen size and chemical composition, especially impurity level, on measured mechanical properties of casting alloys, mechanical property comparisons are less exact. To be acceptable based on the criteria discussed earlier, JIS class 1 must satisfy the following limitations:

(a) The maximum aluminum and silicon levels should each be limited to 0.005 percent to enhance pressure tightness and surface quality.

(b) Class 1 material must satisfy the ultimate tensile strength acceptance criterion and the elongation acceptance criterion.

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CHEMICAL REQUIREMENTS

The chemical compositional ranges for the major alloying elements copper, tin, lead, and zinc in JIS class 2, class 6, and class 7 alloys are identical to or very closely overlap the ASTM B584 requirements for alloys C90300, a tin bronze, C83600, a leaded red brass, and C92200, a leaded tin bronze, respectively. The maximum total impurity levels permitted in these three JIS classes are very close to the sum of the maximum levels for nickel, antimony, iron, phosphorus, and sulfur specified in B584 for the three corresponding alloys.

The chemical compositional range for the major alloying elements copper, tin, and zinc in JIS class 1 alloy very closely overlap the ASTM B584 requirements for these elements in alloy C84400, a semi-red brass. The lead compositional range specified in JIS class 1 (3.1% to 7.0%), however, only partially overlaps the B584 requirement for alloy C84400 (6.0% to 8.0%). The lead is almost totally insoluble in this alloy and exists as isolated particles in the solid matrix. Further, this lead-rich phase is the last to solidify and is believed to fill in some of the interdendritic porosity common to semi-red brasses. Thus, the primary function of lead is to improve machinability and to enhance pressure tightness so that the somewhat lower lead range in JIS class 1 is not inconsistent with the requirements of alloy C84400 in B584 within these possible limitations. The total impurity level specified for class 1 is similar to and consistent with the sum of the maximum levels for nickel, antimony, iron, phosphorus, and sulfur specified in B584 for alloy C84400.

Aluminum and silicon are generally very harmful impurities in many copper casting alloys, including tin bronzes (i.e. C90300), semi-red brasses (i.e. C84400), leaded red brasses (i.e. C83600), and leaded tin bronzes (i.e. C92200), and must be limited to extremely low concentrations. Aluminum strongly influences the solidification behavior of these alloys resulting in a greater proability of lead sweating, loss of pressure tightness, and a decrease in ductility. Silicon enhances metal-mold reactions and lead sweating, degrading surface quality and reducing mechanical properties, such as ductility. The maximum aluminum and silicon contents permitted by B584 alloys are very low but are not specified in JIS H5111 for any class material. The strong influence on properties by aluminum and silicon contamination suggests that limits should be specified for JIS classes which satisfy the other chemical compositional limits.

The chemical compositional range for JIS H5111 class 3 alloy does not satisfy the requirements for any alloy in ASTM B584. However, this JIS alloy is equivalent, based on chemical composition, to a Copper Development Association alloy, C92400, a leaded tin bronze.

MECHANICAL REQUIREMENTS

The determination of mechanical properties of castings requires careful control over the preparation of the test specimen. The solidification behavior of these chemically complex copper casting alloys is very important because the cooling rate strongly affects the resultant casting grain size, extent and location of chemical segregation, and the extent and location of shrinkage and porosity. These factors dominate the final mechanical properties of the casting. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties than the component casting poured at the same time from the same heat of metal as a result of exaggerated differences in size.

Both ASTM B584 and JIS H5111 require the determination of mechanical properties from separately cast test bars, and thus the requirements for these two specifications do not necessarily correlate directly with expected properties of the component casting. Depending on the casting size and geometry, the properties may be higher or lower than properties measured on test bars. Further, the mechanical properties of test bars of varying sizes would be expected to behave in a similar manner. The cross-sectional areas of the B584 specimen blanks (refer to ASTM B208-75) range from about 180 mm^2 to 200 mm^2 or a diameter range of about 15 mm to 16 mm. The cross-sectional area of the JIS specimen blank is 3/4 mm^2 with a diameter of 20 mm, larger than the ASTM test bar. In some alloys, this size difference could result in lower ultimate tensile strength, yield strength and percent elongation values for the larger test bar.

Strength Requirements

The minimum ultimate tensile strength values for JIS classes 1 and 2 fall about 16% and 11%, respectively, below the B584 minimum values for alloys C84400 and C90300. The minimum ultimate tensile strength values for JIS classes 6 and 7 fall about 5% and 8%, respectively, below the B584 minimum values for alloys C83600 and C92200. Although JIS H5111 does not specify minimum yield strength values for any class, the expected yield strength values for the JIS classes would probably fall below the B584 minimum values in a manner similar to the ultimate tensile strength behavior.

Ductility Requirements

The JIS test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 3.54 while the ASTM test specimen (see ASTM B208-75) has a circular cross-section with a gage length-to-diameter ratio of 4. Using the relationship between gage length and cross-sectional area, the equivalent JIS elongation value would be larger, about 102% of the ASTM value.

The minimum percent elongation requirement for JIS class 2 is less than 3% below the minimum B584 requirement for alloy C90300. The minimum percent elongation requirements for JIS class 1, class 6, and class 7 are about 21%, 26%, and 27%, respectively, below the minimum B584 requirements for alloys C84400, C83600, and C92200.

DIN 1705-73//ASTM B584-79

INTRODUCTION

The scope statements for these two specifications are similar and refer to copper alloys for castings. Specification ASTM B584-79 applies only to copper alloys suitable for sand castings while DIN 1705-73 includes alloys for sand castings, centrifugal castings, and continuous castings. All of the alloy types specified in B584 are further referenced in ASTM B30-79 as copper-base alloys in ingot form. As a result of the complex alloy designations for copper alloys, the ASTM specifications identify each grade or type by a UNS number (Unified Numbering System) and these UNS numbers will generally be referred to in this analysis. The UNS number for copper alloys has a "C" prefix followed by a five-digit number.

The major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength, and because these products are castings, the associated criteria of pressure tightness and surface quality. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 1705 are considered equivalent to the requirements of ASTM B584 if the DIN values are higher than or within 5% of the B584 minimum value; (2) the percent elongation requirements of DIN 1705 are considered equivalent to the requirements of ASTM B584 if the DIN values are higher than or within 15% of the B584 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the DIN minimum requirement, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

There are many copper alloy casting grades which are distinguished primarily by small differences in chemical composition. In carrying out this comparison, a high level of agreement in chemical composition is required before further determinations of equivalence are made.

CONCLUSIONS

(1) The DIN grades G-CuSn12 (2.1052.01) and G-CuSn12Ni (2.1060.01) from DIN 1705-73 are not equivalent to any grade in ASTM B584-79 because the DIN chemical composition ranges for the major alloying elements do not satisfy the requirements in B584. These two DIN grades are equivalent, based on chemical composition requirements, to sand casting grades found in another ASTM specification, ASTM B427-76, for bronze gear castings.

(2) The DIN grades G-CuSn12Pb (2.1061.01) and G-CuSn10 (2.1050.01) from DIN 1705-73 are not equivalent to any grade in ASTM B584-79 because the DIN chemical composition ranges for the major alloying elements do not satisfy the requirements in B584. These two DIN grades are equivalent, based on chemical composition requirements, to continuous casting grades found in another ASTM specification, ASTM B505-76, for copper alloy continuous castings.

(3) DIN grade G-CuSn10Zn (2.1086.01) from DIN 1705-73 is not equivalent to any grade in ASTM B584-79 because the DIN chemical composition ranges for all of the major alloying elements do not satisfy the requirements in B584. This DIN grade, based on chemical composition, is equivalent to a Copper Development Association grade C92400, a leaded tin bronze.

(4) DIN grade G-CuSn7ZnPb (2.1090.01) from DIN 1705-73 is generally equivalent to alloy C93200 in ASTM B584-79, based on the criteria discussed earlier, subject to the following limitation:

    (a) The maximum aluminum and silicon levels should be limited to 0.005 percent to improve pressure tightness and surface quality.

(5) DIN grade G-CuSn5ZnPb (2.1096.01) from DIN 1705-73 is generally equivalent to alloy C83600 in ASTM B584-79, based on the criteria discussed earlier, subject to the following limitation:

    (a) The maximum aluminum and silicon levels should be limited to 0.005 percent to improve pressure tightness and surface quality.

CHEMICAL REQUIREMENTS

The chemical compositional ranges for the major alloying elements copper, tin, lead, and zinc in DIN grades G-CuSn7ZnPb (2.1090.01) and G-CuSn5ZnPb (2.1096.01) are identical to or very closely overlap the ASTM B584 requirements for alloys C93200, a high lead tin bronze, and C83600, a leaded red brass, respectively. The somewhat higher permitted nickel content for the two DIN grades could result in slightly higher strength levels for these grades compared to the two B584 alloys but this difference is not inconsistent with the overall chemical requirements for C93200 and C83600. The maximum levels for the minor elements antimony, iron, phosphorus, and sulfur in the two DIN grades are the same or very close to the maximum levels permitted by C93200 and C83600.

