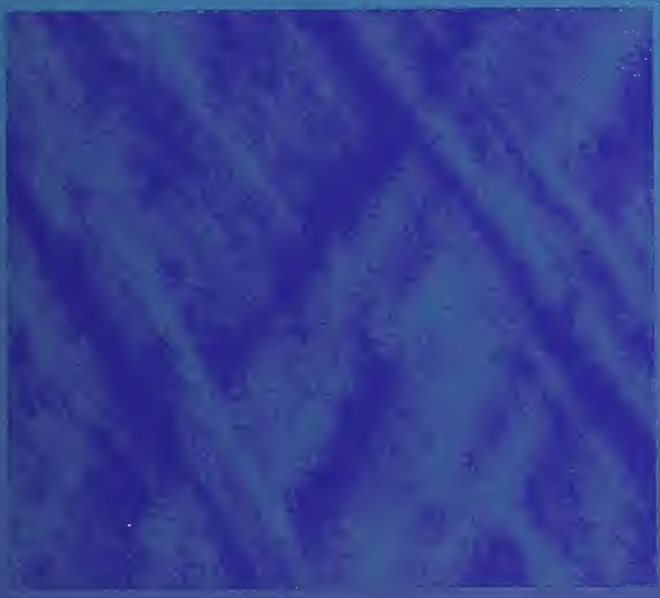
guide

NIST Recommended

Surface Engineering Measurement Standards for Inorganic Materials



Stanley J. Dapkunas

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Surface Engineering Measurement Standards for Inorganic Materials

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Materials Science and
Engineering Laboratory

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In addition to members of the Editorial Committee, Bill Scott and Fran Cverna of the ASM International staff provided valuable perspectives.

Photomicrographs in Figure 1 were originally published by ASM International. These illustrations of surface conditions clarify the organization of this Guide. Sources of the photomicrographs are as follows:

Bare Material – ASM Micrograph Center On-Line Photo CS 1376
Heat Treated – ASM Micrograph Center On-Line, Photo 0027
Oxidized – ASM Micrograph Center On-Line CS 1079
Carburized – ASM Micrograph Center On-Line Photo 0001
Decarburized – ASM Micrograph Center On-Line Photo 0030
Aluminized – ASM Handbook Volume 5, Surface Engineering, 1994, page 614, Figure 3D
Chromized – ASM Metals Handbook, 8th Edition, Atlas of Microstructures of Industrial Alloys, 1972, page 13, Photo 83
Electroplated – ASM Metals Handbook, 8th Edition, Atlas of Microstructures of Industrial Alloys, 1972, Photo 1877
Galvanized/clad – ASM Metals Handbook, 8th Edition, Atlas of Microstructures of Industrial Alloys, 1972, Photo 72
Physical Vapor Deposition – ASM International, Journal of Thermal Spray Technology, Vol. 6, No. 1, March 1988, page 37, Figure 5
Thermal Sprayed – ASM International, Journal of Thermal Spray Technology, Vol. 6, No. 1, March 1988, page 37, Figure 4

Figure 2. Applicability of Coating Thickness Measuring Methods, is reprinted, with permission, from ASTM B 659-90(2003) Standard Guide for Measuring Thickness of Metallic and Inorganic Coatings, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Preface

Surface engineering of materials is important in applications as diverse as medical implants and gas turbines. Historically, a coating or cladding was added to a surface, or a surface was treated, to enhance properties or performance. However, increasingly, heat treated, implanted, coated and clad surfaces are viewed as part of a materials system where the substrate and surface complement each other in achieving a performance goal for a component. The integration of the surface and substrate as an engineered system creates a situation where failure of the surface may, in effect, be failure of the system and thus characterization of surfaces and measurement of surface properties are important to the design, maintenance, and analysis of the whole system.

The advantages of engineered surfaces have stimulated development of surface treatment and coating processes as well as materials and, consequently, commerce. Commerce in engineered materials depends upon the ability to specify and measure composition, microstructure, dimensions and properties as well as performance in applications of interest.

The intent of this Guide is to give the materials community a resource for identifying standard methods which are used to measure surface properties and to characterize surface engineered materials.

This Guide has been prepared with the support of the Ceramics Division of the National Institute of Standards and Technology and the cooperation of the Surface Engineering Committee of ASM International.

Specific thanks are due the Editorial Committee which oversaw this effort. Members of that committee include:

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Dr. Debra Kaiser, Chief, Ceramics Division, NIST, Gaithersburg, MD

Mr. Steven Lampman, ASM International, Materials Park, OH

Dr. James Treglio, Molecular Metallurgy, Inc., El Cahon. CA

ASM International generously provided the illustrative photomicrographs in Figure 1, Quick Guide to Surface Measurement Standards. Sources of specific photomicrographs are provided in the Acknowledgements section of this document.

ASTM International generously provided Figure 2, Applicability of Coating Thickness Measuring Methods. The source of Figure 2 is ASTM B 659-90 (2003) Standard Guide for Measuring Thickness of Metallic and Inorganic Coatings.

More information on the SP 960 series can be found on the Internet at http://www.nist.gov/practice guides. This website includes a complete list of NIST Practice Guides and ordering information.

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1. Introduction

This Guide is intended to aid the technical and scientific community in the evaluation of engineered surfaces by identifying standard methods for measurement of pertinent properties and characteristics. Methods included in this Guide are for use with inorganic materials, i.e., metals and ceramics, used in structural, i.e., load bearing, applications.

"Surface Engineering" has been defined as the treatment of the surface and near surface regions of a material to allow the surface to perform functions that are distinct from those functions demanded from the bulk of the material[1]. "Surface Engineering" has also been expanded to include consideration of the design of the surface and substrate as a system[2]. Engineered surfaces typically provide wear, corrosion or thermal protection and may be created by techniques such as heat treatment to modify microstructure, implantation to modify composition, or coating and cladding where a very different material is applied to a surface. Generally, an engineered surface enhances the performance of a load bearing substrate. This is in contrast to a functional surface, like a printed circuit, which is supported by a substrate.

Surface engineering is critical to the technical and/or economic success of many technologies. For example, gas turbines rely on coatings for corrosion and thermal protection to achieve durability and high efficiency, reciprocating engines rely on treated and coated surfaces for wear resistance, and medical implants are coated to improve bone adherence and biocompatibility.

There are several reasons to evaluate engineered surfaces:
to ascertain conformance to specifications;
- to monitor process control by regular measurement of selected properties such as hardness or finish;
- to assess relevant properties in the development of materials or processing methods
- to ascertain performance through exposure to, or operation in, the intended application, followed by measurement or characterization of attributes such as extent of corrosive penetration or wear; and,
- to predict performance through exposure in an environment which simulates the intended application, again, followed by evaluation of appropriate attributes.

Addressing these three purposes requires property measurement or characterization by methods that not only meet the needs of the party conducting the measurement but also are satisfactory to the user or purchaser of the material or component of interest. Therefore, it is often necessary for organizations that develop, or provide, and purchase, or use, materials and components to agree on a commonly accepted method of measurement. Obviously, the availability of commonly accepted measurement methods facilitates commerce by removing ambiguities that may arise when the same nominal property is determined by unique or unusual techniques.

Furthermore, some properties are so broadly useful, because they provide a common denominator for comparing materials, that considerable effort has been invested in their consistent measurement. Hardness, for example, is a useful property for comparing

materials or for determining the effect of different heat treatments on a single material. The value of consistent and valid measurement of such properties has led to the development of standard test methods, i.e., "standards". Standards specify measurement details such as specimen design, test apparatus and calibration, test procedures, data reporting, limits of applicability, and uncertainty.

Standard measurement methods are an important component in engineering design and construction. For example, standard test methods may be codified, that is, made part of a system of principles or rules. ASTM (formerly the American Society for Testing and Materials) standards for property measurement are included in the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code, which is a basis for design and fabrication.

The widespread use of standards and the value they bring to commerce in materials and components has necessitated the formation of organizations whose function is to foster development of standard measurement methods. These standards organizations can be civilian and voluntary, as is ASTM, or governmental, as is the JIS (Japan Institute of Standards).

The organizations which have accepted responsibility for standards development also make the standards available for interested parties and update the standards, as appropriate. The standards are usually up-dated with significant contribution and review by the technical community concerned.

In the United States, standards organizations with an interest in surface engineering measurements include ASTM, SAE (Society of Automotive Engineers), ASME International (American Society of Mechanical Engineers) and ANSI (American National Standards Institute). These organizations develop consensus standards through the efforts of volunteers, often with scientific support from NIST (the National Institute of Standards and Technology).

The DOD (Department of Defense), NASA (National Aeronautics and Space Administration) and other government agencies conduct research on engineered surfaces and can establish test methods which amount to standards. These test methods address those agencies' specific needs but may eventually be adopted by ASTM or other standards organizations.

International standards are generally developed through the cooperative efforts of national or regional standards organizations and reflect the methods developed for those bodies' standards. The ISO (International Organization for Standardization) is the most notable international organization active in the development of methods for measurement of material properties.

This Guide includes few standards for measurement of corrosion, friction, wear and abrasion. Standards in these fields that are included focus on evaluation of specific surface conditions. The large number of corrosion and wear standards based on corrodent or wear mechanism warrant separate compilation, as has been done in the

"Friction and Wear Testing Source Book of Selected References from ASTM Standards and ASM Handbooks". That Source Book was issued jointly by ASTM International and ASM International in 1997 and is available from those organizations.

Lastly, it is important to note that "standards", i.e., standard test methods, are well considered approaches to property measurement or material characterization and are the consensus opinion of experienced practitioners and researchers. As such, they are a means for those inexperienced in a specific field to quickly gain knowledge of what is regarded as a reputable measurement technique. Standard test methods do not always include state-of-the-art techniques or address applications which are still in the research stage and subject to rapid change.

This Guide does not provide details included in the standards identified and should not be viewed as a substitute for those standards. Standards should be purchased from the issuing organization at the following addresses:

ASTM
100 Barr Harbor Drive
West Conshocken, PA 19428-2959

ASME
Three Park Avenue
New York, NY 10016-5990

ISO
Case postale 56
CH-1211
Geneva 20
Switzerland

SAE International
400 Commonwealth Drive
Warrendale, PA 15096-0001

[1] ASM Handbook, Volume 5, Surface Engineering, Copyright 1994 by ASM International, Materials Park, Ohio 44073-0002

[2] http://www.twi.co.uk/j32/unprotected/band_1/surfaceengineering.htm

2. Organization of the Guide and Locating Standards

2.1 Organization of the Guide

This Guide is organized to enable rapid identification of standard measurement methods ("standards") appropriate to the user's interests.

The Guide includes standards appropriate for the following surface conditions:

- bare surfaces which have the same composition, phase and structure from surface to interior;
- treated surfaces wherein the base material has been subjected to conditions which change surface composition, structure, phase, or properties; and,
- coated surfaces wherein the base material has had specific additional material deposited on its surface, often significantly increasing the base material's dimensions.

Treated surfaces are those that have been subjected to processes such as carburization, decarburization, nitridation, surface implantation, surface heat treatments and abrasive blast hardening or cleaning.

Coated surfaces are those that have been covered with material having composition and properties significantly different from the base material. Coating processes include electroplating, physical vapor deposition, thermal spray and galvanizing, for example.

The greatest part of this document consists of summaries of over 200 standards.
A summary of each standard is provided in a template that includes the following information, as appropriate:

- Standards Identification including issuing organization, standard identification number and standard title;
- General Description including an overview of the method and the contents of the standard;
- Intended Application including the stated purpose for which the standard was developed;
- Specimen Requirements including the size, condition or other characteristics necessary or valid use of the method;
- Data Produced including the nature of the data produced (visual or instrument generated numeric, for example) and further refinements or calculations necessary, and,
- Limits of the method including inappropriate application, accuracy, precision or safety concerns.

The templates are within Sections 3 through 12 of this Guide.
Within each Section or Sub-section, standards are in the following order:
- ASME Standards,
- ASTM Standards,
- ISO Standards,

- Military and Industry Standards, and
- SAE Standards.

Sections 3 through 12 are organized as follows:
- general aspects of surface inspection and product evaluation (Sections 3,4 and 5),
- standards specific to selected coating processes (Section 6), and
- standards for measurement of specific characteristics or properties (Sections 7 through 12).

This Guide also has the following features which support Sections 3 through 12:
- Figure 1. Quick Guide to Surface Measurement Standards which progresses in increasing detail from "Surface Condition" to "Property of Interest" to "Measurement method" to the "Appropriate Section" which includes relevant standards;
- Section 13. Surface Engineering Measurement Standards, a compilation of titles of all standards in Sections 3 through 12, organized by issuing organizations and those organizations' alpha-numeric identification;
- Section 14. Index, a comprehensive compilation of key words associated with each standard;
- Figure 2. Applicability of Coating Thickness Measuring Methods, which is included in Section 7 and provides an ASTM summary of methods for measuring thickness by several methods.

2.2 Locating Standards

There are four routes for locating a standard of interest:
- Surface Condition Based
  Figure 1, Quick Guide to Surface Measurement Standards, gives a rapid, although not comprehensive, route to a relevant standard by starting with the surface condition illustrated and proceeding through the property of interest to measurement method to the section in which the standard(s) are located;
- Property or Characteristic Based
  Proceeding directly to Sections 3 through 12 will enable browsing through standards which address general issues such as terminology or accreditation, properties or characteristics, material, or measurement method;
- Standard Based
  Section 13, the compilation of standards in Sections 3 through 12, enables the user to proceed directly to the summary of the standard of interest when the standard is known; and,
- Key Words
  Standards can also be accessed by use of the alphabetized Index in Section 14. The Index is based on key words descriptive of the content of each standard.

Also, Figure 2, Applicability of Coating Thickness Measuring Methods, can be used within Section 7 to focus on useful methods and the Index can be used to quickly identify standards with similar purposes or methods issued by different organizations. Sections 3 through 12 also enable comparison of standards issued by different organizations.

Figure 1. Quick Guide to Surface Measurement Standards

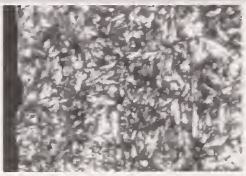
Surface Condition	Property	Method	Section	Page
Bare 	Specifications			
	Geometrical Product Specifications (GPS)		**4.1**	**25**
	Acceptance standards, Visual		**4.1**	**25**
	Surface defects, fasteners		**4.2**	**42**
	Surface chemistry		**9.1**	**148**
		– Terminology		
		– Depth profiling (AES)		
		– Glow discharge optical		
		– Emission spectroscopy		
	Surface profile & texture	– Visual	**4.1,**	**25,**
		– Profilometry	**4.2**	**42**
		– Scanning Tunnel Micros.		
		– Focussing microscope		
		– Replica		
	Surface defects		**4.1**	**25**
		– Classification		
		– Liquid penetrant		
		– Infrared		
		– Eddy current		
		– Acoustic emission		
		– Etch		
		– Replica		
		– Magnetic particle		
	Cleanliness		**4.1**	**25**
		– Visual		
		– Tape		
		– Bresle		
		– Conductometric		
		– Refractometric		
		– Titimetric		
	Gloss		**4.2**	**42**
		– Goniophotometry		
	Oxide finger penetration		**8.1**	**136**
		– Microscopy		
	Microstructure		**8.1**	**136**
		– Microscopy		
	Hardness		**10.2, 3**	**155ff**
		– Comparison testers		
		– Scratch testers		
		– Indentation testers (7 types)		
		– Scleroscope		
		– Files		
	Residual stress		**10.1**	**153**
		– Hole-drilling strain gages		
		– X-ray diffraction		

Figure 1. Quick Guide to Surface Measurement Standards *(cont'd)*

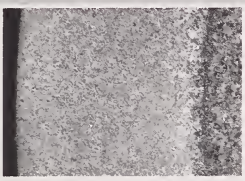
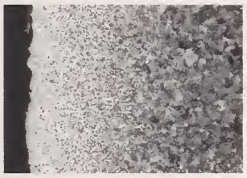
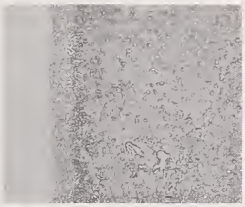
Surface Condition		Property	Method	Section	Page
Heat Treated		Contractor accreditation		3.2	12
		Case depth		7.1	88
			– Hardness		
		Surface temper		4.2	42
			– Etch inspection		
Oxidized		Oxide thickness		7.2	97
			– Microscopy		
Carburized		Carburization depth		7.1	88
			– Hardness		
			– Microscopy		
Decarburized		Decarburization depth		7.1	88
			– Hardness		
			– Microscopy		
			– Chemical		
Anodized		Sampling		3.3	21
		Thickness		7.2	97
			– Gravimetric		
			– Split beam microscopy		
Aluminized		Specification		6.5	80
		Coating thickness		7.2	97
			– Microscopy		
Chromized		Contractor accreditation		3.2	12
		Coating thickness		7.2	97
			– Microscopy		

Figure 1. Quick Guide to Surface Measurement Standards *(cont'd)*

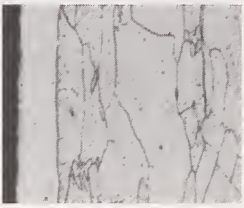
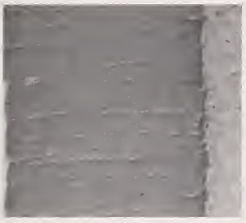
Surface Condition	Property	Method	Section	Page
Electroplated 	Sampling		3.2	12
	Contractor accreditation		3.3	21
	Coating thickness		7.2	97
		– Coulometric – Magnetic – Acid dissolution – Beta backscatter – X-ray spectrometry – Interference microscopy – Microscopical – Eddy current – Profilometric – Radial sectioning		
	Coating mass, X-ray fluorescence		7.3	125
	Grinding damage		4.1	25
	Interfacial width, sputter depth profiling		9.1	148
	Porosity, Gold		8.2	141
		– Acid vapor – Paper electrography – Gel-bulk electrography – Sulfurous acid/sulfur dioxide – Flowers of sulfur		
	Gross defects & mechanical damage		8.2	141
		– Polysulfide immersion		
	Hardness		10.2	155
		– Knoop – Vickers		
	Ductility		11.1	181
		– Bend test	11.2	187
	Adhesion			
	Corrosion site characterization			
		– Interference microscopy	12.2	198
	Hydrogen embrittlement			
		– Electronic	12.2	198

Figure 1. Quick Guide to Surface Measurement Standards *(cont'd)*

Surface Condition	Property	Method	Section	Page
Galvanized/ Clad 	Case study practices		6.3	75
	Coating mass measurement		7.3	125
		– Gravimetric – X-ray fluorescence – Triple spot		
	Composition		7.3	125
		– Triple spot		
Physical Vapor Deposited 	TiN Specification		6.6	82
	Contractor accreditation		3.2	12
	Coating thickness		7.2	97
		– Microscopical – Radial sectioning		
Thermal Sprayed 	Contractor accreditation		3.2	12
	Specifications		6.7	83
	Thickness		7.2	97
		– Radial sectioning		
	Phase content, hydroxyapatite		9.2	152
		– X-ray diffraction		
	Shear strength		11.1	181
		– Mechanical		
	Tensile strength		11.1	181
		– Mechanical		
	Fatigue strength		11.1	181
		– Mechanical		
	Adhesion/cohesion strength		11.2	187
		– Mechanical		
	Abrasion resistance		11.2	187
		– Taber Abraser		

3. General Standards for Surface Engineering Measurement

3.1 Terminology

ASTM A 902 *Standard Terminology Relating to Metallic Coated Steel Products*	
General Description	**Data Produced**
This Standard is a compilation of 47 definitions of terms related to metallic coatings used in the steel industry. The Standard also includes recommended key words for ASTM Committee A-5 Standards.	Not applicable/specified.

Intended Application	Specimen Requirement	Limits
Clarity of terminology used in coated steel product descriptions.	Not specified.	Not specified.

ISO 2079 *Surface Treatment and Metallic Coatings – General Classification of Terms*	
General Description	**Data Produced**
This document provides general terms and definitions for several surface treatments and identifies relevant ISO standards for those treatments. Terms and definitions are provided in English, French, Russian and German.	Not specified.

Intended Application	Specimen Requirement	Limits
Intended to clarify relevant standards.	Not specified.	Not specified.

ISO 2080
Electroplating and Related Processes – Vocabulary

General Description	Data Produced
This Standard provides definitions of 804 terms used in electroplating and related processes such as metal finishing. Definitions are in English, French, Russian and German.	Not specified.

Intended Application	Specimen Requirement	Limits
Intended to clarify relevant standards.	Not specified.	Not specified.

SAE AS 4194
Sheet and Strip Surface Finish Nomenclature (Aerospace Standard)

General Description	Data Produced
Defines nomenclature for two surfaces (2D and 2B) of sheet and two surfaces (No. 1 and No. 2) of strip material and bright annealed finish.	Not specified/applicable.

Intended Application	Specimen Requirement	Limits
Provides explanations of terms used to describe surface finish of iron, nickel, cobalt and titanium base alloys used in aerospace applications.	Not specified/applicable.	Not specified/applicable.

3.2 Laboratory Accreditation

SAE AS 7101
National Aerospace and Defense Contractors Accreditation Program (NADCAP) General Requirements for Materials Test Laboratory Accreditation Program (Aerospace Standard)

General Description	Data Produced
Establishes the minimum requirements for materials testing laboratories accredited by NADCAP. Test methods for metallic materials are specified by reference to SAE, ASTM, military, ISO and ANSI documents. Methods referenced include those for: chemical, mechanical, metallography and microhardness, hardness, corrosion, mechanical test specimen preparation, differential thermal analysis, heat treating, X-ray diffraction and fastener testing. Document includes definitions, and survey requirements.	Not specified/applicable.

Intended Application	Specimen Requirement	Limits
Intended to give guidance for many aspects of a testing laboratory required for accreditation.	Not specified/applicable.	Not specified/applicable.

SAE AS 7109
National Aerospace and Defense Contractors Accreditation Program Requirements for Coatings (Aerospace Standard)

General Description	Data Produced
This Standard establishes requirements for suppliers of coating services to be accredited by the National Aerospace and Defense Contractors Accreditation Program (NADCAP). It does not include measurement methods but serves as the basic document for accompanying Aerospace Standards for specific types of coatings which include measurement or testing requirements.	Not specified.

Intended Application	Specimen Requirement	Limits
Coating supplier accreditation.	Not specified.	Not specified.

SAE AS 7109-1
National Aerospace and Defense Contractors Accreditation Program Requirements for Thermal Spray (Aerospace Standard)

General Description	Data Produced
This Standard is a supplement to SAE AS 7109 addressing: OXY/Fuel Powder and Wire Spray, Plasma Thermal Spray, HVOF/D-Gun Spray, Low Pressure Plasma Spray (LPPS) and Electric Arc Wire Spray. Accreditation requirements for the following applications are included: High/low Temperature Hard Coatings, Anti-fretting Coatings, Thermal Barrier Coatings, Abrasive Seal Coatings, Abradable Coatings, Dimensional Build-up Coatings and High Temperature LPPS Coatings. Aspects addressed include: Technical Experience, Process Planning, Manufacturing, Material Powder/Wire Control, Cleaning, Masking, Grit Blasting, Spray Booths, Oxy/Fuel, Plasma Thermal Spray, HVOF/D-Gun, LPPS, Electric Arc Wire, Process Gases, De-mask/Clean, Supplemental Heat Treating, Sealing Sprayed Coatings, Inspection and Compliance. Characterization and measurement are covered in the “Inspection” section.	Not specified.

Intended Application	Specimen Requirement	Limits
Coating supplier accreditation.	Not specified.	Not specified.

SAE AS 7109-2
National Aerospace and Defense Contractors Accreditation Program Requirements for Vapor Deposit (Aerospace Standard)

General Description	Data Produced
This Standard supplements SAE AS 7109, specifically addressing physical vapor deposition (PVD, Class A) which includes sputter and electron beam deposition and chemical vapor deposition (CVD, Class B). The following aspects of accreditation are described: Technical Experience, Manufacturing, Material Control, Vapor Process Operation Sheet, Part Treatment, Cleaning, Masking, Surface Preparation, Chambers/Pump Systems, Process Gases, Supplementary Chemical Treatment, Inspection and Compliance. Characterization and measurement are included in the "Inspection" section.	Not specified.

Intended Application	Specimen Requirement	Limits
Coating supplier accreditation.	Not specified.	Standard methods for characterization or inspection are not specified.

SAE AS 7109-3
National Aerospace and Defense Contractors Accreditation Program Requirements for Cementation (Aerospace Standard)

General Description	Data Produced
This Standard supplements SAE AS 7109, specifically addressing pack processes (Class A) which includes above pack and in-pack deposition, and slurry processes (Class B). The following aspects of accreditation are included: Technical Experience, Process Planning, Manufacturing, Material Control, Cleaning, Masking, Grit Blasting, Packing/Furnace Loading, Coating/ Thermal Treatment, De-mask/Clean, Supplementary Chemical Processing, Inspection and Compliance. Characterization and measurement are included in the "Inspection" section.	Not specified.

Intended Application	Specimen Requirement	Limits
Coating supplier accreditation.	Not specified.	Standard methods for characterization or inspection are not specified.

SAE AS 7109-4
National Aerospace and Defense Contractors Accreditation Program Requirements for Stripping (Aerospace Standard)

General Description	Data Produced
This Standard supplements SAE AS 7109, specifically addressing stripping of coated material. Stripping methods addressed include: electrolytic, mechanical (grit blast, grinding, machining) water jet, molten salt and chemical. The following aspects of accreditation are included: Equipment and Facilities, Process Planning, Manufacturing, Material Control, Stripping, Water Jet, Molten Salt, Chemical, Process Control Laboratory Procedures (Solution Analysis), Post Strip Cleaning, Bake Embrittlement Relief and Compliance.	Not applicable/specified.

Intended Application	Specimen Requirement	Limits
Coating supplier accreditation.	Not specified.	Not specified.

SAE AS 7109-5
National Aerospace and Defense Contractors Accreditation Program Requirements for Coating Evaluation Laboratory Practices (Aerospace Standard)

General Description	Data Produced
This Standard supplements SAE AS 7109, specifically addressing coating evaluation. Specific details of evaluation methods are not described but appropriate references to other documentation (e.g. ASTM) are included. The Standard covers those aspects of evaluation which must be addresses to warrant accreditation, including: Personnel, Procedures, Equipment and Facilities, Quality Assurance-Lab Specific, Round Robin Programs, Hardness Testing, Metallography and Thickness, Mechanical Testing, Heat treating of Specimens, Specimens (such as per ASTM C 633), Replacement Testing and Retesting, Test Reports/ Certificates, Tensile Testing, Bend Testing and Nonstandard Compliance.	Not specified.

Intended Application	Specimen Requirement	Limits
Coating supplier accreditation.	Not specified.	Not specified.

SAE AS 7109-6
National Aerospace and Defense Contractors Accreditation Program Requirements for Plating of Coated Parts Laboratory Practices (Aerospace Standard)

General Description	Data Produced
This standard is a supplement to SAE AS 7109, specifically addressing plating of coated parts. The document calls out aspects of plating which must be addressed to meet accreditation requirements. These aspects are included: Equipment and Facilities, Part Processing Control, Cleaning Procedures, Masking, Lot Integrity, Housekeeping, Test and Inspection, Process Control Laboratory Procedures (Solution Analysis) and Compliance. Test and Inspection specifies the use of procedures in the following ASTM Standards: B 244, B 487, B 499, B 504, B 530, B 567 and B 568.	Not specified.

Intended Application	Specimen Requirement	Limits
Coating supplier accreditation.	Not specified.	Not specified.

SAE AS 7109-7
National Aerospace and Defense Contractors Accreditation Program Requirements for Heat Treating for Suppliers of Coatings (Aerospace Standard)

General Description	Data Produced
This Standard is a complement to SAE AS 7109, specifically addressing heat treating during the coating process. This standard does not include surface related measurement or testing and is included only for completeness in the AS 7109 series.	Not specified.

Intended Application	Specimen Requirement	Limits
Coating supplier accreditation.	Not specified.	Not specified.

3.3 Sampling

ASTM B 602
Standard Test Method for Attribute Sampling of Metallic and Inorganic Coatings

General Description	Data Produced
This Method gives sampling plans intended for use in the inspection of coatings for conformance to ASTM specifications. The plans are based on inspection by attributes. That is, the article is inspected and classified as either conforming to a requirement placed on it or not conforming. The Method includes a general description of the approach, ordering information, formation of inspection lot,sampling, inspection and lot disposal, and drawing of samples.	Varies with specification.

Intended Application	Specimen Requirement	Limits
Sampling inspection permits the estimation of the overall quality of a group of product articles through the inspection of a relatively small number of product items drawn from the group. The selection of a sampling plan provides purchasers and sellers a means of identifying the minimum quality levels that are considered satisfactory.	Varies with specification.	Sampling plans yield estimates of the quality of product, thus the results of the inspection are subject to error. Through the use of sampling plans, the risk of error is known and controlled.

ASTM B 697
Standard Guide for Selection of Sampling Plans for Inspection of Electrodeposited Metallic and Inorganic Coatings

General Description	Data Produced
This Guide provides guidance in the selection of sampling plans to determine whether submitted lots of coated products comply with the specifications applicable to the coatings. A sampling plan guides the examination of a relatively small part of the articles in a lot. That examination allows a decision as to whether the lot does or does not conform to specifications. The sampling plans are attribute plans. Each examined article is classified as conforming or not conforming to each coating requirement and the number of nonconforming articles compared to a maximum allowable number. Supplements ASTM B 602.	Number of articles with acceptable properties.

Intended Application	Specimen Requirement	Limits
Acceptance sampling is used when a decision must be made about what to do with a quantity of articles. Used where cost of inspection is high and consequences of accepting a nonconforming article are not serious; or, where 100% inspection is boring or fatiguing and likely to result in errors; or, when inspection requires a destructive test.	Varies with property or characteristic of interest.	It is important that the inspection lot be homogeneous; i.e., that the articles in the lot be from the same supplier, single finishing line, finished at the same time, etc.

ASTM B 762
Standard Test Method of Variables Sampling of Metallic and Inorganic Coatings

General Description	Data Produced
This Method gives sampling plans for inspection of coatings on products for the purpose of deciding whether lots of the coated articles conform to specifications for the coatings. A characteristic of the coating on drawn articles is measured and the values obtained are used to estimate the number of articles in the lot that do not conform to a numerical limit.	Number of articles in a lot that do not conform to a numerical limit.

Intended Application	Specimen Requirement	Limits
Acceptance testing of lots of coated articles.	Varies with property or characteristic of interest.	A variables plan requires that: the characteristic of interest is measurable; the test method gives a numerical measure of the characteristic; the specification places a numerical limit on the measured value; variation of the characteristic from article to article be normally distributed; and, each article is tested in the same way. If one or more of the above conditions are not met, an attributes plan must be used; e.g., ASTM B 602 or ASTM B 697.

ISO 4519
Electrodeposited Metallic Coatings and Related Finishes – Sampling Procedures for Inspection by Attributes

General Description	Data Produced
This Standard establishes sampling plans and procedures for inspection of electrodeposited metallic coatings using attributes of those materials. The procedures described may be applied to finished products or materials processing. The sampling plans are based on acceptable quality levels (AQLs) of 1.5 and 4.0%. The standard includes definitions, defect classifications, acceptance and rejection responsibilities, sample selection methods and plans, detailed guidance on determination of acceptability and procedures for drawing random samples. This standard is based on ISO 2858.	Varies with property of interest.

Intended Application	Specimen Requirement	Limits
Provides a basis for purchase specifications and may be applied to related finishes. This standard supports determination of lot acceptability by the use of a sampling plan.	Not specified.	The plans are intended primarily for examination of continuing series of lots but may be used for examination of isolated lots. This standard is not applicable to sampling and testing of electroplated mechanical fasteners (*See* ISO 3269).

4. Surface Inspection and Product Quality

4.1 General (bare and coated)

ASTM B 866
Standard Test Method for Gross Defects and Mechanical Damage in Metallic Coatings by Polysulfide Immersion

General Description	Data Produced
This Method describes a technique for determining gross defects and/or mechanical damage to metallic coatings on copper or copper alloy substrates. The Method is useful for techniques where the coating does not tarnish in an alkaline polysulfide solution. Suitable coatings include gold, nickel, tin, tin-lead, palladium or their alloys. The Method consists of immersing the test area in a solution of alkaline sodium sulfite for 60 s at 74 °C and examining the test area for signs of copper reaction products using a 10x microscope. The Method gives polysulfide solution preparation, test procedure and examination and evaluation guidelines.	Visible indications of defects.

Intended Application	Specimen Requirement	Limits
Intended to ascertain the presence of defects from processing and mechanical damage from use as manifested by exposure of copper under plate or copper basis metal.	Clean surfaces.	Method is relatively insensitive to the presence of small pores. ASTM B 809 should be used instead. Method is not recommended for prediction of product performance or simulation of field failure mechanisms. Generally, corrosion products less than 0.05 mm (0.002 in.) in diameter are not counted in the evaluation. Work should be performed in a fume hood.

ASTM B 877
Standard Test Method for Gross Defects and Mechanical Damage in Metallic Coatings by the Phosphomolybdic Acid (PMA) Method

General Description	Data Produced
This test standard gives equipment and methods for using phosomolybdic acid (PMA, a solid complex of molybdenum trioxide and phosphoric acid) to detect gross defects and mechanical damage in gold, silver or palladium coatings over substrates of nickel, copper or copper alloys. The test consists of removing oxides in the defect area by exposure to hydrochloric acid fumes and applying a drop of PMA with an applicator to the area in question. PMA contact with exposed under plate or substrate causes the molybdenum trioxide to turn blue.	Visible indications of defects.

Intended Application	Specimen Requirement	Limits
To determine the presence of mechanical damage, wear-through and other gross defects in the coating. Intended for the evaluation of individual samples, one at a time, with a microscope at 10x to 30x.	Thoroughly cleaned, particle free surfaces. A test area of less than 2 mm allows examination by microscope. Test areas may require masking to prevent PMA reaction with exposed base metal edges.	This is essentially a pass/fail test. It may not be suitable for some precious metal alloy coatings that contain significant concentrations of non-precious metals (e.g., nickel or copper). PMA reacts with tin, lead and tin-lead solder. Test is relatively insensitive to small pores. Test not recommended for prediction of product performance. Test is destructive and tested pieces should not be put into service.