Aluminum and silicon are generally very harmful impurities in many copper casting alloys, including leaded red brasses (i.e. C83600) and leaded tin bronzes (i.e. C93200) and must be limited to extremely low concentrations. Aluminum strongly influences the solidification behavior of these alloys resulting in the greater likelihood of lead sweating, loss of pressure tightness, and a decrease in ductility. Silicon enhances metal-mold reactions and lead sweating, degrading surface quality and reducing mechanical properties, such as ductility. The maximum aluminum and silicon contents permitted by alloys C93200 and C83600 are very low but are not specified in any alloy grades in DIN 1705. The strong influence on properties by aluminum and silicon contamination of B584 alloy C93200 and C83600 suggests that limits should be specified for DIN grades which satisfy the other chemical compositional limits.

The chemical compositional ranges for the other grades in DIN 1705, including G-CuSn12 (2.1052.01), G-CuSn12Ni (2.1060.01), G-CuSn12Pb (2.1061.01), G-CuSn10 (2.1050.01), G-CuSn6ZnNi (2.1093.01), G-CuSn2ZnPb (2.1098.01), and G-CuSn10Zn (2.1086.01) do not satisfy the chemical requirements for any alloys in B584. Many of these DIN grades, however, are equivalent, based on chemical composition, to alloys identified in other ASTM specifications.

MECHANICAL PROPERTIES

The determination of mechanical properties of castings requires careful control over the preparation of the test specimen. The solidification behavior of these chemically complex copper casting alloys is very important because the cooling rate strongly affects the resultant casting grain size, extent and location of chemical segregation, and the amount and location of shrinkage and porosity. These factors dominate the final mechanical properties of the casting. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties from the component casting poured at the same time from the same heat of metal as a result of exaggerated differences in size.

Both ASTM B584 and DIN 1705 require the determination of mechanical properties from separately cast test bars, and thus the requirements for these two specifications do not necessarily correlate directly with expected casting properties. Depending on the casting size and geometry, the properties of the casting may be higher or lower than properties measured on test bars. The cross-sectional areas of the B584 test bars (refer to ASTM B208-75) range from about 180 mm^2 to 200 mm^2 or a diameter range of about 15 mm to 16 mm while DIN 1705 permits a range of cross-sectional areas from about 100 mm^2 to 250 mm^2 or a diameter range of about 11 mm to 18 mm. For purposes of this comparison, it is assumed that the results from the ASTM and DIN test bars can be directly compared because the DIN size range overlaps the ASTM range.

The basis for determining yield strength varies slightly between B584 and DIN 1705. The B584 yield strength value is calculated for a strain of 0.5% while the DIN yield strength is calculated at 0.2% strain. Thus the B584 yield strength value would be equal to or somewhat higher than the DIN value.

Strength Requirements

The minimum ultimate tensile strength and yield strength values for DIN G-CuSn7ZnPb (2.1090.01) exceed the minimum requirements for B584 alloy C93200. The minimum ultimate tensile strength value for DIN G-CuSn5ZnPb (2.1096.01) exceeds the minimum requirement for B584 alloy C83600 while the DIN minimum yield strength value, based on 0.2% strain, is probably within 5% of the C83600 alloy requirement, based on 0.5% strain.

Ductility Requirements

The DIN test specimen has a circular cross-section with a constant gage length to diameter ratio of 5 while the ASTM test specimen (see ASTM B208-75) has a circular cross-section with a gage length to diameter ratio of 4. Based on the relationship between gage length and cross-sectional area, the equivalent DIN elongation value would be about 96% of the ASTM value.

The minimum percent elongation requirement for DIN G-CuSn7ZnPb satisfies the minimum requirement for B584 alloy C93200 while the minimum requirement for DIN G-CuSn5ZnPb is 5% below the minimum B584 requirement for alloy C83600.

JIS H3250-77//ASTM B124-79

INTRODUCTION

Although the scope statements from these two specifications refer to copper and copper alloys, primarily in the form of rod and bar, the focus of each document is different. Specification ASTM B124-79 identifies a group of 15 alloys capable of being hot forged by various methods. These alloys, prior to being forged, are normally available in several tempers depending on method of fabrication, i.e. as hot extruded. Since these alloys are intended to be subsequently forged, only chemical requirements are specified because the mechanical properties of any forging are influenced by size and shape. Thus acceptance of material under B124 is based on chemistry together with such physical characteristics as length and straightness. Specification ASTM B283-77 covers the requirements of 13 of the alloys in B124 for die forgings produced by the hot pressing method. Again, mechanical properties are generally not specified although typical properties for these alloys in the as-forged condition are quoted for reference. (When three of the alloys are specified as forgings to meet ASME Boiler and Pressure Vessel Code requirements reduced tensile requirements are given as part of the Supplementary Requirements section.)

Specification JIS H3250, however, covers copper and copper alloy rod and bar fabricated as extruded rod, drawn rod, or forged rod. Appropriate mechanical property requirements together with chemical requirements are assigned to each alloy based on method of fabrication and temper. A more appropriate comparison would be between JIS H3250 and the individual alloy ASTM specifications for rod and bar, such as ASTM B21 Nabal Brass Rod, Bar, and Shapes; ASTM B133 Copper Rod, Bar, and Shapes; ASTM B150 Aluminum Bronze Rod, Bar, and Shapes; etc. These individual alloy specifications contain in addition to the chemical requirements, mechanical property requirements based on temper. Therefore, the present analysis is limited primarily to the chemical requirements of B124.

The comparisons were not carried out based on descriptive words such as naval brass, aluminum bronze, high silicon bronze, etc. which do not always have the same precise meaning. There are many wrought copper alloys which are distinguished primarily by small differences in chemical composition. In carrying out this comparison, a high level of agreement in chemical composition is required. As a result of the complex alloy designations for copper alloys, the ASTM specifications identify each grade or type by a UNS number (Unified Numbering System) and these UNS numbers will usually be referred to in this analysis. The UNS number for copper alloys is designated by a "C" prefix followed by a five-digit number.

Material furnished under specification B124-79 must conform to the applicable requirements of ASTM B249-79, General Requirements for Wrought Copper and Copper-Alloy Rod, Bar, and Shapes. (The appropriate edition of B249 to use is that edition concurrent with the edition of B124 of interest.)

CONCLUSIONS

(1) JIS class C1100 from JIS H3250-77 is generally equivalent to alloy C11000, electrolytic tough pitch copper, in ASTM B124-79 based on chemical requirements.

(2) JIS class C3603 from JIS H3250-77 is generally equivalent to alloy C37700, forging brass, in ASTM B124-79 based on chemical requirements.

(3) JIS class C4641 from JIS H3250-77 is generally equivalent to alloy C48200, medium leaded naval brass, in ASTM B124-79 based on chemical requirements.

(4) JIS class C6161 from JIS H3250-77 is generally equivalent to alloy C62300, aluminum bronze, in ASTM B124-79 based on chemical requirements.

(5) JIS class C6191 from JIS H3250-77 is generally equivalent to alloy C61900, aluminum bronze, in ASTM B124-79 based on chemical requirements, subject to the following limitation:

   (a) The maximum lead content should be limited to 0.02 percent to maintain ductility for working operations.

(6) The JIS classes C1020, C1201, C1220, C2600, C2700, C2800, C3601, and C4622 from JIS H3250-77 are not equivalent to any alloy in ASTM B124-79 because the JIS chemical composition ranges for the major alloying elements do not satisfy the requirements in B124. These JIS classes are equivalent based on chemical composition requirements to alloys found in other ASTM specifications.

(7) JIS class C3712 from JIS H3250-77 is not equivalent to any alloy in ASTM B124-79 because the JIS chemical composition ranges for all of the major alloying elements do not satisfy the requirements in B124. This JIS class, based on chemical composition, is generally equivalent to a Copper Development Association grade C37100, a leaded brass.

(8) JIS classes C1221, C3602, C3604, C3771, C6241, C6782, and C6783 from JIS H3250-77 are not equivalent to any alloy in ASTM B124-79 because the JIS chemical composition ranges for the major alloying elements do not satisfy the requirements in B124.

JIS H3250-77//ASTM B124-79

CHEMICAL REQUIREMENTS

The chemical compositional requirement for JIS class C1100 alloy is identical to the ASTM B124 requirement for alloy C11000, electrolytic tough pitch copper.

The chemical compositional ranges for the major alloying elements copper, lead, iron, zinc, aluminum, manganese, and nickel in JIS class C4641 and class C6161 alloys are identical to or very closely overlap the ASTM B124 requirements for alloys C48200, a medium leaded naval brass, and C62300, an aluminum bronze, respectively. The maximum levels of manganese and nickel in JIS class C6161 exceed the limits in C62300 from B124. These higher JIS limits for manganese, used primarily as a secondary alloying element for modifying the grain structure, and nickel, used for increasing strength and hardness, are not inconsistent with the requirements of B124.

The chemical compositional ranges for the major alloying elements copper, lead, iron, zinc, aluminum, manganese, and nickel in JIS class C3603 and Class C6191 alloys are within or closely overlap the ASTM B124 requirements for alloys C37700, forging brass, and C61900, an aluminum bronze, respectively. The maximum levels of nickel and manganese in JIS class C6191 exceed the limits in C61900 in B124. The somewhat higher JIS limits for manganese and nickel are not inconsistent with the requirements of B124. A maximum level for lead is specified for C61900 in B124 and is not specified in JIS class C6191. Lead will severely reduce the ductility of this alloy during working operations and thus should be limited.

The chemical compositional ranges for the other classes in JIS H3250, including C1020, C1201, C1220, C1221, C2600, C2700, C2800, C3601, C3602, C3604, C3712, C3771, C4622, C6241, C6782, and C6783 do not satisfy the chemical requirements for any alloys in ASTM B124. Many of these JIS classes, however, are equivalent based on chemical composition to alloys identified in other ASTM specifications.

MECHANICAL REQUIREMENTS

Mechanical property requirements are not specified in ASTM B124 because these alloys are intended to be subsequently forged and thus their final properties will depend on various forging parameters. The use of these alloys in rod and bar form as the final shape is described in a number of other ASTM specifications for the specific copper alloys indentified in B124. These additional specifications containing mechanical property requirements are listed in the general requirement specification for copper alloy rod, bar, and shapes, ASTM B249-79. The JIS specification, H3250, covers a variety of copper alloys in rod and bar form in their as-fabricated condition, i.e. extruded, drawn, and forged and includes both chemical and mechanical requirements. The comparison between ASTM B124 and JIS H3250, therefore, can only be made based on chemical composition. A more appropriate comparison would be between the individual alloy specifications listed in B249 and JIS H3250.

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JIS H3300-77//ASTM B88-78

INTRODUCTION

The scope statement for these two specifications are similar and refer to seamless copper pipes and tubes. Specification ASTM B88-78 applies only to copper tubes for general plumbing applications while JIS H3300 includes all copper and copper alloy seamless pipes and tubes in two quality grades for many applications in both ambient and elevated temperature environments. Both specifications permit tubing to be supplied in the annealed or drawn condition in both coils and straight lengths. As a result of the complex alloy designations for copper alloys, the ASTM specification identifies each grade or type by a UNS number (Unified Numbering System) and these UNS numbers will generally be referred to in this analysis. The UNS number for copper alloys is designated by a "C" prefix followed by a five-digit number.

The major design criteria for the intended applications of these products are the static strength properties and hardness as well as qualitative tests for material soundness and pressure tightness. These qualitative tests include expansion and flattening tests, hydrostatic tests, and eddy-current tests.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS H3300 are considered equivalent to the requirements of ASTM B88 if the JIS values exceed or are within 5% of the B88 maximum or minimum values; and (2) the hardness requirements of JIS H3300 are considered equivalent to the requirements of B88 if the JIS values are within 5% of the B88 maximum or minimum values; and (3) JIS H3300 pipe to be equivalent must satisfy the qualitative test requirements of B88. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

There are many wrought copper and copper alloy grades which are distinguished primarily by small differences in chemical composition. In carrying out this comparison, a high level of agreement in chemical composition is required.

CONCLUSIONS

(1) JIS class C1020TS, Special Grade, and class C1220TS, Special Grade, from JIS H3300-77 in coiled form and the 0 temper or annealed condition are generally equivalent to ASTM B88-78 alloys C10200 and C12200 in coiled form and the 0 temper or annealed condition based on the criteria discussed earlier, subject to the following limitations:

(a) JIS class C1020TS and C1220TS tube should be in the 0 temper or annealed condition after coiling.

(b) If acceptance is based on hardness measurements, JIS tubes greater than 25 mm outside diameter must be subjected to the hardness test.

(c) If the JIS eddy-current test is used to satisfy the nondestructive test requirements of B88, the correlation between the JIS and ASTM techniques must be established.

(1) JIS tube greater than 50 mm outside diameter must be tested.

(d) If the JIS hydrostatic test is used to satisfy the nondestructive test requirements of B88, all JIS diameter tubes must be hydrostatically tested except for those sizes specified in B88 that may be pneumatically tested.

(2) JIS class C1020TS, Special Grade, and class C1220TS, Special Grade, from JIS H3300-77 in straight length form and the OL temper condition are generally equivalent to ASTM B88-78 alloys C10200 and C12200 in straight length form and the 0 temper or annealed condition based on the criteria discussed earlier, subject to the following limitations:

(a) If acceptance is based on hardness measurements, JIS tube greater than 25 mm outside diameter must be subjected to the hardness test.

(b) If the JIS eddy-current test is used to satisfy the nondestructive test requirements of B88, the correlation between the JIS and ASTM techniques must be established.

(1) JIS tube greater than 50 mm outside diameter must be tested.

(c) If the JIS hydrostatic test is used to satisfy the nondestructive test requirements of B88, all JIS diameter tubes must be hydrostatically tested except for those sizes specified in B88 that may be pneumatically tested.

(3) JIS class C1020TS, Special Grade, and class C1220TS, Special Grade, from JIS H3300-77 in straight length form and the H temper or drawn condition are generally equivalent to ASTM B88-78 alloys C10200 and C12200 in straight length form and the H temper condition based on the criteria discussed earlier, subject to the following limitations:

(a) If acceptance is based on hardness measurements, JIS tube greater than 25 mm outside diameter must be subjected to the hardness test.

(b) If the JIS eddy-current test is used to satisfy the nondestructive test requirements of B88, the correlation between the JIS and ASTM techniques must be established.

(1) JIS tube greater than 50 mm outside diameter must be tested.

(c) If the JIS hydrostatic test is used to satisfy the nondestructive test requirements of B88, all JIS diameter tubes must be hydrostatically tested except those sizes specified in B88 that may be pneumatically tested.

(4) JIS class C1100 from JIS H3300-77 is not equivalent to ASTM B88-78 because the JIS chemical composition range for copper does not satisfy the requirements of any grade in B88. This JIS class is equivalent to grade C11000 found in ASTM specification, ASTM B188-75, Seamless Copper Bus Pipe and Tube.

(5) JIS class C1201 and class C1221 from JIS H3300-77 are not equivalent to ASTM B88-78 because the JIS chemical composition range for copper does not satisfy the requirements of any grade in B88. These two classes do not correspond to any UNS numbered grade.

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JIS H3300-77//ASTM B88-78

CHEMICAL REQUIREMENTS

The basic chemical composition limits for B88 are limited to almost pure copper and phosphorized copper grades with a minimum copper content of at least 99.9 weight percent. Five UNS grades are identified as being interchangeable, differing only in the residual phosphorus levels. The chemical composition limits for JIS class C1020 and class C1220 are essentially identical to the B88 composition limits for UNS grades C10200 and C12200. The chemical composition requirements for the other classes in JIS H3300, including C1100, C1201, C1221, C2200, C2300, C2600, C2700, C2800, C6561, C4430, C6870, C6871, C6872, C7060, C7100, and C7150, do not satisfy the chemical requirements for the other UNS grades in ASTM B88.

For ASTM alloy C10200, specification B88 requires a microscopic examination to insure the absence of cuprous oxide. The presence of cuprous oxide enhances the susceptibility of the alloy to hydrogen embrittlement. Dexodized coppers (e.g. C12200) are generally not subject to hydrogen embrittlement. Although specification JIS H3300 does not require an examination for cuprous oxide, a specific test for hydrogen embrittlement is required, and thus is consistent with the requirement in B88.

HEAT TREATMENT

Specification B88 requires the seamless copper tube to be furnished in one of two temper conditions: annealed-0 or drawn-H. Coiled tube must be annealed after coiling while straight lengths are normally in the drawn condition but may also be in the annealed condition. Specification JIS H3300 also calls for tube to be furnished in a number of temper conditions included drawn-H and two annealed designations 0 and OL. However, JIS H3300 does not distinguish between coils and straight lengths and temper condition. Thus, to be equivalent, the JIS classes in the coiled form should be annealed while straight lengths can be either as drawn or annealed.

DIMENSIONAL TOLERANCE

Specification B88 contains standard tube sizes from nominal 1/4 inch outside diameter to nominal 12 inch outside diameter in three standard wall thickness types: Type K, Type L, and Type M. Dimensional tolerance requirements are specified for the outside diameter, wall thickness, and roundness for all three types. Specification JIS H3300 includes two quality grades based on dimensional tolerance requirements: Common Grade and Special Grade. The JIS Special Grade dimensional tolerance requirements for wall thickness and roundness for JIS class C1020 and class C1220 satisfy the B88 requirements for Type K, Type L, and Type M pipe. The JIS outside diameter dimensional tolerance requirements for JIS Type K, Type L, and Type M pipe for class C1020 and class 1220 satisfy the B88 requirements for Type K, Type L, and Type M pipe in both the annealed and drawn condition.

MECHANICAL PROPERTIES

Strength and Hardness Requirements

Specification B88 requires either the strength and grain size requirement or the hardness requirements to be satisfied for annealed tube. For drawn tube, either the strength or hardness requirement must be satisfied. Specification JIS H3300, however, requires tension tests for class C1020 and class C1220 in both the annealed temper and drawn temper. Hardness tests are optional for both classes in both the annealed temper and drawn temper. Grain size measurements are optional for the annealed temper for both JIS classes. However, when hardness tests are required, tension tests need not be performed. For purposes of this comparison, the strength and hardness requirements will be assumed to be mandatory.

The minimum ultimate tensile strength requirements for JIS class C1020 and class C1220 tube in the annealed or 0 and 0L temper conditions slightly exceed the B88 minimum requirements for UNS alloys C10200 and C12200 in the 0 temper or annealed condition. The minimum ultimate tensile strength requirements for JIS class C1020 and class C1220 tube in the drawn or H temper condition substantially exceed the B88 minimum requirements for UNS alloys C10200 and C12200 in the H temper condition.