ISO 3274
Geometrical product Specifications (GPS) – Surface Texture: Profile Method – Nominal Characteristics of Contact (stylus) Instruments

General Description	Data Produced
This Standard defines profiles and the general structure of contact (stylus) instruments for measuring surface roughness and waviness. Instrument properties and basic specifications for profile meters and profile recorders are included. It influences chain link 5 for roughness, waviness and primary profiles in the GPS matrix model.	Not specified/applicable.

Intended Application	Specimen Requirement	Limits
The primary purpose is to enable comparison of similar surfaces or the comparison of results from different measuring instruments.	Not specified/applicable.	Not specified/applicable.

ISO 4288
Geometrical Product Specification (GPS) – Surface Texture: Profile Method – Rules and Procedures for the Assessment of Surface Texture

General Description	Data Produced
This Standard specifies the rules for comparison of the measured values with the tolerance limits for surface texture parameters defined inISO 4287, ISO 12085, ISO 13565-2 and ISO 13565-3. It includes: parameter estimation, rules for comparison (areas to be inspected, 16% rule, max.-rule, uncertainty), parameter estimation, rules and procedures for inspection, and a "Simplified procedure for roughness inspection".	Numeric values of roughness.

Intended Application	Specimen Requirement	Limits
Influences chain links 3 and 4 of ISO standards for roughness and primary profiles in the GPS matrix model.	Not specified/applicable.	Not useful for descriptions of surface defects.

ISO 8502
Preparation of Steel Substrates Before Application of Paints and Related Products – Tests for the Assessment of Surface Cleanliness
Part 1: Field test for soluble iron corrosion products
Part 2: Laboratory determination of chloride on cleaned surfaces
Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)
Part 4: Guidance on the estimation of the probability of condensation prior to paint application
Part 5: Measurement of chloride on steel surfaces prepared for painting (ion detection tube method)

General Description	Data Produced
This comprehensive standard describes eight methods for the quantitative determination of surface contaminants on blast cleaned steel, prior to paint or other coating application. Both field and laboratory measurement methods are included. Part 1 describes a semi-quantitative method for analysis of ferrous ions by swabbing the test surface with water soaked cotton and analyzing the wash liquid with an indicator strip. Part 2 describes a technique for determination of chloride by water washing and subsequent titration with mercury nitrate. Part 3 describes a method for analysis of dust contamination by controlled application of transparent pressure sensitive tape to the test surface followed by analysis of the removed tape for adherent particle size and quantity, using a hand lens and comparator charts included in the standard. Part 4: Guidance on the estimation of the probability of condensation prior to paint application based on relative humidity and steel surface temperature. Part 5 describes a field test in which water-soluble chlorides are washed from the surface and the wash liquid analyzed to determine the chloride ion concentration using a detection tube containing silver chromate in a sand carrier. The color change of the tube contents with immersion in different known chloride ion concentrations serves as the calibration for the field test.	Data collected varies with method but generally consists of concentration of contaminant per unit volume which is converted to contaminant per unit surface area.

ISO 8502, Continued
Preparation of Steel Substrates Before Application of Paints and Related Products – Tests for the Assessment of Surface Cleanliness
Part 6: Extraction of soluble contaminants for analysis – The Bresle method
Part 8: Field method for the refractometric determination of moisture
Part 9: Field method for the conductometric determination of water-soluble salts
Part 10: Field method for the titimetric determination of water-soluble chloride
Part 12: Field method for the titimetric determination of water-soluble ferrous ions

General Description	Data Produced
Part 6 describes the fabrication and use of an adhesive patch applied to the test surface into which a suitable solvent for analysis of the contaminant in question is injected. The solvent is repeatedly injected and removed with a syringe and the solvent subsequently analyzed to ascertain the contaminant level. The method is suitable for field use. Part 8 describes the measurement of moisture, generally from condensation, on a surface to which an adhesive patch described in Part 6 is used to contain a mixture of monoethylene glycol and water. The mixture is repeatedly injected and removed followed by measurement of the glycol mass fraction in a refractometer. Part 9 describes a field test for water soluble salts using the technique of Part 6. The change in conductivity of the test water due to solution of salts from the surface is measured and used to calculate the surface density of the salts. Part 10 describes a field method in which the procedure of Part 6 is used to inject water containing sodium fluoride and hydrogen fluoride. The water acts as a solvent for chloride on the surface. The chloride concentration is determined by titration with mercuric nitrate. Part 12 describes the use of the technique in Part 6, or another appropriate method, to remove contaminants from the surface and acidifying the solution with phosphoric acid. The ferrous ion concentration is determined by titration with a dichromate solution.	Data collected varies with method but generally consists of concentration of contaminant per unit volume which is converted to contaminant per unit surface area.

ISO 8502, *Continued*		
Intended Application	**Specimen Requirement**	**Limits**
Intended to determine whether a mechanically blast cleaned surface, or a surface between coating applications, meets cleanliness specifications required to achieve coating performance goals.	Not specified.	Not specified.

ISO 8785
Geometrical Product Specification (GPS) – Surface Imperfections – Terms, Definitions and Parameters

General Description	**Data Produced**
This Standard defines terms used to describe different types of surface imperfections and includes illustrative drawings. The document provides a common vocabulary for use in many types of technical publications and drawings. Fifty-five imperfections are described. Dents, warts and blisters are typical imperfections described in English and French.	Not applicable.

Intended Application	**Specimen Requirement**	**Limits**
Technical documents and specifications.	Not applicable.	Defined imperfections are not related to surface roughness.

ISO 11562
Geometrical Product Specifications (GPS) – Surface tTexture: Profile Method – Metrological Characteristics of Phase Correct Filters

General Description	Data Produced
This Standard specifies the metrological characteristics of phase correct filters for measurement of surface profiles, particularly how to separate the long and short wave content of a surface profile. The document includes definitions of relevant terms, characteristics of phase correct profile filters (including transmission characteristics of long and short wave profile components), limits of error of phase correct filters, and criteria for selection of phase correct filters. The relation of this standard to the GPS matrix model is provided.	Roughness profile.

Intended Application	Specimen Requirement	Limits
Influences links 2 and 3 in the chains of standards for primary profile in the GPS matrix model.	Not specified/applicable.	Not specified.

ISO 12085 *Geometrical Product Specification (GPS) – Surface Texture: Profile Method – Motif Parameters*	
General Description	**Data Produced**
This Standard defines terms used in the determination of surface texture by the motif method and the motif method, including a calculation method for combination of motifs. Annexes provide information on the relation between motif parameters (roughness profile, waviness profile and primary profile) and function of surfaces as well as the relation of the standard to the GPS matrix model.	Quantifiable roughness profile representation.

Intended Application	**Specimen Requirement**	**Limits**
Influences links 2, 3 and 4 of the surface texture chain of standards on roughness and waviness profile in the GPS matrix model.	Not specified/applicable.	Not specified.

ISO 13565-1
Geometrical Product Specifications (GPS) – Surface Texture: Profile Method – Surfaces Having Stratified Functional Properties
Part 1: Filtering and general measurement conditions

General Description	Data Produced
This Standard describes a filtering method for description of surfaces that have deep valleys underlying a finely finished plateau with a small amount of waviness. ISO 11562, by comparison, describes a reference line undesirably influenced by the presence of valleys. ISO 13565-1 provides a filtering approach that suppresses the valley influence on the reference line. This Standard addresses surfaces common in internal combustion cylinder liners. The filtering process to determine the roughness profile, selection of cut-off wavelength and the evaluation length and relation to the GPS matrix model are included.	Quantifiable roughness profile representation.

Intended Application	Specimen Requirement	Limits
This Standard influences links 2 and 3 in the chain of standards for roughness profile in the GPS matrix model.	Not specified.	Not specified.

ISO 13565-2
Geometrical Product Specifications (GPS) – Surface Texture: Profile Method – Surfaces Having Stratified functional Properties
Part 2: Height characterization using the linear material ratio curve

General Description	Data Produced
This document defines parameters based on the linear material ratio curve for the evaluation of the valley suppressed roughness profile defined in ISO 13565-1. The Standard includes determination of parameters, covering roughness profile, calculating equivalent straight line, and calculation of parameters for the material ratio curve.	Quantifiable roughness profile representation.

Intended Application	Specimen Requirement	Limits
This Standard addresses chain link 2 for roughness profile in the General GPS matrix.	Not specified.	Not specified.

ISO 13565-3
Geometrical Product Specifications(GPS) – Surface Texture: Profile Method – Surfaces Having Stratified Functional Properties
Part 3: Height characterization using the material probability curve

General Description	Data Produced
This Standard gives a method for calculation of parameters used to numerically characterize two components, a coarse valley texture and a fine plateau texture, through the generation of a material probability curve, determination of its linear regions and linear regressions through these regions.	Quantifiable roughness profile representation.

Intended Application	Specimen Requirement	Limits
The parameters are intended to aid in assessing tribological behavior of, for example, lubricated sliding surfaces and to control manufacturing processes.	Not specified.	Not specified.

SAE J358
Nondestructive Tests (SAE Information Report)

General Description	Data Produced
This Information Report identifies several techniques and associated SAE documents applicable for the detection and in some cases measurement of, defects which may be surface related. A table is included which provides physical principles of the techniques, appropriate materials to be inspected, applications, advantages and limitations. Infrared, magnetic particle, eddy current, penetrating radiation, ultrasonic, acoustic, and leakage techniques are briefly described.	Not specified.

Intended Application	Specimen Requirement	Limits
Information purposes.	Not specified.	Not specified.

SAE J359
Infrared Testing (SAE Information Report)

General Description	Data Produced
This is a very brief description of the infrared technique for nondestructive testing. This does not contain significant detail regarding technique or capabilities.	Not specified.

Intended Application	Specimen Requirement	Limits
Information purposes.	Not specified.	Not specified.

SAE J420
Magnetic Particle Inspection (SAE Information Report)

General Description	Data Produced
This is a very brief description of the use of magnetic particle inspection to nondestructively identify surface and near surface defects and discontinuities in ferromagnetic materials such as iron and steel.This technique aids in visual inspection and may be enhanced through the use of long wavelength ultraviolet light.	Not specified.

Intended Application	Specimen Requirement	Limits
Not specified.	Not specified.	Not specified.

SAE J425
Electromagnetic Testing by Eddy-Current Methods (SAE Information Report)

General Description	Data Produced
This Report gives very general descriptions on the uses of eddy current testing, a nondestructive technique, for inspection of surface defects, principles of operation and procedures. The Report is not intended to give detailed guidance. ASTM Standards and other documents are identified as sources of additional information.	Data varies with instrument design and manufacturer.

Intended Application	Specimen Requirement	Limits
General information.	Surface free of loose scale and other material.	Hot rolled material with thin, tight scale – seams as shallow as 0.25 mm (0.010 in.) are detected. Polished (ground) surfaces- seams and cracks as shallow as 0.025 mm (0.001 in.) are detected.

SAE J426
Liquid Penetrant Test Methods (SAE Information Report)

General Description	Data Produced
This Report provides a brief description of the principle of the use of liquid penetrant inspection. In this technique, a liquid is applied to a surface and excess fluid removed and remaining penetrant trapped in surface imperfections such as cracks or pores is detected when a "developer" is applied. The developer shows the presence of remaining liquid. Short descriptions of types of penetrants, developers and methods of penetrant removal are provided. Related SAE and ASTM documents are listed.	Visible indications of surface discontinuities.

Intended Application	Specimen Requirement	Limits
General information.	Clean parts without paint or other surface coatings which can mask imperfections of interest on metal or other non-porous materials.	Not specified.

SAE J428 *Ultrasonic Inspection (SAE Information Report)*	
General Description	**Data Produced**
This document provides brief descriptions of the uses (including surface discontinuities) of ultrasonic techniques, principles of operation, types of tests with limited discussion of advantages and disadvantages.	Not specified.

Intended Application	Specimen Requirement	Limits
Not specified.	Not specified.	Not specified.

SAE J1242 *Acoustic Emission Test Methods (SAE Information Report)*	
General Description	**Data Produced**
This Report gives brief descriptions of the operating principle and procedure for acoustic emission detection and monitoring of changes such as crack growth in a material.	Varies with instrument.

Intended Application	Specimen Requirement	Limits
Provides information on this nondestructive technique to determine whether further consideration is warranted.	Not specified.	Not specified.

SAE AMS 2440A
Inspection of Ground, Chromium Plated Steel Parts
(Aerospace Material Specification)

General Description	Data Produced
This Specification covers the requirements, procedures, and acceptance/rejection criteria for inspecting ground chromium plated surfaces for grinder induced damage to the chromium plate substructure. Examples of damage revealed by fluorescent dye inspection are provided.	Visual appearance of cracks when viewed with black light.

Intended Application	Specimen Requirement	Limits
Not specified.	Specimens should be temper etch inspected and magnetic particle inspected prior to plating. Ground plated parts are cleaned and dried to remove any material that would interfere with the inspection.	Inspection shall be conducted by certified inspectors (STN-TC-1A, Level II). Questionable inspections shall be resolved by a Level III penetrant inspector. Procedure is as specified in ASTM E-1417. Temper etch is per AMS 2649 and magnetic particle inspection is per ASTM E 1444.

4.2 Products (bare and coated)

4.2.1 Fasteners

ASTM F 788/F 788M
Standard Specification for Surface Discontinuities of Bolts, Screws, and Studs, Inch and Metric Series

General Description	Data Produced
This Specification establishes allowable limits for various types of surface discontinuities that result from manufacture of bolts, nuts screws and studs. The specification covers metric series with nominal diameters of 4mm and greater and minimum tensile strengths of 800 MPa and inch series with nominal diameters of No. 5 (0.1250 in.) and larger and with specified minimum tensile strengths of 90,000 psi and greater. The Specification describes types of discontinuities, limits of size and location permitted, inspection and evaluation. Inspection is visual with magnification to 10x allowed.	Visible evidence of surface defects.

Intended Application	Specimen Requirement	Limits
Intended for establishment of purchase specifications.	Not specified.	Not specified.

ASTM F 812/F 812M
Standard Specification for Surface Discontinuities of Nuts, Inch and Metric Series

General Description	Data Produced
This Specification establishes allowable limits for various types of surface discontinuities that result from manufacture of metric series nuts with nominal diameters 5 mm and larger and inch series nuts with nominal diameters 0.250 inch and larger. Types of discontinuities are described, limits on discontinuity size and location provided, test method (ASTM F 606) for strength of nuts specified, visual inspection and evaluation procedures described.	Visible evidence of surface defects.

Intended Application	Specimen Requirement	Limits
Intended for establishment of purchase specifications.	Not specified.	The limits established for metric nuts with nominal diameters of 5 mm to 24 mm are essentially identical to those in ISO/DIS 6157/II. There are no ISO standards for nuts greater than 24 mm.

ISO 4042
Fasteners – Electroplated coatings

General Description	Data Produced
This is a broad Standard which addresses the dimensional requirements for coating thickness for steel and copper alloy fasteners and gives recommendations for hydrogen embrittlement relief for high tensile strength or hardness and for surface hardened fasteners. The following issues are addressed: dimensional requirements before and after electroplating, situations which call for hydrogen embrittlement relief, corrosion protection, coating thickness requirements and measurement. Ordering requirements and surface coating designation systems are identified. Annexes address: hydrogen embrittlement relief; salt spray corrosion protection performance; guidance for procedures to accommodate thick coatings; determination of batch average thickness; designation code for coatings; and, surface areas of bolts, screws and nuts.	Measured characteristics or performance required by specifications.

Intended Application	Specimen Requirement	Limits
Provides a basis for description of and specification of threaded fasteners coated by electroplating. It may also be applied to non-threaded parts such as washers and pins.	Varies with property measured.	Recommended coatings may be applied to screws that cut their own threads (wood screws, self tapping screws, etc.) with maximum batch average thickness given in the standard ignored unless otherwise specified. Hydrogen embrittlement is a major issue highlighted. Note is made that complete elimination of hydrogen embrittlement cannot be assured and alternative procedures to those in the standard should be evaluated, as appropriate.

ISO 6157-1
Fasteners – Surface Discontinuities
Part 1: Bolts, screws and studs for general requirements

General Description	Data Produced
This Standard details the causes, appearance and limits for the following surface discontinuities: quench cracks, forging cracks, forging bursts, shear bursts, raw material seams and laps, voids, folds and tool marks. It applies to bolts, screws and studs with nominal thread diameters 5 mm and larger, product grades A and B and property classes up to and including 10.9 unless otherwise specified in product standards or purchasing agreements.	Varies with technique.

Intended Application	Specimen Requirement	Limits
Establishes limits for surface discontinuities.	Product of interest must be sufficiently clean to be examined visually or non-destructively (e.g., eddy current or magnetic method). Secondary samples examined by cross-sectioning if first examination indicates surface discontinuities.	Limits (size of discontinuity) vary with type and size of item.

ISO 6157-2
Fasteners – Surface Discontinuities
Part 2: Nuts

General Description	Data Produced
This Standard details the causes, appearance and limits of the following surface discontinuities: quench cracks, forging and inclusion cracks, cracks in the locking element of all – metal prevailing torque type nuts, cracks in the washer ring of nuts with captive washers, shear bursts, bursts, seams, folds, voids and tool marks. It applies to nuts with nominal thread diameters from 5 mm through 39 mm, product grades A and B and all property classes according to ISO 898-2 and ISO 898-6 unless otherwise agreed to in product standards or purchasing agreements.	Varies with technique.