The maximum allowed hardness for JIS class C1020 and class C1220 tube in the 0 temper condition is identical to the B88 requirements for alloys C10200 and C12200 in coil form in the 0 temper condition. The maximum allowed hardness for JIS class C1020 and class C1220 tube in the 0L temper condition is identical to the B88 requirement for alloys C10200 and C12200 in straight lengths in the 0 temper condition. The minimum required hardness for JIS class C1020 and C1220 in the drawn or H temper condition for tube 25 mm or less in outside diameter substantially exceeds the minimum required hardness for the B88 alloys C10200 and C12200. This is consistent with the comparison of the minimum ultimate tensile strengths. For JIS class C1020 and C1220 tube greater than 25 mm diameter, a minimum hardness is not required. Since B88 allows hardness tests to replace the tension test requirements, JIS class C10200 and C12200 tube over 25 mm diameter in the H temper condition must satisfy the B88 hardness requirement if tension tests are omitted.

Grain size requirements for these alloys are used primarily to insure adequate cold formability, especially for coiled tube. Fine grain material, typically 0.025 mm or less, have a lower formability than material with grain sizes greater than 0.035 mm. Thus, B88 specifies a larger average grain size for coiled tube than for straight lengths of tube in the 0 temper condition. The JIS average grain size range requirements for classes C10200 and C12200 in the 0 temper condition overlaps the B88 minimum grain size for alloys C1020 and C1220 in coil form in the 0 temper condition. The lower grain size limit of the JIS range falls below the minimum B88 requirement. However, the JIS tensile strength and hardness requirements satisfy the B88 requirements so the lower minimum JIS grain size limit should not result in unacceptable performance. The JIS maximum grain size limit for classes

C1020 and C1220 in the OL temper condition is not inconsistent with the minimum B88 grain size requirement for straight lengths of alloys C10200 and C12200 in the 0 temper condition.

Expansion Test and Flattening Test Requirements

Specification B88 requires tubes in the 0 temper condition to be expanded on a hardened, tapered steel pin with an included angle of 60° to a 40% or 30% expansion of the outside diameter depending on the outside diameter. This qualitative test characterizes the ability of the tube to be flared for fittings. Specification JIS H3300 requires the identical test for tubes 100 mm or under in outside diameter except the more severe 40% expansion is also required on larger sizes of pipe than specified by B88

Alternatively B88 permits a flattening test for tube greater than 100 mm in diameter while 0 temper instead of the expansion test. Specification JIS H3300, however, requires the expansion test for tubes 100 mm or less in diameter and requires the flattening test for tubes greater than 100 mm in diameter in both the 0 and OL temper. Both B88 and JIS H3300 specify the identical flattening test and acceptance criteria.

Nondestructive Test Requirements

Specification B88 requires all tubes to be subjected to either an eddy-current test or a hydrostatic test. The B88 eddy-current test uses notch-depth standards as the testing criterion, while the hydrostatic test requirement permit pneumatic testing for specific sizes and tube wall thicknesses. Specification JIS H3300 contains as optional requirements the use of eddy-current, hydrostatic, or pneumatic tests on tubes 50 mm or less in outside diameter. The JIS eddy-current test uses holes as reference defects and thus cannot be directly compared to the B88 eddy-current requirements.

Both B88 and JIS H3300 use the same relationship to calculate the applied hydrostatic pressure and use the identical maximum stress in the tube wall and the identical maximum hydrostatic pressure limit. Specification B88 permits pneumatic testing of straight lengths, drawn or annealed, less than 12.7 mm in outside diameter and less than 1.52 mm wall thickness. Further, for tube furnished in coils, hydrostatic or pneumatic tests are allowed. The minimum JIS H3300 pneumatic pressure satisfies or is within 5% of the B88 minimum pressure. In JIS H3300, each of the three nondestructive tests are treated as being equally acceptable while ASTM B88 specifies the pneumatic test only for special situations. Although the JIS test acceptance criteria for the hydrostatic and pneumatic tests are identical to or satisfy the B88 requirements, the choice of test should follow the B88 requirements.

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DIN 17671-74//ASTM B88-78

INTRODUCTION

The scope statements for these two specifications are similar and refer to seamless copper tubes. Specification ASTM B88 applies only to copper tubes for general plumbing applications while DIN 17671 includes all copper and copper alloy seamless tubes. Both specifications permit tubes to be supplied in several thermo/mechanical or temper conditions.

As a result of the complex alloy designations for copper alloys, the ASTM specification identifies each grade or type by a UNS number (Unified Numbering System) and these UNS numbers will generally be referred to in this analysis. The UNS number for copper alloys is designated by a "C" prefix followed by a five-digit number.

The major design criteria for the intended applications of these products are the static strength properties and hardness as well as qualitative tests for material soundness and pressure tightness. These qualitative tests include expansion and flattening tests, hydrostatic tests, and eddy-current tests.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17671 are considered equivalent to the requirements of ASTM B88 if the DIN values exceed or are within 5% of the B88 minimum values; (2) the hardness requirements of DIN 17671 are considered equivalent to the requirements of B88 if the DIN values are within 5% of the B88 maximum or minimum values; and (3) DIN tubes to be equivalent must satisfy the qualitative test requirements of B88. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

There are many wrought copper and copper alloy grades which are distinguished primarily by small differences in chemical composition. In carrying out this comparison, a high level of agreement in chemical composition is required.

CONCLUSIONS

(1) DIN grade SW-Cu (2.0076.10) and grade SF-Cu (2.0090.10) from DIN 17671-74 in the annealed condition are generally equivalent to ASTM B88-78 alloys C12000 and C12200 in the annealed or 0-temper condition based on the criteria discussed earlier, subject to the following limitations:

(a) The average DIN grain size should satisfy the B88 requirement.

(b) The DIN hardness tests should be carried out with a scale that can be converted to the B88 hardness scale for comparison.

(c) The DIN tubes must be shown to satisfy the B88 expansion test requirements, or as an alternative test for tubes over 102 mm in diameter, the DIN tubes must satisfy the B88 flattening test.

(d) The DIN tubes must be shown to satisfy the B88 nondestructive test requirements using eddy-current, hydrostatic, or pneumatic tests as described in B88.

(2) DIN grade SW-Cu (2.0076.26) and grade SF-Cu (2.0090.26) from DIN 17671-74 in the drawn condition are generally equivalent to B88-78 alloys C12000 and C12200 in the drawn or H-temper condition based on the criteria discussed earlier, subject to the following limitations:

(a) The DIN hardness tests should be carried out with a scale that can be converted to the B88 hardness scale for comparison.

(b) The DIN tubes must be shown to satisfy the B88 nondestructive test requirements using eddy-current, hydrostatic, or pneumatic tests as described in B88.

CHEMICAL REQUIREMENTS

The basic chemical composition limits for B88 are limited to almost pure copper and phosphorized copper grades with a minimum copper content of at least 99.9 weight percent. Five UNS grades are identified as being interchangeable, differing only in the residual phosphorus levels. The chemical composition limits for copper and phosphorized copper grades are given in DIN 1787-73. The chemical composition limits for DIN grade SW-Cu (2.0076) are almost identical to the B88 composition limits for UNS grade C12000. The slightly higher residual phosphorus level in DIN SW-Cu results from the deoxidation practice followed. The chemical composition limits for DIN grade SF-Cu (2.0090) are identical to the B88 composition limits for UNS grade C12200.

Copper alloys containing residual cuprous oxide are susceptible to hydrogen embrittlement in certain environments. Specification B88 requires a microscopic inspection of tube samples for the presence of cuprous oxide in alloy C12000. Specification DIN 17671 specifies for the oxygen-free grades of copper, including grades SW-Cu and SF-Cu, the exposure of tube samples to a reducing atmosphere at elevated temperatures and then flattening the samples without cracking. The DIN test procedure which measures the susceptibility of the whole tube sample rather than the limited microscopic examination satisfies the intent of the B88 requirement.

HEAT TREATMENT

Specification B88 requires the seamless tube to be furnished in one of two temper conditions: annealed - 0 or drawn - H. Coiled tube must be annealed after coiling while straight tube lengths are normally in the drawn condition but may also be annealed. Specification DIN 17671 also calls for tube to be furnished in a number of temper conditions which are identified by appended numbers on the alloy grade code, e.g. .01 for annealed. However, DIN 17671 does not distinguish between coils, straight lengths, and temper condition, and thus DIN coiled tubes should be annealed while straight lengths can be either as-drawn or annealed.

DIMENSIONAL TOLERANCE

Specification B88 contains standard tube sizes from nominal 1/4 inch to nominal 12 inch outside diameter in three standard wall thickness types: Type K, Type L, and Type M. Dimensional tolerance requirements are specified for the outside diameter, wall thickness, roundness, and tube length for all three types.

Specification DIN 17671 through DIN 1754 contains standard tube sizes from 3 mm to 210 mm outside diameter in nine standard wall thicknesses. Dimensional tolerance requirements for roundness, tube length, wall thickness, inside diameter, and outside diameter are specified. Further, DIN 1754 specifies three tolerance categories, A, B, or C, depending on the parameters for which tolerance requirements are required. DIN tolerance level A includes the B88 required parameters of outside tube diameter and wall thickness together with the required roundness and tube length tolerances. As a result of the lack of agreement between the B88 and DIN 17671 standard sizes, one English and one metric, comparison have been carried out between similar sizes.