Intended Application	Specimen Requirement	Limits
Establishes limits for surface discontinuities.	Product of interest shall be sufficiently clean to be examined visually at 10x magnification and with appropriate nondestructive methods. ISO 10484, Widening test on nuts, and ISO 10485, Cone proof load on nuts are identified as destructive or referee tests when necessary.	Limits (size of discontinuity) vary with type and size of item.

ISO 6157-3
Fasteners – Surface Discontinuities
Part 2: Bolts, screws and studs for special requirements

General Description	Data Produced
This Standard details the causes, appearance and limits of the following surface discontinuities: quench cracks, forging cracks, forging bursts for hexagonal head and circular head screws, shear bursts for hexagonal and circular head screws, forging cracks in socket head screws, raw material seams and laps, voids, folds, tool marks, laps on the thread, and damages. It applies to bolts, screws and studs with nominal thread diameters of 5 mm and larger; product grads A and B, nominal lengths l < 10d; property class 12.9 or property classes 8.8, 9.8, 10.9 when so specified or agreed to in purchasing agreements.	Varies with technique.

Intended Application	Specimen Requirement	Limits
Establishes limits for surface discontinuities.	Surface coating shall be removed before inspection by visual or nondestructive test. Destructive testing by sectioning at 90° through the discontinuity shall be conducted when nondestructive or visual examination indicates defective products.	Limits (size of discontinuity) vary with type and size of item.

SAE J121
Decarburization in Hardened and Tempered Unified Thread Fasteners (SAE Recommended Practice)

General Description	Data Produced
This Recommended Practice describes measurement classification and specification of decarburization of hardened and tempered steel bolts, screws, studs etc. Microscopic examination of polished and etched cross-sections and microhardness (Knoop 500g, Vickers DPH 300g) measurements are interpreted with respect to cross-section decarburization to establish Class C and Class D inch series threaded products. Definitions of degrees of decarburization are provided.	Microstructure or microhardness indicative of carbon content changes.

Intended Application	Specimen Requirement	Limits
Microscopic examination is intended for inspection purposes, hardness is intended or reference purposes.	Metallographically prepared cross-sections of fasteners.	Not intended to cover steel products which are carburized to achieve special properties.

SAE J122
Surface Discontinuities on Nuts (SAE Recommended Practice)

General Description	Data Produced
This Practice defines, illustrates and specifies allowable limits for eight types of discontinuities on metric series nuts 6.3 mm to 25 mm and inch – series nuts 0.250 in. to 1 in. which are primarily intended for automotive assemblies. Inspection procedures and a sampling plan are included.	Varies with inspection technique, generally visual.

Intended Application	Specimen Requirement	Limits
General information and inspection.	Representative lot samples.	Does not include sampling requirements.

SAE J123
Surface Discontinuities on Bolts, Screws, and Studs in Fatigue Applications (SAE Recommended Practice)

General Description	Data Produced
This document defines, illustrates and specifies allowable limits for surface discontinuities (cracks, seams, bursts, voids, laps, folds, tool marks, nicks and gouges) in bolts, screws and studs primarily intended for automotive applications subjected to severe dynamic stresses (fatigue) where high strength fasteners with fatigue resistance is required. Sampling plans for visual and microscopic inspection are appended.	Observable discontinuities which determine acceptance or rejection of batch.

Intended Application	Specimen Requirement	Limits
Intended for visual inspection of batches of fasteners, and metallographic examination for laps and seams.	As-manufactured items.	Defect limitations are provided primarily as location and orientation specific features.

SAE J1061
Surface Discontinuities on General Application Bolts, Screws, and Studs (SAE Recommended Practice)

General Description	Data Produced
This Practice defines, illustrates and specifies allowable limits for surface discontinuities on bolts, screws and threads in sizes through 24 mm or 1 in. in diameter, lengths to 150 mm or 6 in. with minimum specified tensile strengths of 900 MPa or 120,000 psi and greater intended for use in automotive assemblies. Brief descriptions of inspection and sampling are included.	Varies with inspection method.

Intended Application	Specimen Requirement	Limits
General information and guidance.	Samples representative of the lot(s) of interest.	Does not include sampling requirements.

4.2.2 Sheet and Structural Steel

ASTM D 4417
Standard Test Methods for Field Measurement of Surface Profile of Blast-Cleaned Steel

General Description	Data Produced
This method describes measurement of the surface profile of abrasive cleaned steel using: a. visual comparison with materials of known profile depths; b. measurement of the surface with a fine pointed probe; c. micrometer measurement of a replica of the surface.	Method (a) is a visual examination with 5x or 10x optical magnification and comparison to prepared surfaces. Method (b) provides a dial gage reading. Method (c) provides a micrometer reading.

Intended Application	Specimen Requirement	Limits
Specification acceptance.	Flat, clean surfaces.	For 37 μm to 135 μm peak to height correlation coefficients of: 0.75 visual, 0.99 – probe, 0.93 – tape have been determined. More extensive descriptions of repeatability, reproducibility and precision are provided.

ASTM E 430
Standard Test Methods for Measurement of Gloss of High-Gloss Surfaces by Goniophotometry

General Description	Data Produced
Two test methods for measuring the reflection characteristics responsible for the glossy appearance of high gloss surfaces are covered. These methods evaluate surface characteristics at specular angles of 30° and 20° using commercial instruments. Details of the apparatus and sources, other ASTM methods and guides relevant to the measurement, calibration standards, preparation and standardization of the apparatus, procedure, calculation of gloss and other parameters, reporting, precision and bias are included.	Instrument readings of parameters at various angles and use of these readings to calculate relevant characteristics.

Intended Application	Specimen Requirement	Limits
Measurement of properties for automotive, architectural or other applications to facilitate different components to be specified with matching glossy appearance. Originally applied to bright metals, now applied to automotive and other finishes.	Flat and at least 70 mm (2.75 in.) in the smallest dimension.	Not suitable for diffuse finish surfaces or measurement of color.

ASTM E 1418
Standard Test Methods for Visible Penetrant Examination Using the Water-Washable Process

General Description	Data Produced
This Method describes the use of a water washable visible penetrant for detection of surface discontinuities that are open such as cracks, laps and isolated pores. The Method can be used for non-porous metallic and nonmetallic materials. A liquid penetrant is applied to a surface, allowed to enter discontinuities, washed off with water and a developer applied to draw remaining penetrant out. The Method includes descriptions of reagents and penetrants, procedure, a flow sheet for the general procedure, personnel qualification and requalification requirements.	Visible discontinuities.

Intended Application	Specimen Requirement	Limits
Used for the production examination of large volumes of parts or structures where the emphasis is on productivity.	Surface should be cleaned of grease, dirt and loose debris.	Users and suppliers may require the certification of examination staff per identified ASNT, MIL STD or ANSI recommended practices. In some cases test pieces with real or simulated discontinuities of the smallest expected features may be required.

SAE J810
Classification of Common Surface Imperfections in Sheet Steel (SAE Information Report)

General Description	Data Produced
This Report provides illustrations of 26 common surface imperfections in sheet steel which can be seen with the naked eye. The imperfections are defined, photographically and schematically illustrated, and causes identified.	Not specified.

Intended Application	Specimen Requirement	Limits
Defect/imperfection description for purposes of classification.	Not specified.	Not specified.

SAE J911
Surface Roughness and Peak Count Measurement of Cold Rolled Steel Sheet (SAE Recommended Practice)

General Description	Data Produced
This Practice provides guidance on the measurement of the Roughness Average (Ra) and Peak Count (PC) on the surface of cold-rolled steel. The document relies on ASME B 46.1 for instrumentation specifics. Definitions, equipment, test conditions, materials, procedures and calibration are included. Technique is stylus based.	Data produced varies with instrument.

Intended Application	Specimen Requirement	Limits
General information and guidance.	Specimens representative of the material as produced and removed from an area at least 50 mm (2 in.) from the coil edge. Rolling direction should be identified and the sample be flat and roughly 150 mm (6 in.) long parallel to the rolling direction and 100 mm (4 in.) wide.	The instrument should be calibrated for average surface roughness with a nominal Ra value in the range, typically, of 0.25 μm to 2.5 μm (10 μm to 100 μin.). The standard value for the peak count level should be 1.25 μm (50 μin.) and the standard filter cutoff length for average roughness and peak count measurements on cold-rolled steel should be 0.8 mm (nominally 0.03 in.).

SAE AMS 2649B
Etch Inspection of High Strength Steel Parts
(Aerospace Material Specification)

General Description	Data Produced
This Specification establishes the requirements for detection of overheating by grinding or machining of high strength low alloy steel (tensile strength of 1241 MPa (180 ksi) and higher) and of carburized material in the heat treated condition. The procedure consists of cleaning, etching and visually inspecting for color changes/ variations. Acceptance criteria are included.	Visual indications of overheating.

Intended Application	Specimen Requirement	Limits
Intended for the inspection of bare material and carburized parts.	Guidance for cleaning, including Government documents specifying chemicals, is provided.	SAE ARP 1923 Qualification and Certification of Etch Inspectors are included by reference.

4.2.3 Castings

ASTM A 802/A 802M
Standard Practice for Steel Castings, Surface Acceptance Standards, Visual Examination

General Description	Data Produced
This Practice covers the acceptance criteria for steel castings using visual examination and comparing surface texture, roughness and discontinuities to Steel Castings Research and Trade Association graded reference comparators.	Surface texture, nonmetallic inclusions, gas porosity, solidification discontinuities, sand expansion discontinuities, metal inserts, thermally cut surfaces, mechanically prepared surfaces, welded surfaces.

Intended Application	Specimen Requirement	Limits
Quality control (QC), specification acceptance.	Not specified.	This technique is qualitative.

ISO 11971
Visual Examination of Surface Quality of Steel Castings

General Description	Data Produced
This Standard provides comparisons of standards prepared by the Bureau de Normalisation des Industries de la Founderie (BNIF) and Steel Castings Research and Trade Association (SCRATA) for the visual inspection of surface roughness and surface discontinuities on steel castings.	Not applicable.

Intended Application	Specimen Requirement	Limits
Purchase specifications.	Not applicable.	Qualitative descriptions of surface roughness are determined.

4.2.4 Other

ISO 14104 *Gears – Surface Temper Etch Inspection After Grinding*	
General Description	**Data Produced**
This Standard describes the cleaners, etchants and procedures used to determine and evaluate localized overheating on ground steel surfaces. The method is applicable to gears, shafts, splines and bearings. A surface temper classification system is provided which is based on the visual appearance of the etched surface. ISO 14104 was prepared by The American Gear Manufacturers Association (AGMA) as ANSI/AGMA 2007-B92.	Visual indication of tempering.

Intended Application	**Specimen Requirement**	**Limits**
Qualitative indication of tempering due to surface grinding suitable for process control and purchase specifications.	Debris free degreased surface.	Not applicable to nitrided or stainless steels. Approximately 0.003 mm of stock is removed by nitric acid etching each time the process is performed and may require masking of close tolerance areas. Users are advised to set their own reference standards.

ISO 13665
Seamless and Welded Steel Tubes for Pressure Purposes – Magnetic Particle Inspection of the Tube Body for the Detection of Surface Imperfections

General Description	Data Produced
This document specifies requirements for magnetic particle particle inspection of seamless and welded steel tubes according to four different acceptance levels. The Standard includes: Method of test, Evaluation of indications, Acceptance criteria and Reporting requirements.	Visual indication.

Intended Application	Specimen Requirement	Limits
Intended to be used to detect surface imperfections on outer surfaces of tubes as required by product standards.	Surface should be clean and free of matter which would interfere with indicating particles.	Type and dimension of imperfections detected are dependent on tube manufacturing process and surface finish.

SAE J349
Detection of Surface Imperfections in Ferrous Rods, Bars, Tubes and Wires (SAE Information Report)

General Description	Data Produced
This information Report provides a brief description of techniques for detecting surface imperfections and associated SAE documents which provide more detail. Destructive and non-destructive methods of measuring (quantifying) imperfections are also identified.	Inspection of features which are open to the surface of ferrous bars, tubes, wires; including, seams, laps, pits, scratches, nicks, gouges.

Intended Application	Specimen Requirement	Limits
Information only.	Not specified.	Applicable only to features open to the surface of the article inspected.

SAE AMS 2633B
Ultrasonic Inspection (Aerospace Material Specification)

General Description	Data Produced
This document covers ultrasonic inspection of tubular, centrifugally-cast, corrosion resistant steel cylinders. Applicable ASTM, MIL-STD, ANSI, ASNT and ATA documents as are equipment couplants, reference standards, procedures, and QA provisions.	Varies with instrument.

Intended Application	Specimen Requirement	Limits
Typically used to locate defects such as cracks, voids, spongy areas.	OD and ID surfaces machined to be not rougher than 3.2 μm (125 μin.) (per ANSI B46.1). Surface discontinuities remaining after surface preparation shall not be removed before ultrasonic inspection. Surfaces shall be free of loose scale, particles, oil, grease or other foreign materials.	Not applicable to austenitic alloys where grain boundaries may mask results. Personnel shall be certified per MIL-STD-410.

SAE AMS 2647B
Fluorescent Penetrant Inspection Aircraft and Engine Component Maintenance (Aerospace Material Specification)

General Description	Data Produced
This specification is an extensive guide to the inspection of aircraft and engine components for defects present at an exposed surface using fluorescent penetrant(s). The Specification describes, in detail, procedures for surface preparation, cleaning, defect calibration standards, inspection process, equipment requirements, quality assurance provisions, definition of terms, safety, applicable SAE, ASTM, MIL-STD, ATA, AIA specifications including personnel requirements.	Visual signs of defects.

Intended Application	Specimen Requirement	Limits
Intended for the detection of defects by maintenance and overhaul facilities in the inspection of aircraft and engine components and associated accessories when fluorescent penetrant inspection is specified, but not limited to such applications.	Comprehensive guidance is provided for, primarily, cleaning to remove contaminants which can impede inspection. Considerations for coatings and platings are included.	Defect calibration standards cover cracks in the range of 0.38 mm to 6.35 mm (0.015 in. to 0.250 in.) in five size groups.

5. Surface Finish Evaluation

5.1 General (bare and coated)

ASTM E 1813
Standard Practice for Measuring and Reporting Probe Tip Shape in Scanning Probe Microscopy

General Description	Data Produced
This Practice provides a method for measuring the size and shape of a stylus used in scanning probe microscopy (see ASTM F 1438, for example). Sample shapes and probe characterizers are used for gaining data required for stylus measurement. The Practice includes descriptions of probe and characterizer shapes, procedure and information on analytical probe approximations.	Data can be numeric or graphic.

Intended Application	Specimen Requirement	Limits
Probe shape and orientation data are necessary for determination of which data can reliably be extracted from a scan.	Not specified.	Precision can be affected by characterizer roughness and instrument factors.

ASME B46.1-2002
Surface Texture (Surface Roughness, Waviness, and Lay)
(American National Standard)

General Description	Data Produced
ASME B46.1 is a comprehensive primer on surface texture and has been updated since its introduction in 1940. The current Standard includes the following sections: Terms Related to Surface Texture; Classification of Instruments for Surface Texture Measurement; Terminology and Measurement Procedures for Profiling, Contact, Skidless Instruments; Measurement Procedures for Contact, Skidded Instruments; Measurement Techniques for Area Averaging; Nanometer Surface Texture and Step Height Measurements by Stylus Profiling Instruments; Nanometer Surface Roughness as Measured with Phase Measuring Interferometric Microscopy; Filtering of Surface Profiles; Terminology and Procedures for Evaluation of Surface Textures Using Fractal Geometry; Specifications and Procedures for Precision Reference Specimens; and Specifications and Procedures for Roughness Comparison Specimens. Non-mandatory Appendices A through I provide valuable supporting information.	Data produced varies with instrument.

Intended Application	Specimen Requirement	Limits
Intended to provide a comprehensive, current standard for surface texture measurement.	Surface must be clean of any material which would interfere with a measurement.	Sources of uncertainty are identified for the techniques.

ISO 4287
Geometrical Product Specifications (GPS) – Surface Texture: Profile Method – Terms, Definitions and Surface Texture Parameters

General Description	Data Produced
This Standard specifies terms, definitions and parameters for the determination of surface roughness, waviness and primary profile by profiling methods.	Not specified/applicable.

Intended Application	Specimen Requirement	Limits
This document underlies other standards which describe GPS in detail.	Not specified/applicable.	Not specified/applicable.

ISO 8501-1
Preparation of Steel Substrates Before Application of Paints and Related Products – Visual Assessment of Surface Cleanliness

General Description	Data Produced
This is an Informative Supplement which provides photographic examples of the change of appearance imparted to steel when blast-cleaned with different abrasives to remove rust (Grade C) to preparation grade Sa3, prior to painting. Procedure for use of the comparison photographs is provided.	Visual comparison.

Intended Application	Specimen Requirement	Limits
Pre-painting inspection.	Steel panels.	Qualitative analysis.

SAE J448a
Surface Texture (SAE Standard)

General Description	Data Produced
This document defines terms used in describing surface texture, establishes classifications for degrees of roughness and waviness for lays and gives symbols indicating surface characteristics in drawings. The document does not specify surfaces for specific application, means of processing or any other surface characteristics such as luster, appearance, properties or performance.	Not specified.

Intended Application	Specimen Requirement	Limits
General information.	Not specified.	Not specified.

SAE J449a
Surface Texture Control (SAE Recommended Practice)

General Description	Data Produced
This Practice describes the use of control specimens that are used to facilitate inspection of surfaces prepared at different geographic locations. The document is succinct, giving an outline of steps for control of surface texture.	Comparison of test pieces with control samples varies with inspection method.

Intended Application	Specimen Requirement	Limits
General information.	Roughness and waviness heights are identified for specific control specimens.	Not specified.

5.2 Methods for Specific Products and Processes

ASTM F 1438
Standard Practice for Determination of Surface Roughness by Scanning Tunneling Microscopy for Gas Distribution System Components

General Description	Data Produced
This Method defines the analysis of surface texture using scanning tunneling microscopy (STM) in air or inert liquids; includes interferences, apparatus, sampling, calibration, conditioning, procedure, calculations, and interpretation of data. STM is a non-contact method that can measure surface features in the nanometer range.	Primary data from the test method is graphical.

Intended Application	Specimen Requirement	Limits
Used where surface texture is a selection criteria.	Intended for use on stainless steel with surfaces smoother than Ra = 0.25 μm. Does not cover steels with an oxide layer too thick to permit tunneling.	Repeatability standard deviation (RSD) for successive results obtained by the same operator in the same apparatus with the same sample: Zmax 39 % RSD Ra 31 % RSD

ISO 8503
Preparation of Steel Substrates Before Application of Paints and Related Products – Surface Roughness Characteristics of Blast-Cleaned Steel Substrates
Part 1: Specifications and definitions for ISO surface profile comparators for the assessment of abrasive blast-cleaned surfaces

General Description	Data Produced
ISO 8503 addresses the characterization of steel surfaces which have been blast cleaned with either shot abrasives or grit abrasives prior to painting or application of other coatings. Part 1 specifies the requirements for ISO surface profile comparators which are intended for visual or tactile comparison with blasted steel surfaces. The comparators are made by forming positive replicas (of electroformed nickel, for example) from mild steel master coupons. Separate comparators, with four roughnesses each, are required for shot or grit blasted surfaces. Nominal roughnesses for shot blasted comparators are 25 μm, 40 μm, 70 μm and 100 μm. Nominal roughnesses for grit blasted comparators are 25 μm, 60 μm, 100 μm and 150 μm. Test pieces are rated fine, medium or coarse when matched to the appropriate comparator.	Not specified.

Intended Application	Specimen Requirement	Limits
Process control and specification compliance on-site before application of paints or other coatings.	Comparators should be treated as an instrument and maintained in a clean, grease free condition.	Supports accompanying standards and, where appropriate, may be used to assess surfaces cleaned by other types of blast-cleaning. May be used on surfaces not to be painted.

ISO 8503
Preparation of Steel Substrates Before Application of Paints and Related Products – Surface Roughness Characteristics of Blast-Cleaned Steel Substrates
Part 2: Method for the grading of surface profile of abrasive blast-cleaned steel – Comparator procedure

General Description	Data Produced
Part 2 gives the procedure for comparing the surface of the test piece with each of the four blasted areas on the comparator using visual technique (hand lens up to 7x) or tactile technique.	Visual or tactile comparison.

Intended Application	Specimen Requirement	Limits
Process control and specification compliance on site before application of paints or other coatings.	Dust and debris free surface.	Qualitative evaluation of fine, medium or coarse roughness.

ISO 8503
Preparation of Steel Substrates Before Application of Paints and Related Products – Surface Roughness Characteristics of Blast-Cleaned Steel Substrates
Part 3: Method for the calibration of ISO surface profile comparators and for the determination of surface profile – Focusing microscope procedure

General Description	Data Produced
Part 3 addresses the measurement of surface roughness using a microscope either directly on the test piece or replica, or comparator described in Part 1. The method consists of making a series of maximum peak-to-valley measurements by measuring the distance of microscope stage or objective lens travel from focus on a peak to focus on a valley. The technique requires a microscope with a graduated vernier scale with a scale value of not more than 1 μm.	Numerical peak-to-valley values.

Intended Application	Specimen Requirement	Limits
Calibration of comparators and test piece measurement.	Dust and debris free surface.	The technique is applicable for determination of surface profile within the range for maximum peak-to-valley of 20 μm to 200 μm. The microscope's acceptable depth of field is 2 μm.

ISO 8503
Preparation of Steel Substrates Before Application of Paints and Related Products – Surface Roughness Characteristics of Blast-Cleaned Steel Substrates
Part 4: Method for the calibration of ISO surface profile comparators and for the determination of surface profile – Stylus instrument procedure

General Description	Data Produced
Part 4 addresses the measurement of surface roughness using a stylus with a diamond tip of radius 5 ± 1μm. The method is applicable to the measurement of comparators (Part 1) or to test pieces or replicas. Procedures and calculation are included.	Numerical peak-to-valley values.

Intended Application	Specimen Requirement	Limits
Calibration of comparators and test piece measurement.	Dust and debris free surface.	Qualitative evaluation of fine, medium or coarse.

ISO 8503
Preparation of Steel Substrates Before Application of Paints and Related Products – Surface Roughness Characteristics of Blast-Cleaned Steel Substrates
Part 5: Replica tape method for the determination of the surface profile

General Description	Data Produced
Part 5 addresses the use of a replica tape in measuring surface roughness. Procedures for use of the tape, and a micrometer gage, for the measurement are given.	Numerical peak-to-valley values.

Intended Application	Specimen Requirement	Limits
For on-site measurement of surface profiles before application of paint or other coatings.	Dust and debris free surface.	Applicable within the range of profiles cited for a given grade or thickness of replica tape, typically peak-to-valley profiles of 20 μm to 115 μm.

6. General Product Quality Standards for Specific Coating Processes

6.1 Anodic Coatings

ISO 7599
Anodizing of Aluminum and its Alloys – General Specifications for Anodic Coatings on Aluminum

General Description	Data Produced
This Standard gives general specifications for anodic coatings on aluminum. It defines characteristic properties, lists test methods (ISO Standards) for thickness and mass per unit area, quality of sealing, appearance and color, corrosion resistance, resistance to crazing by deformation, fastness to light and ultraviolet radiation, light reflection properties, electrical breakdown potential, and continuity of the coating. A classification system for anodic coatings is provided based on minimum average thickness in micrometers.	Varies with property of interest.

Intended Application	Specimen Requirement	Limits
Intended to provide a broad inventory of test methods useful in specifying a product or material. The Standard is applicable mainly to coatings of aluminum oxide which are formed on aluminum by an electrolytic oxidation process in which the aluminum acts as the anode.	Varies with property measured.	Not applicable to: (a) non-porous coatings of the barrier type (b) oxide coatings intended to prepare the substrate for subsequent application of organic coatings or electrode position of metals; (c) "Hard anodized" coatings where wear and abrasion resistance are the primary characteristics.

6.2 Conversion Coatings

ISO 3613
Chromate Conversion Coatings on Zinc, Cadmium, Aluminum-Zinc Alloys and Zinc-Aluminum Alloys – Test Methods

General Description	Data Produced
This Standard gives methods for determination of: the presence of colorless chromate conversion coatings; presence and quantity of hexavalent chromium and colored coatings; total chromium content per unit area; mass per unit area of colorless and colored coatings, satisfactory adhesion of chromate conversion coatings and quality of chromate coating. The test methods are generally spot tests or absorption cell measurement with procedures and test solution preparation provided. Adhesion testing is conducted by rubbing the coating with paper and examining for evidence of coating rubbed off. Corrosion resistance is by ISO 9227-salt spray tests.	Color changes indicate presence of species of interest or absorption cell changes for quantitative measures.

Intended Application	Specimen Requirement	Limits
Provides a basis for purchase specifications.	Clean grease free surfaces.	Methods are applicable to (1) colorless and colored chromate conversion coatings containing tri- and hexavalent chromium produced by chemical or electrochemical processes and (2) only to chromate coatings that are free from any supplementary coatings such as oil, water or solvent-based polymers or wax. Substances or procedures are specified that can be injurious to health. Adequate safety precautions are required.

ISO 4520
Chromate Conversion Coatings on Electroplated Zinc and Cadmium Coatings

General Description	Data Produced
This Standard specifies the requirements for chromate conversion coatings on zinc and cadmium intended to give protection against corrosion. A method of application is described in general terms, a classification/designation system is provided and requirements for corrosion resistance based on classification/ designation. Adhesion properties are to be determined by ISO 3613.	Varies with property of interest.

Intended Application	Specimen Requirement	Limits
Provides a basis for purchase specifications.	Varies with property measured.	Finishes for giving particular colors only or specifically to improve paint adhesion are not covered in this standard.

6.3 Galvanized Coatings

ASTM A 896
Standard Practice for Conducting Case Studies on Galvanized Structures

General Description	Data Produced
This Practice gives procedures for conducting case-studies on permanent galvanized structures. The document gives recommendations for visual inspection, general procedure, data to be collected and appropriate forms to be completed. General surveys and accurate monitoring of thickness are covered. For accurate measurement, method B 499 using an electronic magnetic-flux gage is recommended. For general surveys, a hand held magnetic gage using the magnetic attraction principle in accordance with ASTM E 376 is identified.	Coating thickness.

Intended Application	Specimen Requirement	Limits
Determination of the condition of galvanized coatings on buildings, bridges, industrial and other structures.	Surfaces clean of debris.	Method B 499 can achieve accuracies of ± 3 to ± 5% using commercial instruments.

6.4 Electroplated Coatings

ISO 1456
Metallic Coatings – Electrodeposited Coatings of Nickel Plus Chromium and of Copper Plus Nickel Plus Chromium

General Description	Data Produced
This Standard specifies the requirements for decorative, electroplated nickel plus chromium, and copper plus nickel plus chromium coatings on iron, steel, zinc alloys, copper and copper alloys and aluminum and aluminum alloys to provide an attractive appearance and enhanced corrosion resistance. Coating designations which are appropriate to various service conditions are given in terms of thickness and type. Methods of measurement of cracks and pores in chromium coatings, ductility of electrodeposited nickel, and sulfur content of electrodeposited nickel are detailed. Other property measurements are identified by reference to ISO or ASTM Standards.	Varies with property of interest.

Intended Application	Specimen Requirement	Limits
Provides a basis for purchase specifications.	Varies with property measured.	Does not apply to surface condition of substrate metal prior to coating. Does not apply to coatings on sheet, strip or wire in the non-fabricated form or to threaded fasteners or coil springs.

ISO 1458
Metallic Coatings – Electrodeposited Coatings of Nickel

General Description	Data Produced
This Standard gives requirements for nickel electrodeposited coatings that are applied to iron, steel, zinc alloys, copper and copper alloys, aluminum and aluminum alloys for decorative and corrosion resistance purposes. Copper plus nickel coatings applied to iron, steel and zinc alloys are also included. Service condition numbers and coating designations are defined. Requirements for appearance, local thickness, adhesion, ductility, corrosion resistance, stress relief treatments, hydrogen embrittlement relief treatments and sampling are included. ISO thickness measurement methods are referenced. Ductility is determined by bending the coated test piece over a mandrel. Sulfur content of nickel coatings is determined by combustion and iodate titrimetry or by sulfide formation and iodate titrimetry.	Varies with property of interest.

Intended Application	Specimen Requirement	Limits
Provides a basis for purchase specifications.	Clean, grease free surfaces.	The standard does not specify the surface condition required by the substrate prior to coating, and is not applicable to coatings on sheet strip or wire in the non-fabricated form nor to threaded fasteners or coil springs.

ISO 2081
Metallic Coatings – Electroplated Coatings of Zinc on Iron or Steel

General Description	Data Produced
This Standard specifies requirements for a range of electroplated coatings of zinc for the protection of iron and steel against corrosion in various service environments. Information which must be supplied to an electroplater, a classification code, heat treatment including hydrogen embrittlement relief, and simple test methods for thickness and adhesion measurement (by hand burnishing) are provided. Relevant ISO Standards for specification or measurement of some properties are cited.	Quantitative measures of coating thickness are specified. Qualitative measures of adhesion.

Intended Application	Specimen Requirement	Limits
Provides a basis for purchase specifications including heat treating requirements before and after plating.	Base metal surface requirements are qualitative. Plated surfaces should be free of visible defects.	This Standard does not apply to: sheet, strip or wire in the unfabricated form; close-coiled springs; other than protective or decorative purposes. Surface condition of base metal is not specified. The importance of conversion coatings is recognized but those coatings are described in ISO 4520.

ISO 2082
Metallic Coatings – Electroplated Coatings of Cadmium on Iron or Steel

General Description	Data Produced
This Standard specifies requirements for a range of electroplated coatings of cadmium for the protection of iron and steel against corrosion in various service environments. Information which must be supplied to an electroplater, a classification code, heat treatment including hydrogen embrittlement relief, and simple test methods for thickness and adhesion measurement (by hand burnishing) are provided. Relevant ISO Standards for specification or measurement of some properties are cited. This standard is very similar to ISO 2081.	Quantitative measures of coating thickness are specified. Qualitative measures of adhesion.

Intended Application	Specimen Requirement	Limits
Provides a basis for purchase specifications including heat treating requirements before and after plating.	Base metal surface requirements are qualitative. Plated surfaces should be free of visible defects.	This Standard does not apply to: sheet, strip or wire in the unfabricated form; close-coiled springs; other than protective or decorative purposes. Surface condition of base metal is not specified.The importance of conversion coatings is recognized but those coatings are described in ISO 4520. Purchasers must specify the classification code required, not only ISO 2082.

6.5 Diffusion Coatings

ASTM B 874
Standard Specification for Chromium Diffusion Coating Applied by Pack Cementation Process

General Description	Data Produced
This Specification gives requirements for chromium diffusion of metals by the pack cementation process. A brief description of the process, definition of terms used in the process, classification by base metal category, ordering and processing requirements, test methods and sampling requirements. Test methods are referenced for coating thickness (ASTM C 664, B 487) decarburization (E 1077), chromium content (E 766).	Varies with property of interest.

Intended Application	Specimen Requirement	Limits
This Specification can be used in establishing specifications for purchase of coated materials and components.	Not specified.	Diffusion thickness requirements are as follows: Class I (carbon base) 0.0762 mm* (0.003 in.) min. Class II (low alloys) 0.0762 mm (0.003 in.) min. Class III (stainless steels) 0.0508 mm (0.002 in.) min. Class IV (nickel base alloys) 0.0254 mm (0.001 in.) min. The outer 15% of the coating shall contain 20% chromium by weight.

* SI (metric) units are calculated because the original standard included only customary units

ASTM B 875
Standard Specification for Aluminum Diffusion Coating Applied by Pack Cementation Process

General Description	Data Produced
This Specification gives requirements for aluminum diffusion of metals by the pack cementation process. A brief description of the process, definition of terms used in the process, classification by base metal category, ordering and processing requirements, test methods and sampling requirements. Test methods are referenced for coating thickness (ASTM C 664, B487), aluminum content to be measured by beta backscatter or X-ray fluorescence.	Varies with property of interest.

Intended Application	Specimen Requirement	Limits
This Specification can be used in establishing specifications for purchase of coated materials and components.	Not specified.	Diffusion thickness requirements are as follows: Class I (carbon and low alloy) 0.127 mm* (0.005 in.) min. Class II (stainless steels) 0.0762 mm (0.003 in.) min. Class III (nickel base alloys) 0.0254 mm (0.001 in.) min. The outer 15% of the coating shall contain 28% aluminum by weight, minimum.

* SI (metric) units are calculated because the original standard included only customary units

6.6 Physical Vapor Deposition (PVD)

AMS 2444A
Coating, Titanium Nitride Physical Vapor Deposition (Aerospace Material Specification)

General Description	Data Produced
This document provides requirements for the application and properties of titanium nitride coating on metallic parts applied by physical vapor deposition. Coatings covered are divided into three classes: Class 1 – 1.27 μm to 3.81 μm (0.00005 in. to 0.00015 in.) thick; Class 2 – 2.54 μm to 6.10 μm (0.00010 in. to 0.00024 in.) thick; and, Class 3 – 6.35 μm to 12.70 μm (0.00025 in. to 0.00050 in.) thick. Processing requirements, properties, quality, quality assurance, preparation for delivery and surface roughness suggestions are included. Property measurement methods are identified by reference to ASTM Standards, including: for thickness ASTM B 487, B 499, B568, E 376, E 1182; for hardness E 92 and E 384. A qualitative adhesion test using a tape pull-off method is described.	Varies with property or characteristic of interest.

Intended Application	Specimen Requirement	Limits
Provides information useful in purchase specification.	Varies with property or characteristic of interest.	Useful for identifying those properties and characteristics important to PVD materials and methods of measurement.