The DIN dimensional tolerance requirements for wall thickness, roundless, an d tube length satisfy the B88 requirements for similar sized tubes. The DIN dimensional tolerance limits for outside tube diameter exceed the B88 requirements for all tube sizes for both drawn and annealed tempers and thus do not satisfy B88. However, this deficiency generally would not affect performance and is not inconsistent with the intent of B88.

MECHANICAL PROPERTIES

Strength and Hardness Requirements

Specification B88 requires either the strength and grain size requirements or the hardness requirements to be satisfied for annealed tube. For drawn tube, either the strength or hardness requirement must be satisfied. Grain size requirements for these annealed alloys are used primarily to insure adequate cold formability, especially for coiled tube. Fine grain material, typically 0.25 mm or less, has a lower formability than material with a grain size greater than 0.035 mm. Thus, B88 specifies a larger average minimum grain size for coiled tube than for straight tube lengths. Specification DIN 17671, however, requires tension tests and hardness tests for grades SW-Cu and SF-Cu in all temper conditions but does not specify grain size requirements for the annealed temper and the hardness values are not guaranteed. For purposes of this comparison, the strength, grain size, and hardness requirements will be assumed to be mandatory.

The minimum ultimate tensile strength requirements for DIN grades SW-Cu and SF-Cu in the annealed condition (2.0076.10 and 2.0090.10) for wall thickness 3 mm or greater are 3% below the B88 requirements for UNS alloys C12000 and C12200 in the annealed temper. The minimum ultimate tensile strength requirements for DIN grades SW-Cu and SF-Cu in the annealed condition (2.0076.10 and 2.0090.10) for wall thickness less than 3 mm satisfy the B88 requirements for UNS alloys C12000 and C12200 in the annealed temper. The minimum ultimate tensile strength requirements for DIN grades SW-Cu and SF-Cu in the drawn condition (2.0076.26 and 2.0090.26) are 4% below the B88 requirements for UNS alloys C12000 and C12200 in the drawn temper.

The expected Brinell hardness values contained in DIN 17671 are based on a 2.5 mm diameter ball with an applied load of 62.5 Kg. The hardness requirements contained in B88 are based on the Rockwell F and 30T scales. ASTM E140 contains conversion tables for the Rockwell scales and Brinell scales for 2 mm balls and 20 Kg loads or 10 mm balls and 500 Kg loads for copper alloys. However, a conversion between different Brinell scales is not available and thus the DIN 17671 and B88 hardness data cannot be compared.

Expansion Test and Flattening Test Requirements

Specification DIN 17671 does not include expansion test or flattening test requirements.

Nondestructive Test Requirements

Specification DIN 17671 does not include eddy-current test or hydrostatic test requirements.

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JIS H3632-73//ASTM B111-79

INTRODUCTION

The scope statements for these two specifications are similar and refer to seamless copper and copper alloy tubes for condensers and heat exchanger applications. Specification ASTM B111-79 includes copper, brass, bronze, and copper nickel alloys in a variety of thermo/mechanical or temper conditions. Specification JIS H3632-73, however, is limited to brass alloys in the annealed condition. As a result of the complex alloy designations for copper alloys, the ASTM specification identifies each grade or type by a UNS number (Unified Numbering System) and these UNS numbers will generally be referred to in this analysis. The UNS number for copper alloys is designated by a "C" prefix followed by a five-digit number.

The major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength. In addition, qualitative tests for corrosion resistance, formability, and pressure tightness are also specified in B111. These qualitative tests include expansion and flattening tests, corrosion tests, hydrostatic tests, pneumatic tests, and eddy-current tests.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS H3632 are considered equivalent to the requirements of ASTM B111 if the JIS values exceed or are within 5% of the B111 minimum strength values; (2) the JIS tube and pipe must satisfy the qualitative test requirements of B111. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) JIS class 1, C4430TS, Special Grade, from JIS H3632-73 is generally equivalent to ASTM B111-79 alloy C44300 based on the criteria discussed earlier, subject to the following limitations:

(a) Both tension tests and a grain size determination must be conducted on the JIS alloy.

(b) To be equivalent, JIS class 1 tube must be shown to satisfy the yield strength acceptance criterion.

(c) If the JIS eddy-current test is used to satisfy the nondestructive test requirement, the ASTM hold sensitivity requirements must be satisfied.

(d) To be equivalent, JIS class 1 tube must satisfy the longer ASTM mercurous nitrate immersion test.

(2) JIS class 4, C6870TS, Special Grade, from JIS H3632-73 is generally equivalent to ASTM B111-79 alloy C68700 based on the criteria discussed earlier, subject to the following limitations.

(a) Both tension tests and a grain size determination must be conducted on the JIS alloy.

(b) To be equivalent, JIS class 4 tube must be shown to satisfy the yield strength acceptance criterion.

(c) If the JIS eddy-current test is used to satisfy the nondestructive test requirement, the ASTM hole sensitivity requirements must be satisfied.

(d) To be equivalent, JIS class 4 tube must satisfy the longer ASTM mercurous nitrate immersion test.

(3) JIS class 2, C6871TS, and class 3, C6872TS, from JIS H3632-73 are not equivalent to ASTM B111-79 because the JIS chemical composition limits do not satisfy the requirements of any grade in B111. These two classes do not correspond to any UNS numbered grade.

CHEMICAL REQUIREMENTS

The chemical composition ranges for all alloying elements in JIS class 1 (C4430) are identical to or very closely overlap the ASTM B111 requirements for alloy C44300, arsenical admiralty brass. The minimum tin level for the JIS grade is slightly below the B111 minimum requirement but this should not have an impact on the behavior of these materials. The chemical composition ranges for all alloying elements in JIS class 4 (C6870) are identical to the B111 requirements for alloy C68700, arsenical aluminum brass.

The chemical composition requirements for the other classes in JIS H3632, including class 2 (C6871) and class 3 (C6872) do not satisfy the chemical requirements for any of the other UNS grades in B111.

HEAT TREATMENT

Specification B111 specifies that alloys C44300 and C68700 are normally furnished in the annealed or 0 temper condition. Specification JIS H3632 also requires class 1 and class 4 tube to be furnished in the 0 temper condition.

DIMENSIONAL TOLERANCE

Specification B111 includes standard tube sizes up to 50 mm outside diameter. Dimensional tolerance requirements are specified for the outside diameter, wall thickness, and tube length. Specification JIS H3632 includes two quality grades for each alloy grade based on dimensional tolerance requirements: Common Grade and Special Grade. The JIS Special Grade dimensional tolerance requirements for outside diameter, wall thickness, and tube length satisfy the B111 requirements.

MECHANICAL PROPERTIES

Strength and Grain Size Requirements

Specification B111 requires both strength and grain size requirements to be satisfied for annealed tube. Specification H3632 requires one or the other, either strength requirements or grain size limits. To be considered equivalent, JIS tube must satisfy both requirements.

The minimum ultimate tensile strength for class 1 (C4430) and class 4 (C6870) exceed the B111 minimum requirement for UNS alloys C44300 and C68700. Specification JIS H3632 does not contain minimum yield strength requirements as specified by B111 for both alloys. To be acceptable, JIS class 1 and class 4 tubes must be shown to satisfy the B111 requirements.

The grain size requirements specified in both B111 and JIS H3632 are identical. Specification B111 also uses the microscopical grain size determination to insure complete recrystallization while JIS H3632 does not explicitly require evidence of recrystallization except through the specified grain size range.

Expansion Test and Flattening Test Requirements

Specification B111 requires tube specimens to be expanded on a tapered pin with an included angle of about 7° to a 20% expansion of the inside diameter without cracking, for alloys C44300 and C68700. Specification JIS H3632 requires tube specimens to be expanded about a pin with an included angle of 60° to a 25% expansion of the outside diameter. The large included angle for the tapered pin in the JIS procedure probably results in a locally greater strain gradient, and combined with the larger percent expansion based on outside diameter vs. inside diameter results in the JIS test requirement being more severe than the ASTM requirement.

Specifications B111 and JIS H3632 specify the identical flattening test requirement.

Nondestructive Test Requirements

Specifications B111 and JIS H3632 require either an eddy-current test, a hydrostatic pressure test, or a pneumatic test to fulfill the nondestructive test requirements.

Specification B111 allows either notches or holes to be used to calibrate the eddy-current equipment while JIS H3632 requires only a hole calibration. The hole calibration sensitivity in the JIS procedure is lower than in the ASTM procedure so that if the JIS eddy-current test is used for acceptance, the higher ASTM sensitivity requirements must be met.

Specifications B111 and JIS H3632 use the same relationship to compute the applied hydrostatic pressure. The JIS procedure requires a 4% higher outer fiber stress than the ASTM procedure and thus the JIS test is more severe. Both ASTM and JIS have the identical maximum hydrostatic pressure limit.

The minimum pneumatic pressure required by JIS H3632 satisfies or is within 5% of the B111 minimum pressure.

CORROSION REQUIREMENTS

Specifications B111 and JIS H3632 require tube specimens to be immersed in a mercurous nitrate solution to determine the susceptibility to stress corrosion cracking. Copper alloys containing 20% or more zinc (e.g. ASTM C44300 or JIS C4430) are highly susceptible to stress corrosion cracking. The presence of residual stresses due to incomplete annealing and recrystallization can be detected by this test through the appearance of cracks as a result of immersion.

Although there are differences in the composition of the mercurous nitrate solution, the major difference lies in the ASTM requirement for a 30 minute immersion while JIS H3632 specifies only a 15 minute immersion. Since second order effects such as grain size and microstructure can affect the rate at which cracks develop, the longer ASTM test time would provide a more conservative test of susceptibility.