6.7 Thermal Spray

ISO 2063
Metallic and Other Inorganic Coatings – Thermal Spraying – Zinc Aluminum and Their Alloys

General Description	Data Produced
This Standard gives general information useful to thermal spray materials users. The standard applies to thermal sprayed coatings of zinc or aluminum deposited on iron and steel for corrosion protection. A classification scheme for zinc, aluminum or Zn-Al alloy coatings based on thickness is included. The standard addresses surface preparation, extent of thickness measurement required based on surface area, measurement method by reference to ISO 2178 and ISO 1463. Adhesion testing by a "Grid test" wherein a hand scribed grid allows delamination of the coating with tape pull off, and a "Tensile" method similar to ASTM C 633, is included.	Measure of coating thickness and adhesion.

Intended Application	Specimen Requirement	Limits
Provides some basis for material specification.	Varies with property measured.	The standard does not apply to coatings other than zinc or aluminum. Application of aspects of the standard to other metals may be adopted by agreement of interested parties. The standard does not apply to repairs of damaged metal areas. The method of thermal spray (plasma, flame, cold spray, etc) is not specified. The tensile adhesion test is not claimed to be reproducible, requiring the same operation in the same facility to have consistency.

MILITARY STANDARD
MIL-STD 1687A(SH)
Thermal Spray Processes for Naval Ship Machinery Applications

General Description	Data Produced
This Standard addresses many aspects of the deposition of materials for the repair and corrosion protection of Naval shipboard machinery. Evaluation of deposits and deposit/substrate systems by metallographic analysis for oxide and porosity content, bond strength by ASTM C 633, and bend tests are identified.	Data varies with test.

Intended Application	Specimen Requirement	Limits
Intended to provide guidance for shipboard machinery repair.	Bend tests are conducted on nominally 2 in. x 3 in. x 0.50 in. thick (5.18 cm x 7.62 cm x 1.17 cm)* panels. Coating thicknesses are to be 0.008 ± 0.002 in. (0.0203 cm ± 0.00508 cm)* unless otherwise specified by the manufacturer.	Not specified.

* SI (metric) units are calculated because the original standard included only customary units

6.8 Glass and Enamel Coatings

ASTM C 536
Standard Test Method for Continuity of Coatings in Glassed Steel Equipment by Electrical Testing

General Description	Data Produced
This method covers the detection of discontinuities in the glass coating applied to steel equipment where the discontinuities would result in early failure due to chemical attack of the metal substrate. The test consists of sweeping the surface of the glass with a point or brush type probe and observing discharges between the probe and the metal substrate. The metal substrate is connected to the ground side of a voltage generator, the probe to the other side. The voltage used is 5000 V at 2.5 mA and may be from stationary AC or portable DC. Equipment suppliers are identified.	A visible and audible spark forms at discontinuities in the glass coating.

Intended Application	Specimen Requirement	Limits
The test is applicable to manufacturing and inspection testing as well as field testing.	Clean dry surfaces.	The method is qualitative.

ASTM C 537
Standard Test Method for Reliability of Glass Coatings on Glassed Steel Reaction Equipment by High Voltage

General Description	Data Produced
This Method covers the detection of discontinuities in the glass coating as areas of the coating where the glass may be thin enough to result in premature failure in service where highly corrosive conditions can cause severe damage to the exposed metal substrate. The test consists of sweeping the surface of the glass with a point or brush type probe and observing discharges between the probe and the metal substrate.The metal substrate is connected to the ground side of a voltage generator, the probe to the other side. The DC voltage used is up to 20,000 V at 2.5 mA. Equipment supplier is identified.	A visible and audible spark forms at discontinuities in the glass coating.

Intended Application	Specimen Requirement	Limits
The test is intended to provide information which allows repair of the coating before leaving the manufacturing facility.	Clean dry surfaces.	The method is qualitative. Voltage levels can be preset based on desired minimum thickness of glass. Testing can create punctures in the glass coating when the glass thickness is insufficient to withstand the applied voltage. Those punctures can be repaired by additional glass application before the equipment leaves the manufacturing facility.

ASTM C 743
Standard Test Method for Continuity of Porcelain Enamel Coatings

General Description	Data Produced
This Method permits the detection of discontinuities and areas of light coverage (thin coatings) in porcelain enamel coatings on metal substrates. The technique is similar to ASTM C 536 and ASTM 537 which are intended for thicker glass coatings. An AC or DC high voltage discharge instrument with a continuously variable output voltage over the range of at least 0 kV to 4 kV which can be set to 0.1 kV is required. A calibration curve of enamel thickness vs. discharge arcing voltage is established per Annex A1. A test probe of 100 mesh wire gauze is passed over the surface at selected voltages. An arc between probe and base metal will occur at discontinuities, indicating failure. The test can be used to indicate presence of defects open to the base metal and enamel surface, areas of light coverage, or compliance with a specification. Procedures are given and equipment suppliers are identified.	A visible and audible spark.

Intended Application	Specimen Requirement	Limits
Material evaluation or specification compliance.	Clean dry surfaces.	Arc formation can be calibrated to coating thickness for specific material and equipment.

7. Standards for Measurement of Surface Treatment Depth, Coating Thickness and Mass

7.1 Surface Treatment Depth

ASTM B 721
Standard Test Method for Microhardness and Case Depth of Powder Metallurgy (P/M) Parts

General Description	Data Produced
This method describes the measurement of Knoop or Vickers microhardness on the polished cross-section of a powder metallurgy part, including the hardened surface, to develop a hardness vs depth curve used to define the transition from case hardened to core material. Case depth and effective case depth determinations are described. Method includes summary of microhardness and case depth measurements, surface preparation, procedure reporting, precision and bias. This is intended to be a companion to ASTM Test Method E 384, Test Method for Microhardness of Materials.	Microhardness as a function of distance from surface.

Intended Application	Specimen Requirement	Limits
Measurement of proper hardness and thickness of the case to meet engineering function.	Metallographic specimen with edge retention and for densities below 6.6 g/cm^3, vacuum impregnation with resin or epoxy to support the structure.	Interlaboratory measurements of an unknown sample after measurement of test blocks with known hardnesses were conducted. For a laboratory to duplicate any of the other laboratories, 95% of the readings should be within 5.3 HRC; for six reading averages, within 2.2 HRC.

ASTM E 1077
Standard Test Methods for Estimating the Depth of Decarburization of Steel Specimens

General Description	Data Produced
This document describes screening methods, microscopical methods, microindentation hardness methods and chemical analysis methods to determine the depth of decarburization of steels. Sampling, procedures for the methods, reporting, precision and bias are included.	Carbon content as a function of depth from the surface determined by chemical analysis, microstructural change or microhardness change with depth, both reflecting decarburization.

Intended Application	Specimen Requirement	Limits
The methods may be used to qualify material for shipment, machining guidance, or to assess the effect of processing.	Varies with method.	For 20 or more measurements decarburization depths can be estimated to within 0.025 mm (0.001 in.) with a relative accuracy of 10% to 20% with microscopical methods. Estimates of total or effective decarburization by microindentation at a given location are generally accurate within 0.025 mm (0.001 in.).

ISO 2639
Steels – Determination and Verification of the Depth of Carburized and Hardened Cases

General Description	Data Produced
This Standard defines case-hardened depth and gives methods for its determination. The depth is determined by measurement of a hardness gradient on a cross-section perpendicular to the surface. Hardness may be measured by Vickers or Knoop methods, upon agreement of the parties concerned. The procedure for determination of case-hardened depth, verification of the measurement and reporting are included.	Microhardness as a function of distance from the surface.

Intended Application	Specimen Requirement	Limits
Applicable for measurement of carburized and carbonitrided cases and parts heat treated to a final hardness of less than 450 HV 1 at a distance of three times the case hardened depth from the surface or by special agreement between parties.	Polished cross-sections.	Case hardened depth is defined as the perpendicular depth between the surface and the layer having a Vickers hardness of 550 HV 1 in accordance with ISO 6507-1 or equivalent Knoop hardness in accordance with ISO 4545.

ISO 3754
Steel – Determination of Effective Depth of Hardening After Flame or Induction Hardening

General Description	Data Produced
This Standard defines the effective depth of flame or induction hardening by measurement of Vickers hardness on a polished cross-section perpendicular to the hardened surface. Effective depth is defined as the distance from the surface where the Vickers hardness under a load of 9.8 N is equal to the "hardness limit". The hardness limit is defined as 0.80x minimum surface hardness, expressed in mm.	Microhardness as a function of distance from the surface.

Intended Application	Specimen Requirement	Limits
Suitable for measurement of hardness where a cross-section can be removed.	Polished cross-sections.	Applies to hardened layers with a depth greater than 0.3 mm and parts which in the surface hardened condition, have a hardness less than the hardness limit-100 at a distance 3x the effective depth of hardening.

ISO 4970
Steel – Determination of Total or Effective Thickness of Thin Surface-Hardened layers

General Description	Data Produced
This Standard specifies a micrographic method and a microhardness method for measuring the total effective thickness of surface-hardened layers less than 0.3 mm in thickness. These layers may be obtained by mechanical or thermochemical methods. Procedures for the micrographic and microhardness are given in general terms.	Microhardness as a function of distance from surface or microstructural variation resulting from hardening treatment.

Intended Application	Specimen Requirement	Limits
Not specified.	Metallographic specimens suitable for visual microstructural analysis or microhardness measurements.	Not applicable to thin layers not continuous with the base metal. Thicknesses greater than 0.3 mm are covered by ISO 2639, Steel-Determination and verification of the effective depth of carburized and hardened cases, and ISO 3754, Steel-Determination of effective depth of hardening after flame or induction hardening.

SAE J419
Methods of Measuring Decarburization
(SAE Recommended Practice)

General Description	Data Produced
This document describes typical methods for measurement of the extent of decarburization (loss of carbon from the surface) of ferrous materials. The methods described are: microscopic examination of the microstructure of a metallographic specimen; measurement of hardness, including cross-section microhardness traverse, longitudinal traverse and measurement of file hardness; and chemical analysis including analysis of machining chips and electron microprobe. Definitions and illustrative micrographs are included.	Images of microstructure which illustrate changes due to carbon loss, hardness measurements which reflect change in carbon content and qualatative differences in hardness manifested by changes in resistance to filing.

Intended Application	Specimen Requirement	Limits
To determine suitablity of material for intended purpose, process evaluation, acceptance testing.	Metallographic sections typically normal to the surface with edge protection and retention. Hardness measurements are made on specimens hardened by quenching with minimum carbon loss.	Accuracy of method used is dependent on degree of decarburization, base carbon content and microstructure. Metallographic and hardness methods are inaccurate for small amounts of decarburization in high carbon (above 0.06%), high hardness steels.

SAE J423
Methods of Measuring Case Depth (SAE Standard)

General Description	Data Produced
This Standard addresses techniques of measuring the case depth of ferrous material. The case is much harder than the core material as a result of carburizing, nitriding, carbonitriding, cyaniding, induction or flame heating or another process in which chemical composition or mechanical properties or both are affected by the process. Chemical methods, including analysis of machining chips or microprobe analysis of prepared cross-sections, are described. Mechanical (hardness) measurements and visual techniques (observation of cut or fractured and etched cross-sections) and microscopic methods are described in detail.	Information or data relating composition or hardness to distance from surface.

Intended Application	Specimen Requirement	Limits
Specification acceptance, process evaluation.	Varies with technique.	Case depths measured by different methods can vary significantly.

SAE ARP 1341
Determining Decarburization and Carburization in Finished Parts of Carbon and Low-Alloy Steels
(Aerospace Recommended Practice)

General Description	Data Produced
This Practice addresses determination of decarburization and carburization for heat treated carbon and low-alloy steel parts other than those case hardened. The Practice includes visual inspection of metallographic specimens and microhardness survey. ASTM E 3 and E 407 are the metallographic references. ASTM E 384 is the microhardness guide. Criteria for determination of (1) complete decarburization by visual examination and (2) total decarburization (complete plus partial) by microhardness of (a) hardened and (b) hardened and tempered are provided.	Microhardness values determined from indent traverses perpendicular to the surface and visual interpretation of microstructure at 100x.

Intended Application	Specimen Requirement	Limits
Inspection for acceptance.	Metallographic specimens may be prepared from a part after complete heat treatment or from separate samples processed with the part, having identical surface treatment and from the same heat, preferably.	Not applicable to raw material or case hardened parts.

SAE ARP 1820
Chord Method of Evaluating Surface Microstructural Characteristics (Aerospace Recommended Practice)

General Description	Data Produced
This Practice describes a metallographic preparation technique in which a simple disc specimen which has been subjected to the same treatment as a batch of identical material is polished on a chord of its circular cross-section to provide a magnified cross-section for microstructural and microhardness assessment of thin layers of decarburization and intergranular oxidation. The Practice is intended for hardened steel and gives procedures for hardness assessments for depth of partial decarburization, severity of partial decarburization, carburization and nitriding, and recommended rejection criteria for the preceeding conditions as well as depth of intergranular oxidation.	Microhardness as a function of distance from surface.

Intended Application	Specimen Requirement	Limits
It is useful for process control in heat treatment of steel parts and may be useful for evaluation of plated coatings.	Disc or disc-sector specimens 3 mm to 6 mm (0.125 in. to 0.250 in.) thick, 6 mm to 12 mm (0.250 in. to 0.50 in.) radius of same alloy as parts at issue with texture of circumferential surface approximately 0.8 μm (32 μin.). Surfaces must be free of carburization, nitriding, decarburization and intergranular oxidation before use.	Limits (rejection criteria) are based on achieving, for high strength steels (maximum tensile strength of greater than 1520 MPa (220,000 psi)) optimum fatigue performance of surfaces which are shot peened and for low strength steels (maximum tensile strength less than 1520 MPa (220,000 psi)) what is commonly achievable in modern protective atmosphere furnaces.

7.2 Coating Thickness

Figure 2. Applicability of Coating Thickness Measuring Methods

Substrates	Coatings							
	Copper	Nickel	Chro-mium	Auto-cata-lytic Nickel	Zinc	Cad-mium	Gold	Palla-dium
Magnetic steel (including corrosion-resisting steel)	CM	CM[A]	CM	C[B]M[A]	CM	BCM	BM	BM
Non-magnetic stainless steels	CE[D]	CM[A]	C	C[B]	C	BC	B	B
Copper and alloys	C only on brass and Cu-Be	CM[A]	C	C[B]	C	BC	B	B
Zinc and alloys	C	M[A]	–	–	–	B	B	B
Aluminum and alloys	BC	BCM[A]	BC	BC[B] E[A,B]	BC	BC	B	B
Magnesium and alloys	B	BM[A]	B	B	B	B	B	B
Nickel	C	–	C	–	C	BC	B	B
Silver	B	BM[A]	B	B	B	–	B	–
Glass sealing nickel-cobalt-iron alloys UNS No. K94610	M	CM[A]	M	C[B]M[A]	M	BM	BM	BM
Nonmetals	BCE[D]	BCM[A]	BC	BC[B]	BC	BC	B	B
Titanium	B	BM[A]	BC[B]	BE[A,B]	B	B	B	B

[A]Method is sensitive to permeability variations of the coating.
[B]Method is sensitive to variations in the phosphorus content of the coating.
[C]Method is sensitive to alloy composition.
[D]Method is sensitive to conductivity variations of the coating.

Figure 2. Applicability of Coating Thickness Measuring Methods *(cont'd)*

Substrates	Coatings						
	Rhodium	Silver	Tin	Lead	Tin-Lead Alloys	Non-Metals	Vitreous and Porcelain Enamels
Magnetic steel (including corrosion-resisting steel)	BM	BCM	BCM	BCM	B[C] C[C] M	BM	M
Non-magnetic stainless steels	B	BCE[D]	BC	BC	B[C] C[C]	BE	E
Copper and alloys	B	BC	BC	BC	B[C] C[C]	BE	E
Zinc and alloys	B	B	B	B	B[C]	BE	–
Aluminum and alloys	B	BC	BC	BC	B[C] C[C]	E	E
Magnesium and alloys	B	B	B	B	B[C]	E	–
Nickel	B	BC	BC	BC	B[C] C[C]	BE	–
Silver	–	–	–	BC	B[C]	BE	E
Glass sealing nickel-cobalt-iron alloys UNS No. K94610	BM	BM	BM	BCM	B[A] C[C] M	BM	–
Nonmetals	B	BC	BC	BC	B[C] C[C]	–	–
Titanium	B	B	B	B	B[C]	BE	–

Note: B = Beta backsetter; C = Coulometric; E = Eddy current; and M = Magnetic

Note: Figure 2, Applicability of Coating Thickness Measuring Methods, is reprinted, with permission, from ASTM B 659-90(2003) Standard Guide for Measuring Thickness of Metallic and Inorganic Coatings, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

ASTM B 244
Standard Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy-Current Instruments

General Description	Data Produced
Coating thickness is determined with an electromagnetic instrument that measures changes in apparent impedance of the coil inducing the eddy currents in the basis metal. The method is useful for measuring the thickness of anodic coatings on aluminum alloys but chemical conversion coatings are too thin to be measured with this method. Includes apparatus, list of instrument suppliers, factors affecting accuracy, calibration, procedure, reporting.	Coating thickness.

Intended Application	Specimen Requirement	Limits
Nondestructive measurement of thickness of a nonconductive coating on a nonmagnetic basis metal.	Calibration standard required.	Uncertainty for a single measurement of a thin coating is constant and independent of coating thickness and is not less than 0.5 μm. For thicknesses greater than 25 μm, uncertainty is proportional to coating thickness. Coating thickness can be determined within 10% or 1 μm, whichever is greater, of the true thickness.