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DIN 1785-67//ASTM B111-79

INTRODUCTION

The scope statements for these two specifications are very similar and refer to seamless copper and copper alloy tubes for surface condensers and heat exchanger applications. Specification ASTM B111-79 includes copper, brass, bronze, and copper nickel alloys in a variety of thermo/mechanical or temper conditions. Specification DIN 1785-67 also includes copper, brass, bronze, and copper nickel alloys but only in a stress-free condition. The DIN temper condition probably corresponds to either the stress relieved (HR50) or the annealed (0) condition.

As a result of the complex alloy designations for copper alloys, the ASTM specification identifies each grade or type by a UNS number (Unified Numbering System) and these UNS numbers will generally be referred to in this analysis. The UNS number for copper alloys is designated by a "C" prefix followed by a five-digit number.

The major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength. In addition, qualitative tests for stress corrosion resistance, formability, and pressure tightness are also specified in B111. These qualitative tests include expansion and flattening tests, corrosion tests, hydrostatic tests, pneumatic tests, and eddy-current tests.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 1785 are considered equivalent to the requirements of ASTM B111 if the DIN values exceed or are within 5% of the B111 minimum strength values; (2) the DIN tubes must satisfy the qualitative test requirements of B111. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) DIN alloys SB-Cu and SF-Cu from DIN 1785-67 are not generally equivalent to ASTM B111-79 alloys C14200 and C12200, respectively, because of the substantial difference between the permitted B111 temper conditions, various drawn conditions, and the permitted DIN temper condition, annealed.

(2) DIN alloy (CuZn 30 (2.0265) from DIN 1785-67 is not equivalent to ASTM B111-79 because the DIN chemical composition limits do not satisfy the requirements of any grade in B111. This alloy, based on chemical composition, is equivalent to UNS alloy C26000, cartridge brass, which is not included in B111.

(3) DIN alloy CuZn 28 SnF 33 (2.0470.19) from DIN 1785-67 is generally equivalent to ASTM B111-79 alloy C44300 based on the criteria discussed earlier, subject to the following limitations:

(a) The minimum DIN yield strength must be shown to satisfy the B111 acceptance criterion.

(b) All DIN tube sizes must satisfy the B111 hydrostatic test requirements.

(4) DIN alloy CuZn 20 AlF 40 (2.0460.29) from DIN 1785-67 is generally equivalent to ASTM B111-79 alloy C68700 based on the criteria discussed earlier, subject to the following limitation:

(a) All DIN tube sizes must satisfy the B111 hydrostatic test requirements.

(5) DIN alloy CuAl 5 As F35 (2.0918.19) from DIN 1785-67 is generally equivalent to ASTM B111-79 alloy C60800 based on the criteria discussed earlier, subject to the following limitation:

(a) All DIN tube sizes must satisfy the B111 hydrostatic test requirements.

(6) DIN alloy CuNi 10 FeF 30 (2.0872.19) from DIN 1785-67 is generally equivalent to ASTM B111-79 alloy C70600 in the annealed condition, based on the criteria discussed earlier, subject to the following limitations:

(a) The minimum DIN yield strength must be shown to satisfy the B111 acceptance criterion.

(b) All DIN tube sizes must satisfy the B111 hydrostatic test requirements.

(7) DIN alloy CuNi 30 FeF 37 (2.0822.29) from DIN 1785-67 is generally equivalent to ASTM B111-79 alloy C71500 in the annealed condition based on the criteria discussed earlier, subject to the following limitations:

(a) The minimum DIN yield strength must be shown to satisfy the B111 acceptance criterion.

(b) All DIN tube sizes must satisfy the B111 hydrostatic test requirements.

DIN 1785-67//ASTM B111-79

CHEMICAL REQUIREMENTS

The chemical composition ranges for the alloying elements in DIN Sb-Cu and SF-Cu alloys are identical to or very closely overlap the ASTM B111 requirements for phosphorized copper alloys C14200 and C12200, respectively. The slightly higher residual phosphorus levels permitted in the DIN alloys is a result of the deoxidation practice and is consistent with the intent of B111.

The chemical composition ranges for the alloying elements in DIN CuZn 28 Sn fall within or very closely overlap the B111 requirements for C44300, admiralty metal.

The chemical composition ranges for the alloying elements in DIN CuZn 20 AL are within or very closely overlap the B111 requirements for C68700, aluminum brass.

The chemical composition ranges for the alloying elements in DIN CuAl 5 As are within or very closely overlap the B111 requirements for C60800, aluminum bronze.

The chemical composition ranges for the alloying elements in DIN CuNi 10 Fe are identical to or within the B111 requirements for C70600, 90-10 copper nickel.

The chemical composition ranges for the alloying elements in DIN CuNi 30 Fe are identical to or within the B111 requirements for C71500, 70-30 copper nickel.

The chemical composition ranges for alloying elements in DIN CuZn 30 do not satisfy the chemical requirements for any UNS grade in B111. The chemical composition limits do satisfy the requirements for UNS alloy C26000, cartridge brass.

HEAT TREATMENT

Specification B111 requires alloys C44300, C60800, C68700 to be furnished in the annealed condition; alloy C71500 to be furnished either annealed or drawn and stress relieved; alloy C70600 to be furnished either annealed or light drawn; and alloys C12200 and C14200 to be furnished either light-drawn, hard-drawn, or hard-drawn, end annealed. Further, all B111 alloys in the annealed condition must satisfy grain size requirements.

Specification DIN 1785 requires only that all alloys be in the stress-free condition while also containing grain size requirements. The lack of clarity with regard to temper condition for the DIN alloys, either stress relieved or annealed, is not significant provided good agreement is obtained between the strength requirements and the stress corrosion tests.

DIMENSIONAL TOLERANCE

Specification B111 includes standard tube sizes up to 50 mm outside diameter. Dimensional tolerance requirements are specified for the outside diameter, wall thickness, and tube length. Specification DIN 1785 includes standard tube sizes up to 30 mm outside diameter. The DIN wall thickness tolerance limit for all wall thicknesses except 1.5 mm and 2 mm satisfy the B111 requirements. The DIN limits for 1.5 mm wall thickness tubes are 7% to 9% greater than the B111 requirements while for 2 mm wall thickness the DIN limits are 6% to 7% greater. These deficiencies should not be significant provided the B111 hydrostatic test requirements are satisfied.

The DIN outside diameter tolerance limits are within and thus satisfy the B111 diameter tolerance limits.

The DIN tube length tolerance limits for tubes less than 2.4 meters long and tubes more than 9 meters long satisfy the B111 requirements. For tubes between 2.4 meters and 9 meters in length, the DIN tolerance limits are up to 60% greater than the B111 limits. However, these differences are less than 3 mm in length and thus are not important in this comparison.

MECHANICAL PROPERTIES

Strength and Grain Size Requirements

Specifications B111 and DIN 1785 specify both strength and grain size requirements. The DIN grain size range is almost identical to the B111 requirements suggesting that the DIN tubes are in the annealed or 0 temper condition.

The minimum DIN ultimate tensile strength and yield strength values for DIN alloys SB-CuF 25 and SF-CuF 25, are 2% and 28% below the B111 and C12200 minimum requirements for alloys C14200 and C12200 in the light drawn (H55) condition. This further suggests that the DIN alloys are in the annealed condition.

The minimum DIN ultimate tensile strength for DIN alloy CuZn 28 SnF 33 satisfies the requirements of B111 for alloy C44300 while the DIN minimum yield strength is 7% below the B111 requirement.

The minimum DIN ultimate tensile strength and yield strength requirements for alloy CuZn 20 AlF 40 satisfy the B111 requirements for alloy C68700.

The minimum DIN ultimate tensile strength and yield strength requirements for alloy CuAl 5 AsF 35 satisfy the B111 requirements for alloy C60800.

The minimum DIN ultimate tensile strength for alloy CuNi 10 FeF 30 satisfies the requirements of B111 for alloy C70600 in the annealed condition while the DIN minimum yield strength is 7% below the B111 requirement.

The minimum DIN ultimate tensile strength for alloy CuNi 30 Fe satisfies the requirements of B111 for alloy C71500 in the annealed temper, while the DIN minimum yield strength is 6% below the B111 requirement.

Expansion Test and Flattening Test Requirements

Specification B111 requires tube specimens to be expanded without cracking on a tapered pin with an included angle of about 7° to a 20% or 30% expansion of the inside diameter depending on the alloy. Specification DIN 1785 requires specimens to be expanded on a pin with an included angle of 45° to a 30% expansion of the inside diameter for all alloys. The larger included angle used in the DIN test should result in a locally greater strain gradient and combined with an equal or larger expansion requirement results in a more severe test than the ASTM procedure.

Specification DIN 1785 specifies that a tube specimen be completely flattened without cracking while B111 specifies flattening a specimen only to a distance equal to three wall thicknesses, a less severe requirement.

Nondestructive Test Requirements

Specification DIN 1785 requires either an undefined eddy-current test or a hydrostatic pressure test to verify pressure tightness. Specification B111 permits either an eddy-current test, a hydrostatic pressure test, or a pneumatic test. For this analysis, the hydrostatic pressure test requirements will be compared.