ASTM B 487
Standard Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of a Cross-Section

General Description	Data Produced
Local thickness measurement of metal and oxide coatings using an optical microscope on a mounted, ground and polished cross-section. Provides factors influencing the measurement, guidance on preparation and measurement of cross-sections, procedure, reporting, precision and bias.	Numerical value of coating thickness.

Intended Application	Specimen Requirement	Limits
Suitable for acceptance testing.	Polished cross-section through oxide/coating and substrate. Cross-section perpendicular to coating, surface flat, entire width of coating in focus at magnification used for measurement, coating cross-section.	Thickness can be determined to within 1 μm or 10% whichever is greater of the actual coating thickness. The method is capable of giving an absolute measuring accuracy of 0.8 μm and for thicknesses greater than 25 μm a reasonable error is of the order of 5% or better.

ASTM B 499
Standard Test Method for Measurement of Coating Thickness by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metals

General Description	Data Produced
The thickness of nonmagnetic coatings on magnetic substrates is measured with instruments which measure the magnetic attraction between a magnet and the substrate as influenced by the thickness of nonmagnetic coatings on magnetic substrates; or the reluctance of a magnetic flux path passing through the coating and the substrate. Standard includes factors influencing accuracy, instrument calibration, procedure, reporting, precision and bias. Method is nondestructive.	Coating thickness.

Intended Application	Specimen Requirement	Limits
Suitable for specification acceptance testing and SPC/SQC. Method requires same magnetic properties in calibration specimen substrate as in the test specimen.	Substrate (basis metal) thickness affects measurement and is dependent on specific instrument. Roughness, curvature, edge effects are important.	Measurement uncertainty may be less than 10% at 95% confidence level consistently. Uncertainty may be greater for coating thicknesses less than 25 μm.

ASTM B 504
Standard Test Method for Measurement of Thickness of Metallic Coatings by the Coulometric Method

General Description	Data Produced
The thickness of metallic coatings is determined by electrochemically stripping an approximately 0.1 cm^2 test area and either calculating the amount of material removed based on the amount of electricity used or by calibration against standards with known coating thicknesses. Standard includes factors affecting accuracy, calibration of instrument, procedure, precision and bias, electrolytes, and measurable coating/substrate combinations suitable for this method.	Coating mass interpreted as coating thickness.

Intended Application	Specimen Requirement	Limits
Useful where a small spot of coating can be destroyed.	This localized test may not measure variations in coating or alloying between coating and substrate.	Uncertainty of less than 10% may be achieved. The uncertainty may be greater for thicknesses less than 1 μm or greater than 50 μm.

ASTM B 530
Standard Test Method for Measurement of Coating Thickness by the Magnetic Method: Electrodeposited Nickel Coatings on Magnetic and Nonmagnetic Substrates

General Description	Data Produced
This is a nondestructive technique for measuring the thickness of electrodeposited nickel using the principle of magnetic attraction for up to 50 μm for magnetic substrates and 25 μm for nonmagnetic substrates. Reluctance gage measurements for coating thicknesses of up to 1 mm or more can be made on both types of coating/substrates. Calibration, procedure, reporting, precision and bias are included.	Coating thickness as provided on specific instruments.

Intended Application	Specimen Requirement	Limits
Specification acceptance.	The magnetic properties of the coating and substrate should be the same as the instrument calibration standard.	Uncertainty of less than 10% may be achieved. The uncertainty may be greater for thicknesses less than 25 μm.

ASTM B 555
Standard Guide for Measurement of Electrodeposited Metallic Coating Thickness by the Dropping Test

General Description	Data Produced
This is a destructive test which consists of measuring the time it takes to dissolve an electroplated surface with drops of corrosive solution applied at a constant rate until the substrate is exposed, assuming the time is proportional to the coating thickness. This method is suitable for an approximate determination. Includes factors affecting accuracy, apparatus, reagents and materials, test solutions for cadmium, zinc, tin and copper, procedure, computation of thickness, reproducibility and accuracy. End point is determined visually and is operator dependent.	Time to penetrate through the coating converted to coating thickness.

Intended Application	Specimen Requirement	Limits
Approximate determination of coating thickness.	A clean surface is required and calibration against a specimen of the same composition to reduce uncertainty.	Reproducibility for a single operator is estimated to be ± 2 drops (equivalent to 1.2 s) or ± 5%, whichever is greater.

ASTM B 556
Standard Guide for Measurement of Thin Chromium Coatings by Spot Test

General Description	Data Produced
This is a destructive test wherein a drop of hydrochloric acid is placed on a thin electrodeposited chromium coating on nickel or stainless steel and the time to penetrate the chromium is measured. The time to penetrate is proportional to the thickness of the coating. The method is not as accurate as ASTM B 504. The guide includes: test solutions, preparation of test area, procedure, calculation of thickness as a function of temperature.	Time to penetrate the coating converted to thickness.

Intended Application	Specimen Requirement	Limits
Approximate determination of thickness of decorative coatings up to 1.2 μm in thickness.	A clean surface is required on which a 6 mm diameter ring of paraffin or wax is formed to retain the acid.	Accuracy is about ± 20% for thicknesses up to 1.2 μm.

ASTM B 567
Standard Test Method for Measurement of Coating Thickness by the Beta Backscatter Method

General Description	Data Produced
This is a nondestructive method wherein beta particles from a radioisotope impinge the test piece through a mask which controls the area exposed and the back scattered beta particles are counted and interpreted as coating thickness. The area exposed and the back scattered beta particles are used to measure the mass of the coating per unit area which is used to calculate thickness when the coating density is known. Metallic and nonmetallic coatings on metallic and nonmetallic substrates can be measured when the atomic numbers of the coating and substrate differ by at least 5 for most applications. The test method includes terminology, summary of the test method, instrumentation, factors affecting measurement accuracy, instrument calibration, referee test, procedure reporting and precision and bias.	Coating thickness determined by calculation from density and measured backscattered radiation.

Intended Application	Specimen Requirement	Limits
Suitable for specification acceptance if mass per unit area is specified. Not suitable if thickness is specified and density of the coating material varies or is unknown.	The method is sensitive to thickness of thin substrates. Sensitivity is reflective of saturation thickness which depends on energy of the isotope and density of material.	Coating thickness can be determined with an uncertainty of less than 10% at 95% confidence level.

ASTM B 568
Standard Test Method for Measurement of Coating Thickness by X-ray Spectrometry

General Description	Data Produced
This is a nondestructive technique for measuring the thickness of metallic and nonmetallic coatings. Incident radiation from X-ray tubes or radioisotopes causes emission of secondary radions characteristic ofthe elements comprising the coating and the substrate. Secondary radiation is analyzed by wavelength dispersion or energy dispersion. Measurement of the intensity of the coating material's emission or substrate's emission and subsequent absorption by the coating are compared to standards of the same material combination. The method includes: summary of the method, factors affecting accuracy, instrument calibration, standardless techniques, referee test, procedure, precision and bias.	Coating thickness determined by X-ray emission or absorption compared to emission or absorption of a standard.

Intended Application	Specimen Requirement	Limits
Measures coating substrate combinations not readily measured by other techniques. Addresses electroplated coatings.	Reference materials of the same density, composition, voids and porosity needed.	Coating thicknesses of 0.01 μm to 75 μm can be measured. Uncertainty of less than 10% at 95% confidence level can be determined. Uncertainty may be greater than 10% with coating thicknesses less than 1 μm.

ASTM B 588
Standard Test Method for Measurement of Thickness of Transparent or Opaque Coatings by Double-Beam Interference Microscope Technique

General Description	Data Produced
This is a nondestructive method for measuring the thickness of transparent coatings (e.g., anodic coatings on aluminum) by use of a double beam interference microscope. The top surface of the coating and the substrate surface are located with white light interference fringe group(s) and the elevation difference determined by counting the number of monochromatic fringes by which the white light fringes are displaced. The number of fringes multiplied by half the light wavelength is the coating thickness. Opaque coatings are destructively measured by stripping the coating and similarly measuring the number of fringes between surfaces. The method includes apparatus, sample preparation for destructive technique, thickness measurement, accuracy requirement, precision and bias.	Fringes which are counted and interpreted as film or coating thickness.

Intended Application	Specimen Requirement	Limits
Suitable for specification acceptance.	Surface(s) must be sufficiently mirrorlike to form recognizable fringes.	Transparent coatings 1 μm to 10 μm can be measured. Opaque coatings 0.1 μm to 10 μm can be stripped and measured. Transparent coatings 0.2 μm to 10 μm can be stripped and measured. Transparent coating thickness on a metal substrate can be determined either within ± 0.2 μm or within 5% of the thickness, whichever is greater. A metal coating on a metal substrate can be determined to either within 0.1 μm or within 5% of the coating thickness, whichever is greater.

ASTM B 659
Standard Guide for Measuring Thickness of Metallic and Inorganic Coatings

General Description	Data Produced
This guide provides a brief overview of methods for measuring the thickness of metallic and inorganic coatings applied by electrodeposition, mechanical methods, vacuum deposition, anodic oxide and chemical conversion which are addressed by ASTM standards. ASTM standards and corresponding ISO standards are referenced. A table showing the applicability of various coating thickness measuring methods for combinations of coating materials and substrates is included.	Not included.

Intended Application	Specimen Requirement	Limits
Acceptance testing.	Not included.	Generally, measurements with an uncertainty of less than 10% of the coating thickness are included.

ASTM B 681
Standard Test Method for Measurement of Anodic Coatings on Aluminum and Other Transparent Coatings on Opaque Surfaces Using the Light-Section Microscope

General Description	Data Produced
This Method covers a procedure for the nondestructive measurement of transparent coatings on reflective, opaque substrates. A beam of light (preferably filtered or monochromatic) approximately 1 μm in width by 1 mm in length, is reflected off the specimen surface at an incident angle of 45°. The displacement between the rays reflected off the coating surface and the coating-substrate interface is related mathematically to the coating thickness. The method provides apparatus requirements, measurement procedure, calibration, calculations and precision and bias information. The microscope should have a magnification range from 100x to 500x, and a filar micrometer eyepiece capable of measuring object distances in the range of 1 μm to 40 m with an accuracy of ± 0.2 μm.	Distance between coating surface and coating-substrate interface used to calculate coating thickness.

Intended Application	Specimen Requirement	Limits
Suitable for quality control and acceptance testing.	The coating must be between 2 μm to 40 μm in thickness and its index of refraction must be known. Coating and substrate must be sufficiently smooth and clear.	Single operator repeatability is ± 0.2 μm. Reproducibility is ± 0.5 μm by different operators using different instruments. Accuracies of ± 1 μm can be achieved using the calibration procedures specified.

ASTM C 664
Standard Test Methods for Thickness of Diffusion Coating

General Description	Data Produced
Two test methods are provided. Method A, determination of dimensional change thickness, defined as the difference in thickness before and after coating utilizes a machinist's type micrometer reading to 0.0025 mm (0.0001 in). Method B, determination of total coating thickness, defined as the distance between the observably unaffected substrate and the exterior of the coating, utilizes an optical microscope to measure features on a polished cross-section.	Thickness is measured.

Intended Application	Specimen Requirement	Limits
Quality control and acceptance testing.	Method A requires a surface free of debris. Method B requires a polished cross-section.	Method A has a precision of ± 0.005 mm (0.0002 in.). Method B has a precision of ± 0.0025 mm (0.0001 in.).

ASTM E 376
Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Examination Methods

General Description	Data Produced
This Practice is a general description of the issues pertinent to the use of magnetic-field or eddy-current measurement of coating thickness. Both techniques are non-destructive. Factors which can interfere with the measurements are enumerated. Magnetic gages are designed to measure thickness of a non-magnetic coating on a magnetic substrate as well as nickel on magnetic or non-magnetic substrates. Eddy current gages can only be used if the electrical conductivity of the coating and substrate differ significantly. The Practice includes descriptions of the phenomena on which the measurements are based, factors interfering with the measurements, items which should be agreed upon by contractual parties using the methods, calibration and standardization, procedure, reporting, precision and bias.	Can vary with instrument but generally parameter measured is compared to a standard material.

Intended Application	Specimen Requirement	Limits
Used in specification compliance assessment.	Specimens should be clean and preferably flat. Detailed specimen requirements vary with material combination, and instrument.	Generally, measurement should be conducted such that the coating thickness can be determined within ± 10% of its true thickness or within ± 2.5 μm or ± 0.0001 in, whichever is the greater. Qualification/ certification of non-destructive testing (NDT) personnel may be required in contractual agreement.

ASTM E 1182
Standard Test Method for Measurement of Surface Layer Thickness by Radial Sectioning

General Description	Data Produced
This Method describes a technique wherein a cylindrical or spherial tool is used to grind through the coating into the substrate. A microscope is used to measure the dimensions of the crater at the surface and at the coating/ substrate interface. The measured properties are used to calculate the coating thickness.	Measurement of dimensions of exposed surface edge and substrate/surface layer interface, together with dimensions of the cylinder or sphere used to wear through the surface layer, are used to calculate thickness of surface layer.

Intended Application	Specimen Requirement	Limits
Quality control measurement, research, development and materials acceptance of surface layers applied for corrosion, wear resistance or other purposes. This method is used for evaluation of PVD (physical vapor deposited) coatings.	Specimen surfaces to be worn should be representative of product. Surfaces should be cleaned before testing. Cleaning solvents should not alter the coated surface.	Suitable for measurement of surface layers 0.05 μm to 200 μm in thickness. Thicker layers should be measured by other methods, e.g., ASTM B 487. This method shall not be used for layers thinner than 0.5 μm if other suitable methods are available. Relative precision decreases with decreasing layer thickness. For platings greater than 12 μm thick, 95% repeatability and reproducibility become relatively constant at ± 4 to 5% of the coating thickness.

ISO 1463
Metallic and Oxide Coatings – Measurement of Coating Thickness – Microscopical Method

General Description	Data Produced
This Standard is an excellent guide to measurement of local thickness of metallic coatings, oxide layers and porcelain or vitreous enamel coatings by use of optical microscopy and polished cross-sections. The Standard includes factors affecting measurement uncertainty, specimen preparation, measurement method, reporting, uncertainty, use of tapered cross-sections and measurement of tooth-constructed coatings. Typical etchants and their application are listed.	Numeric measure of dimensions.

Intended Application	Specimen Requirement	Limits
Routine analysis.	Polished metallographic specimens.	Appropriate methods will allow coating thickness to be measured to within 1 μm or 10%, whichever is greater, of the actual coating thickness. Absolute measurement uncertainty of 0.8 μm possible. Careful preparation and suitable instruments give a capability of measurement uncertainty of 0.4 μm under reproducible conditions.

ISO 2128
Anodizing of Aluminum and its Alloys – Determination of Thickness of Anodic Oxide Coatings – Non-destructive Measurement by Split Beam Microscope

General Description	Data Produced
This method consists of using a split beam microscope which directs parallel beams of light onto the transparent coating on a reflective substrate. Luminous lines from the coating surface reflection and from the coating- substrate interface reflection are observed at the ocular. The measured distance between the lines is used to calculate coating thickness.	Distance measured with microscope, with magnification and refractive index data used to calculate oxide coating thickness.

Intended Application	Specimen Requirement	Limits
Measurement of oxide coating thickness.	Oxide coating should not be opaque and the surface should not be severely pitted.	Useful for industrial aluminum oxide coatings greater than 10 μm thick or for smooth coatings greater than 5 μm thick.

ISO 2177
Metallic Coatings – Measurement of Coating Thickness – Coulometric Method by Anodic Dissolution

General Description	Data Produced
This Standard describes measurement of coating thickness by anodic dissolution of the metallic coating on a substrate based on knowledge of the area being dissolved, current density, time of dissolution and integrated quantity of electricity used. Measurements and calculations are based on comparison with control specimens of known thickness in the same test conditions. The Standard includes information on suitable electrolytes, factors affecting measurement accuracy, procedure, expression (calculation) of results, reporting, types of instruments and uncertainty.	Electrochemical data used in calculation of thickness.

Intended Application	Specimen Requirement	Limits
Routine analysis.	Specimens must be clean of any material which can interfere with material dissolution, including corrosion products, conversion coatings and passive layers.	The method can provide coating thickness measurements within 10% of true thickness. Special equipment is required for coatings greater than 50 μm or less than 0.2 μm. The method is only applicable to conductive coatings.

ISO 2178
Nonmagnetic Coatings on Magnetic Substrates – Measurement of Coating Thickness – Magnetic Method

General Description	Data Produced
This Standard specifies the method for use of commercially available (generally) instruments which determine the thickness of non-magnetic coatings, including enamel, on magnetic substrates. Instruments measure either the magnetic attraction between a permanent magnet (probe) and the magnetic substrate, as influenced by the coating thickness, or the reluctance of a magnetic flux path passing through the coating and the substrate. The Standard includes descriptions of factors affecting accuracy, instrument calibration and procedure.	Instrument specific read-out.

Intended Application	Specimen Requirement	Limits
Nondestructive thickness measurement, generally.	Specimens should be generally flat with measurements not made near edges or abrupt changes in surface contour.	Calibration standards as similar to the test piece as practical are desired. The coating thickness should be determinable to within 10% of its true thickness or to within 1.5 μm, whichever is greater.