The hydrostatic test pressure required in B111 is computed from a relationship between maximum surface stress, tube diameter, and wall thickness while in DIN 1785, a fixed pressure is used for all tube sizes. Only two DIN tube sizes, the 23 mm OD and 1 mm wall thickness and the 28 mm OD and 1 mm wall thickness, satisfy the B111 requirements. The test pressure for all other tube sizes are from 2% to 29% below the B111 requirements.

CORROSION REQUIREMENTS

Specifications B111 and DIN 1785 require tube specimens to be immersed in a mercurous nitrate solution to determine the susceptibility to stress corrosion cracking. The ASTM and DIN test procedures are very similar.. Copper alloys containing 20% or more zinc (e.g. C44300 and C68700) are highly susceptible to stress corrosion cracking. The presence of residual stresses due to incomplete annealing and recrystallization can be detected by this test through the appearance of cracks after immersion.

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INTRODUCTION

The scope statements for these two specifications are similar and refer to copper casting alloys. Specification ASTM B62-76 applies to one specific alloy composition, so-called ounce metal, for application as valves, flanges, and fittings while JIS H5111-76 covers bronze castings for general use without regard to casting method. However, comparisons are not carried out based on descriptive words such as bronze, brass, tin bronze, etc. which do not always have precise meanings. As a result of the complex alloy designations for copper alloys, the ASTM specifications identify each grade or type by a UNS number (Unified Numbering System) and these UNS numbers will generally be referred to in this analysis. The UNS number for copper alloys is designated by a "C" prefix followed by a five-digit number.

The major design criteria for the intended applications of these products are the static strength properties, and because these products are castings, the associated criteria of pressure tightness and surface quality. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique material parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of JIS H5111 are considered equivalent to the requirements of ASTM if the JIS values are higher than or within 5% of the B62 minimum value; (2) the percent elongation requirements of JIS H5111 are considered equivalent to the requirements of ASTM B62 if the JIS values are higher than or within 15% of the B62 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected JIS elongation values would normally exceed the JIS minimum requirement, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

There are many copper alloy casting grades which are distinguished primarily by small differences in chemical composition. In carrying out this comparison, a high level of agreement in chemical composition is required before further determinations of equivalence are made.

CONCLUSIONS

(1) JIS class 6 alloy from JIS H5111-76 is generally equivalent to ASTM B62-76, alloy C83600, based on the criteria discussed earlier, subject to the following limitations:

   (a) The maximum aluminum and silicon levels should each be limited to 0.005 percent to enhance pressure tightness and surface quality.

   (b) The JIS minimum percent elongation requirement is about 26% below the B62 minimum requirement. However, test specimen blank size and chemical composition, especially impurity levels, have a major influence on measured mechanical properties of casting alloys. To be acceptable, JIS class 6 must be shown to fall within the percent elongation acceptance criterion.

JIS H5111-76//ASTM B62-76

CHEMICAL REQUIREMENTS

The chemical compositional ranges for the major alloying elements copper, tin, lead, and zinc in JIS class 6 are identical to or very closely overlap the ASTM B62 requirements for leaded red brass. The maximum total impurity level permitted for JIS class 6 is slightly greater than the sum of the maximum B62 levels for nickel, antimony, iron, phosphorus, and sulfur.

Aluminum and silicon are generally very harmful impurities in many copper casting alloys, including leaded red brasses (i.e. C83600), and must be limited to extremely low concentrations. Aluminum strongly influences the solidification behavior of these alloys resulting in a greater probability of lead sweating, loss of pressure tightness, and a decrease in ductility. Silicon enhances metal-mold-reactions and lead sweating, degrading surface quality and reducing mechanical properties, such as ductility. The maximum aluminum and silicon contents permitted by the B62 alloy is very low but are not specified in JIS H5111 for any class material. The strong influence on properties by aluminum and silicon contaminations suggests that limits should be specified.

MECHANICAL REQUIREMENTS

The determination of mechanical properties of castings requires careful control over the preparation of the test specimen. The solidification behavior of these chemically complex copper casting alloys is very important because the cooling rate strongly affects the resultant casting grain size, extent and location of shrinkage and porosity. These factors dominate the fine mechanical properties of the casting. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties than the component casting poured at the same time from the same heat of metal as a result of exaggerated differences in size.

Both ASTM B62 and JIS H5111 require the determination of mechanical properties from separately cast test bars, and thus the requirements for these two specifications do not necessarily correlate directly with expected properties of the component casting. Depending on the casting size and geometry, the properties may be higher or lower than properties measured on test bars. Further, the mechanical properties of test bars of varying sizes would be expected to behave in a similar manner. The cross-sectional areas of the B62 specimen blanks (refer to ASTM B208-75) range from about 180 mm^2 to 200 mm^2 or a diameter range of about 15 mm to 16 mm. The cross-sectional area of the JIS specimen blank is 314 mm^2 with a diameter of 20 mm, larger than the ASTM test bar. In some alloys, this size difference could result in lower ultimate tensile strength, yield strength and percent elongation values for the larger test bar.

Strength Requirements

The minimum ultimate tensile strength value for JIS class 6 falls about 4% below the B62 minimum value. Although JIS H5111 does not specify minimum yield strength values for any class, the expected yield strength value for class 6 would probably fall below the B62 minimum value in a manner similar to that observed for the ultimate tensile strength behavior.

Ductility Requirements

The JIS test specimen has a circular cross-section with a constant gage length-to-diameter ratio of 3.54 while the ASTM test specimen (see ASTM B208-75) has a circular cross-section with a gage length-to-diameter ratio of 4. Using the relationship between gage length and cross-sectional area, the equivalent JIS elongation value would be larger, about 102% of the ASTM value. The minimum percent elongation requirement for JIS class 6 is about 26% below the minimum B62 requirement.

DIN 1705-73//ASTM B62-76

INTRODUCTION

The scope statements for these two specifications are similar and refer to copper alloys for castings. Specification ASTM B62-76 applies only to one alloy composition suitable for sand casting of valves, flanges, and fittings while DIN 1705-73 includes alloys for sand castings, centrifugal castings, and continuous castings. The alloy specified in B62 is further referenced in ASTM B30-79 as a copper-base alloy in ingot form. As a result of the complex alloy designations for copper alloys, the ASTM specifications identify each grade or type by a UNS number (Unified Numbering System) and these UNS numbers will also be referred to in this analysis. The UNS number for copper alloys has a "C" prefix followed by a five-digit number.

The major design criteria for the intended applications of these products are the static strength properties, ultimate tensile strength and yield strength, and because these products are castings, the associated criteria of pressure tightness and surface quality. The percent elongation requirement, characterizing tensile ductility, is not usually considered to be a useful design parameter because it is not a unique parameter, depending on specimen geometry and gage length as well as the material's intrinsic ductility. Percent elongation, however, can be used for comparison purposes and to show the effect of other variables, such as composition and/or heat treatment on material ductility.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 1705 are considered equivalent to the requirements of ASTM B62 if the DIN values are higher than or within 5% of the B62 minimum value; (2) the percent elongation requirements of DIN 1705 are considered equivalent to the requirements of ASTM B62 if the DIN values are higher than or within 15% of the B62 minimum value. Allowance of the larger difference for percent elongation is based on: (1) the actual expected DIN elongation values would normally exceed the DIN minimum requirement, (2) percent elongation is not a design parameter but rather a measure of the relative response of the material to plastic deformation, and (3) the unknown precision in the relationship between gage length, cross-sectional area and percent elongation. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

There are many copper alloy casting grades which are distinguished primarily by small differences in chemical composition. In carrying out this comparison, a high level of agreement in chemical composition is required before further determinations of equivalence are made.

CONCLUSIONS

(1) DIN grade G-CuSn5ZnPb (2.1096.01) from DIN 1705-73 is generally equivalent to B62 (alloy C83600), based on the criteria discussed earlier, subject to the following limitation:

(a) The maximum aluminum and silicon levels should be limited to 0.005 percent to improve pressure tightness and surface quality.

CHEMICAL REQUIREMENTS

The chemical composition ranges for the major alloying elements copper, tin, lead, and zinc in DIN G-CuSn5ZnPb (2.1096.01) are identical to the ASTM B62 requirements (alloy C83600) for a leaded red brass. The somewhat higher permitted nickel level for the DIN grade could result in slightly higher strength levels compared to B62 but this difference is not inconsistent with the overall chemical requirements for B62. The maximum levels for the minor elements iron and phosphorus in the DIN grade are identical to the maximum levels permitted by B62.

Aluminum and silicon are generally very harmful impurities in many copper casting alloys, including leaded red brasses such as B62 and should be limited to extremely low concentrations. Aluminum strongly influences the solidification behavior of this alloy resulting in increased lead sweating, loss of pressure tightness, and a decrease in ductility. Silicon enhances metal-mold reactions and lead sweating, degrading surface quality and reducting mechanical properties such as ductility. Maximum aluminum and silicon contents are not, however, specified in B62 or DIN 1705. The ingot form of the B62 alloy used for remelting for the manufacture of castings is specified in ASTM B30-79. Maximum aluminum and silicon levels are specified for alloy C83600 in B30 at very low levels. The strong influence on properties by aluminum and silicon contamination of alloy C83600, recognized in B30, suggests that limits should be specified for DIN grade G-CuSn5ZnPb (2.1096.01).

MECHANICAL PROPERTIES

The determination of mechanical properties of castings requires careful control over the preparation of the test specimen. The solidification behavior of chemically complex copper casting alloys is very important because the cooling rate strongly affects the resultant casting grain size, extent and location of chemical segregation, and the amount and location of shrinkage and porosity. These factors dominate the final mechanical properties of the casting. Not only are mechanical properties often dependent on the casting size or section thickness, but separately cast test bars can have markedly different mechanical properties from the component casting poured at the same time from the same heat of metal as a result of exaggerated differences in size.

Both ASTM B62 and DIN 1705 require the determination of mechanical properties from separately cast test bars, and thus the requirements for these two specifications do not necessarily correlate directly with expected casting properties. Depending on casting size and geometry, the casting properties may be higher or lower than properties determined from test bars. The cross-sectional areas of the B62 test bars (refer to ASTM B208-75) range from about 180 mm^2 to 200 mm^2 or a diameter range of about 15 mm to 16 mm while DIN 1705 permits a range of areas from about 100 mm^2 to 250 mm^2 or a diameter range of about 11 mm to 18 mm. For purposes of this comparison, it is assumed that the results from the ASTM and DIN test bars can be directly compared because the DIN size range overlaps the ASTM range.

The basis for determining yield strength varies slightly between B62 and DIN 1705. The B62 yield strength value is calculated at a strain of 0.5% while the DIN yield strength is calculated at 0.2% strain. Thus, the B62 calculated value would be equal to or somewhat higher than the DIN value.

Strength Requirement

The minimum ultimate tensile strength requirement for DIN G-CuSn5ZnPb (2.1096.01) exceeds the B62 minimum requirement while the DIN minimum yield strength requirement, based on 0.5% strain, is probably within 5% of the B62 minimum requirement.

Ductility Requirement

The DIN test specimen has a circular cross-section with a constant gage length to diameter ratio of 5 while the ASTM test specimen (see ASTM B208-75) has a circular cross-section with a gage length to diameter ratio of 4. Based on the relationship between gage length and cross-sectional area, the equivalent DIN elongation value would be about 96% of the ASTM value.

The minimum percent elongation requirement for DIN G-CuSn5ZnPb is 5% below the minimum B62 requirement.

DIN 17671-74//ASTM B43-79

INTRODUCTION

The scope statements for these two specifications are quite similar and refer to seamless brass pipe. The ASTM specification, B43-79, covers one brass alloy (Copper Alloy UNS No. C23000) in the annealed condition while DIN 17671 covers copper and copper alloys, including brass, tin bronze, nickel silver, copper-nickel, aluminum bronze, and copper-zinc-lead in a variety of thermo/mechanical conditions. Mechanical properties are not specified in B43 although minimum strength properties are quoted for annealed material which must meet requirements of the ASME Boiler and Pressure Vessel Code. For this analysis, the mechanical property requirements of DIN 17671 will be compared to these ASME minimum properties.

The major design criteria for the intended applications of these materials are the static strength properties, ultimate tensile strength and yield strength. There are additional criteria specified in B43 which must be satisfied for the particular applications for this alloy in plumbing and boiler feed lines. These additional criteria include expansion/flattening tests, bend tests, stress corrosion cracking tests, and nondestructive tests.

For purposes of this comparison and based on the previous discussion, the acceptance criteria for the determination of equivalence are: (1) the strength requirements of DIN 17671 are considered equivalent to the requirements of ASTM B43 if the DIN values exceed or are within 5% of the B43 minimum value; and (2) the DIN alloy is considered equivalent to the expansion, bending, stress corrosion, and nondestructive test requirements of B43 if the DIN samples pass these GO-NO GO requirements. The ultimate determination of equivalence between material specifications that are not identical, however, depends on the actual end-use of the material in a structure and the design parameters for that structure.

CONCLUSIONS

(1) DIN grade CuZn 15p (2.0240.10) from DIN 17671-74 is generally equivalent to ASTM B43-79 based on the criteria discussed earlier, subject to the following limitations:

(a) DIN grade CuZn 15 (2.0240.10) specifies a minimum ultimate tensile strength 7% below the B43 minimum and does not specify a minimum yield strength to be acceptable, CuZn 15 (2.0240.10) must be shown to satisfy the strength acceptance criteria.

(b) DIN grade CuZn 15 (2.0240.10, to be acceptable, must be shown to pass the mercurous nitrate test, Section 9 of B43-79.

(c) DIN grade CuZn 15 (2.0240.1) annealed tubes, to be acceptable must be shown to pass the expansion/flattening test, Section 7 of B43-79.

(d) For applications involving bending of the tubes, DIN CuZn 15 (2.0240.10), to be acceptable, must be shown to pass the bend test, Section 8 of B43-79.

(e) For all tubing and pipe, DIN CuZn 15 (2.0240.10), to be acceptable, must be shown to pass one of the two nondestructive tests, section 10 of B43-79.

DIN 17671-74//ASTM B43-79

CHEMICAL REQUIREMENTS

The chemical composition limits for DIN CuZn 15 (2.0240) in DIN 17671-74 are found in DIN 17660-74 and are identical to the chemical composition limits for B43 (copper alloy UNS No. C23000), a red brass.

Mercurous Nitrate Test

Specification B43-79 requires all sizes of tube and pipe to withstand without cracking a 30-minute immersion in a mercurous nitrate solution as described in ASTM B154, Mercurous Nitrate Test for Copper and Copper Alloys. This test is an accelerated test for detecting the presence of residual stresses that could cause failure through stress corrosion cracking. Specification DIN 17671-74 does not contain this test requirement or any similar test procedure.

MECHANICAL PROPERTIES

Specification B43-79 does not provide for mechanical property requirements unless the material is to satisfy the ASME Boiler and Pressure Vessel Code. For this situation, minimum strength properties are required for pipe in the annealed condition. Specification DIN 17671-74 permits the alloys to be produced in a variety of thermo/mechanical conditions including annealed pipe. The mechanical property test specimens permitted by B43 include full pipe sections, or a rectangular specimen 12.5 mm wide, gage length of 50 mm, and full pipe thickness. The full pipe section specimen is preferred and its results take precedence over data from rectangular specimens. Specification DIN 17671-74 through reference to DIN 50140-80 also calls for the tensile test specimens to be full pipe sections and thus the requirements of the two specifications can be directly compared.

Strength Requirements

The minimum ultimate tensile strength requirement specified for CuZn 15 in the annealed condition (material 2.0240.10) is 7% below the minimum B43 requirement to satisfy the ASME Boiler and Pressure Vessel Code. The minimum yield strength requirement in B43 is specified for at 0.5% extension while DIN CuZn 15 specifies a maximum yield strength at 0.2% extension. Thus, the DIN maximum yield strength limit could be somewhat larger if measured at the B43 requirement of 0.5% extension. Although DIN CuZn 15 does not specify a minimum yield strength, its maximum value is almost twice that of the B43 minimum, and therefore probably would satisfy the B43 requirement.

Expansion Test

Specification B43-79 requires annealed tubes to successfully withstand the expansion of the inside tube diameter by 25%, without cracking following the procedure of ASTM B153-77, Expansion of Copper and Copper Alloy Tubing. This test is designed to test the ability of the tube to be expanded, as might be required for applications with flared fittings, or to reveal the presence of longitudinal defects in the tubing. For tubing over 102 mm in diameter, B153 permits an alternative flattening test whereby a section of pipe is flattened in one stroke so that its final height is equal to or less than three times the wall thickness. Specification DIN 17671-74 does not contain this test or any similar test procedure.

Bend Test

For annealed tube and pipe 50 mm or less in outside diameter for applications requiring bending, B43 requires that full sections of pipe be successfully bent around a pin 1.5 times the inside pipe diameter without cracking on the outside or tensile portion of the pipe. Specification DIN 17671-74 does not contain this test or any similar test procedure.

NONDESTRUCTIVE TEST REQUIREMENTS

According to B43, tubing and pipe must successfully pass either an eddy-current test, ASTM E243, Electromagnetic Testing of Seamless Copper and Copper Alloy Tubes, or a hydrostatic pressure test, depending on tubing or pipe diameter. These tests are designed to detect defects likely to cause failure in service (eddy current test) or lack of pressure tightness (hydrostatic test). Specification DIN 17671-74 does not contain this test requirement or any similar test procedure.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Under United States law, United States flag vessels must satisfy applicable United States codes, and further, the materials of construction of these vessels must satisfy the material requirements specified in these codes. For vessels manufactured in foreign countries, a determination must be made as to whether materials of construction produced under foreign specifications for specific components such as piping and flanges, are acceptable in performance to materials produced under approved U.S. specifications.

A program has been initiated at the National Bureau of Standards under the sponsorship of the United States Coast Guard to develop a manual of equivalent engineering standards which specifies those foreign specifications that are equivalent to acceptable domestic specifications, those foreign specifications that are not equivalent, and those that would be equivalent if certain additional criteria are met. Results are presented here of a detailed technical comparison between foreign specifications, principally Deutsche Industrie-Normen (DIN) standards and Japanese Industrial Standards (JIS), and selected domestic material specifications issued by the American Society for Testing and Materials (ASTM) and the American Society of Mechanical Engineers (ASME). This comparison has identified technical areas of commonality, difference, and omission that could have a significant impact on component performance.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

ASTM; copper alloys; DIN; equivalency; foreign specifications; JIS; metal specifications; ships components; specifications; steel

13. AVAILABILITY

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