ISO 2361
Electrodeposited Nickel Coatings on Magnetic and Nonmagnetic Substrates – Measurement of Coating Thickness – Magnetic Method

General Description	Data Produced
This Standard specifies the method of use of instruments which measure the thickness of nickel coatings on magnetic (Type A) and non-magnetic (Type B) substrates. Instruments use either the magnetic attraction between a permanent magnet and the coating/ substrate combination, or the reluctance of a flux path passing through the coating and the substrate. Factors affecting measurement accuracy and procedure are included.	Instrument specific.

Intended Application	Specimen Requirement	Limits
Routine measurement.	Test specimens should be similar to calibration standards.	Instruments using magnetic attraction principle can measure Type A coatings up to 50 μm thick and Type B coatings up to 25 μm thick. Instruments using the reluctance principle can measure thicknesses of Types A and B up to 1 mm. Measurement of thickness should be determined to within 10% of true thickness or within 1.5 μm, whichever is greater.

ISO 3497
Metallic coatings – Measurement of Coating Thickness – X-ray Spectrometric Methods

General Description	Data Produced
This Standard specifies methods for measuring the thickness of metallic coatings by the use of spectrographic techniques which provide mass per unit area data that is converted to linear thickness when coating density is known. Incident radiation from either radioisotopes or X-ray tubes impinges the test piece. Secondary radiation from coating and substrate is measured and compared to radiation from calibration standards. The Standard includes descriptions of the principles of operation and apparatus, factors affecting measurement results, instrument calibration, measurement procedure, reporting and ranges of thickness that can be measured for common coating materials and substrates.	Instrument specific read-out.

Intended Application	Specimen Requirement	Limits
Non-destructive thickness measurements including the evaluation of PVD (physical vapor deposited) coatings.	Standards as similar to test pieces as practical.	The uncertainty should be better than 10%. Measuring ranges for substrate/coating systems vary with measurable thicknesses generally between 7 μm (palladium on titanium) to 60 μm (tin on copper or nickel).

ISO 3543
Metallic and Nonmetallic Coatings – Measurement of Thickness – Beta Backscatter Method

General Description	Data Produced
This Standard describes the use of backscattered beta radiation to measure the thickness of metallic and nonmetallic coatings on metallic and nonmetallic substrates. The technique is appropriate where coating and substrate have appropriately different atomic numbers or equivalent atomic numbers. In that case the intensity of the backscatter will be between that of the substrate and the coating and can be used to determine coating thickness. Principle of operation, apparatus description, factors affecting measurement uncertainty, calibration and procedure are included.	Varies with instrument.

Intended Application	Specimen Requirement	Limits
Non-destructive thickness measurements, generally.	Test specimens should be clean and have oxides or conversion coatings removed. Calibration specimens should be of same curvature and composition and density.	Coating thickness should be measurable to within 10% of the true thickness.

ISO 3868
Metallic and Oher Non-Organic Coatings – Measurement of Coating Thickness – Fizeau Multiple-Beam Interferometry Method

General Description	Data Produced
This Standard provides a method for measurement of the thickness of highly reflective coatings up to 2 μm in thickness using Fizeau multiple-beam interferometry. In this method, a monochromatic light beam of known wavelength is reflected back and forth between the specimen surface, which includes a step between the substrate surface and the exposed (top) coating surface, and a superimposed transparent mirror (Fizeau plate). An interference fringe pattern is formed in the air wedge between the slightly inclined plate and the specimen surface. The fringe spacing and shape are viewed and measured through a microscope with a filar micrometer eyepiece to calculate the step height between the exposed surfaces. The Standard includes factors affecting the measurement accuracy and measurement procedure. Instrument calibration is not required.	Micrometer eyepiece measurements of a visual image of interference fringes.

Intended Application	Specimen Requirement	Limits
Accurate measurement where a portion of the coating can be removed or a portion of the substrate not coated.	Clean, relatively flat and smooth specimens. A highly reflective coating of aluminum or silver on the test piece may be required.	The technique provides an absolute measure of the vertical surface variation ranging from 0.002 μm to 2 μm. Precision is normally ± 0.001 μm in the range 0.002 μm to 0.01 μm using the fringe-line width method, and normally ± 0.003 μm in the 0.01 μm to 2 μm range.

ISO 4518
Metallic coatings – Measurement of Coating Thickness – Profilometric Method

General Description	Data Produced
This Standard specifies a method for the measurement of metal coating thickness by the measurement of the step height from the exterior surface of the coating to the surface of the substrate which has been revealed by removal of the coating or masking during coating deposition. Step height is measured by use of an electronic stylus instrument, a type generally used to measure surface roughness, or by use of an electronic inductive comparator equipped with styli. The Standard provides: operational instrument, factors affecting accuracy, calibration requirements, and measurement procedure.	Instrument generated coating thickness and edge build-up readings.

Intended Application	Specimen Requirement	Limits
Accurate measurement where a portion of the coating can be removed or masked. This method is used for the evaluation of PVD (physical vapor deposited) coatings.	Clean relatively flat well prepared step. Preferably, four well defined circles are prepared by coating removal within a 1 cm by 1 cm square. If a portion of the substrate is masked prior to coating, the area for measurement shall be sufficiently small (1 mm to 2 mm diameter) to preclude edge build-up.	The measurement should be determinable to within 10% or ± 0.005 μm, whichever is greater. Electronic stylus instruments cover a thickness range of 0.005 μm to 250 μm. Electronic inductive comparators cover the range of 1 μm to 1000 μm.

ISO 4522-1
Metallic Coatings – Test Methods for Electrodeposited Silver and Silver Alloy Coatings
Part 1: Determination of coating thickness

General Description	Data Produced
This brief Standard lists techniques for gravimetric and chemical analysis methods of determination of thickness of silver coatings. Microscopical method (ISO 1463), Coulometric method (ISO 2177), magnetic method (ISO 2178), X-ray spectrometric method (ISO 3497), Beta backscatter method (ISO 4543), Interferometric method (ISO 3868) and Profilometric method (ISO 4518) are identified for reference.	Calculation from mass measurements for gravimetric and chemical methods.

Intended Application	Specimen Requirement	Limits
Measurement of thickness of coatings for engineering, decorative or protective purposes.	Varies with technique.	Not specified.

ISO 2064
Metallic and Other Inorganic Coatings – Definitions and Conventions Concerning the Measurement of Thickness

General Description	Data Produced
This Standard defines what is meant by the term "minimum thickness" when used in specifications for metallic and related coatings; specifically, it is defined as a local thickness over a small area. It also specifies some general rules to be followed in the measurement of minimum thickness of coatings.	Not specified.

Intended Application	Specimen Requirement	Limits
Clarification of terms used in specifications.	Not specified.	Articles with less than 1 cm^2 of significant surfaces shall have the number of single measurements made agreed upon by the parties concerned. Articles with more than 1 cm^2 of significant surfaces shall have up to five distributed measurements made in this reference area, and the number of measurements shall be agreed upon by the parties concerned.

7.3 Coating Mass

ASTM A 90/A 90M
Standard Test Method for Weight (Mass) of Coating on Steel Articles with Zinc or Zinc-Alloy Coatings

General Description	Data Produced
This Method details procedures for acidic dissolution of zinc and its alloys from steel products with mass/area determined by mass difference. The Method includes reagents, hazards, sampling, procedure, calculation and reporting.	Coating mass per unit area.

Intended Application	Specimen Requirement	Limits
Comparison with specification requirements.	Sheet- 3330 mm^2 (5.08 $in.^2$) wire- 305 mm to 609 mm (12 in. to 24 in.) in length; other articles- 2000 mm^2 (3 $in.^2$) minimum; threaded articles- portion without thread.	Repeatability= 15.24 g/m^2 (0.049 oz/ft^2)* Reproducibility= 18.66 g/m^2 (0.06 oz/ft^2)* precision not determined.

* SI (metric) units are calculated because the original standard included only customary units

ASTM A 309
Standard Test Method for Weight and Composition of Coating on Terne Sheet by the Triple Spot Test

General Description	Data Produced
This Method describes methods for determining the mass and tin content of terne (80% Pb, 20% Sn) on steel sheet using three acids for stripping the coating. The method includes procedures, reagents, and chemical analysis for stripping with sulfuric acid, electrolytic stripping with hydrochloric acid and sodium hydroxide, silver nitrate, hydrochloric acid and antimony trichloride, hydrobromic acid-bromine solution.	Coating mass per unit area, percent tin in coating.

Intended Application	Specimen Requirement	Limits
Comparison with specification requirements.	Specimens not less than 2000 mm^2 (3 $in.^2$) in area.	The sulfuric acid technique is not recommended for tin determination but yields coating weights which agree to within 3.11 g/m^2 (0.01 $oz./ft.^2$)* between replicate samples and between laboratories. The HCl and antimony trichloride method yields a coating weight which agrees to within 3.11 g/m^2 (0.01 $oz./ft.^2$)* between laboratories and between replicate specimens. Tin values are found to be within 3% for the hydrobromic acid-bromine solution method.

* SI (metric) units are calculated because the original standard included only customary units

ASTM A 428/A 428M
Standard test Method for Weight (Mass) of Coating on Aluminum Coated Iron or Steel Articles

General Description	Data Produced
This Method describes techniques for chemical stripping of aluminum from iron and steel with mass of coating determined by mass difference. The Method includes details on reagents, procedure calculation, sampling and reporting.	Coating mass per unit area.

Intended Application	Specimen Requirement	Limits
Comparison with specification requirements.	Sheet- 2000 mm^2 (3 $in.^2$) minimum; Wire- 300 mm (12 in.) minimum; Other articles- 2000 mm^2 (3 $in.^2$); Threaded articles- portion without thread.	Repeatability= 9.5 g/m^2 (0.031 oz/ft^2) for sheet Reproducibility= 10.4 $g.m^2$ (0.034 oz/ft^2) for sheet Precision not determined.

ASTM A 630
Standard Test Methods for Determination of Tin Coating Weights for Electrolytic Tin Plate

General Description	Data Produced
This document describes four methods for the determination of tin coating weights for electrolytic tin plate. The methods remove the tin, and/or its alloys by electrolytic or acid dissolution. The four methods are: A. Bendix Test Method which determines tin coating weights on steel plate by dissolution of tin from a tin plate anode in a dilute HCl solution. B. Constant Current, Electrolytic Method referee method) may be used to determine not only the total tin coating weight but also that part which is free tin and that which is alloyed by stripping the tin anodically at constant current in HCl electrolyte. C. Stellar's Method determines the total weight of tin carried by a unit area of tin plate by dissolution in HCl. D. Titration Method determines tin coating weight by dissolution of tin in HCl which is hastened by placing the sample in a platinum basket. Procedures, reagents and calculations for each method are provided.	Data produced varies with method. Methods A, C, D require titration and calculation of mass of dissolved tin. Method B requires measurement of time required for stripping at constant current used to calculate mass.

Intended Application	Specimen Requirement	Limits
Specification conformance and process control.	Sheet samples: Method A- disks 57.33 ± 0.02 mm (2.257 ± 0.001 in.) in diameter; Method B- Willey & Kunze procedure, same as Method A; Stannomatic procedure, disk at least 5.08 cm (1.50 in.) in diameter; Method C- test specimen area of 25.807 cm^2 (4 $in.^2$); commonly used Method D is same as Method A.	Methods have different reported limits, precluding comparison.

A 754/A 754M
Standard Test Method for Coating Weight (Mass) of Metallic Coatings on Steel by X-ray Fluoresence

General Description	Data Produced
This Method covers the use of X-ray fluoresence for on-line measurement of mass of Sn, Zn, Al-Zn coatings on steel sheet using X-ray tubes and isotopes and includes: basic principle, factors affecting accuracy calibration, procedure.	Coating mass per unit area.

Intended Application	Specimen Requirement	Limits
On-line measurement of coatings on continuous production lines using direct measurement of intensity of fluoresecent X-rays emitted by the coating or attenuation of fluorescent X-rays emitted by the coating as they pass through the coating. This method is used for evaluation of PVD (physical vapor deposited) coatings.	On-line processing.	Requires calibration curve of same materials, adequate counting time,ability of detector to discriminate between coating and substrate signals.

ASTM B 137
Standard Test Method for Measurement of Coating Mass Per Unit Area on Anodically Coated Aluminum

General Description	Data Produced
This Method details the destructive determination of the mass of anodic coating on aluminum and its alloys. The method consists of disolving the coating from a known surface area in a phosphoric-chromic acid solution maintained at 100 °C and measuring the weight loss.	Coating mass per unit area.

Intended Application	Specimen Requirement	Limits
Suitable for quality control since the mass is an approximation of coating thickness when the density of the coating is known.	Clean surface about 75 mm square.	Uncertainty of less than 10% possible.

ASTM B 767
Standard Guide for Determining Mass Per Unit Area of Electrodeposited and Related Coatings by Gravimetric and Other Chemical Analysis Procedures

General Description	Data Produced
This guide describes the general method(s) for determining mass per unit area of coatings which can be removed from substrates. This is not appropriate for thin coatings over small areas. Method consists of weighing sample before and after removing coating and measuring area from which coating is removed. Guide includes apparatus, specimen preparation, measurement of coated area, gravimetric determination, procedure and extensive list of reagents for removal of metal layers.	Mass and area used to calculate average mass per unit area.

Intended Application	Specimen Requirement	Limits
Acceptance testing.	Specimens with sufficient mass and area which can be measured to give adequate accuracy.	Procedures cannot be used when coating cannot be separated from the substrate.

ASTM D 5723
Standard Practice for Determination of Chromium Treatment Weight on Metal Substrates by X-ray Fluorescence

General Description	Data Produced
This document describes the use of X-ray fluorescence to determine the weight of chromium coating on metal substrates. The method consists of exposing the sample to primary radiation which causes the chromium in the coating to fluoresce. The fluorescence (secondary) radiation intensity is a quantitative measure of the mass of chromium. The measured intensity of the secondary radiation is compared to that obtained from calibration samples of known mass per unit area. The calibration samples should span the expected values to be measured. A commercial instrument supplier is identified, as are sources of calibration standards.	Chromium fluorescence intensity readings which are used to calculate coating weight.

Intended Application	Specimen Requirement	Limits
Generally, intended for determination of coating weight of chromium treatments on metal substrates.	Flat, clean specimens.	Not specified.

ASTM E 1659
Standard Test Methods for Coating Weight and Chemical Analysis of Zinc-Nickel Alloy Electrolytically Coated on Steel Sheet

General Description	Data Produced
Methods are described for determination of mass and nickel content for zinc-nickel coatings on steel. A gravimetric method where the coating is removed with hydrochloric acid is given for coating masses from 20 g/m^2 to 45 g/m^2. Atomic absorption spectrometry analysis is conducted on the solution used in the gravimetric test and results compared with data from a standard solution to determine nickel concentrations from 11.0% to 13.5%.	Measurement of mass and instrument data.

Intended Application	Specimen Requirement	Limits
These are intended to be referee methods for specification compliance testing.	Test pieces should be obtained in accordance with ASTM A 917. Test specimens are 50 mm ± 5 mm squares. One specimen is required for each side to be tested.	Multi-laboratory comparisons of gravimetric method for 20 g/m^2 coating showed a 2 standard deviation of 0.337 g/m^2; 30 g/m^2 showed a 2 standard deviation value of 2.074 g/m^2. Nickel analysis on 20 g/m^2 material showed a 2 standard deviation value of 0.081% for an average 11.34% nickel material; 30 g/m^2 showed a 2 standard deviation of 0.141% for an 11.76% average nickel content.

ISO 2106
Anodizing of Aluminum and its Alloys – Determination of Mass per Unit Area (Surface Density) of Anodic Oxide Coatings – Gravimetric Method

General Description	Data Produced
This destructive method of determination of anodized mass consists of dissolving the anodized coating from the substrate using a mixture of phosphoric acid and chromium trioxide at 100 °C for at least 10 min and weighing the sample before and after removal.	Mass per unit area.

Intended Application	Specimen Requirement	Limits
Coating thickness can be calculated if density is known. Coating density can be calculated if thickness is known.	Coating must be free of oil and grease. Mass should not exceed 100 g. Area should be between 0.08 dm^2 and 1 dm^2.	Suitable for most aluminum alloys except those with copper contents greater than 6%. Estimation of thickness is more accurate for coatings of 10 μm and less in thickness.

ISO 3892
Conversion Coatings on Metallic Materials – Determination of Coating Mass per Unit Area – Gravimetric Methods

General Description	Data Produced
This Standard specifies gravimetric methods for determination of mass per unit area for: phosphate coatings on iron and steel; phosphate coatings on zinc and cadmium; phosphate coatings on aluminum and its alloys; chromate coatings on zinc and cadmium; and, chromate coatings on aluminum and its alloys. Reagents for dissolution of coatings, specimen surface areas required for adequate accuracy, procedures and safety warnings are provided.	Measured mass loss due to coating dissolution and measured surface area are used to calculate coating mass per unit area.

Intended Application	Specimen Requirement	Limits
Determination of conformity to product specification.	Test pieces should have a maximum mass of 200 g. Total surface areas should be between 400 cm^2 for expected coating mass per unit area of less than 1 g/m^2 and 25 cm^2 for expected coating mass per unit area of greater than 50 g/m^2.	Under optimum conditions, the measurement uncertainty of the methods is within 5%. The methods do not indicate the presence of bare spots or sites with thicknesses less than specified. The values obtained are mean thicknesses over the measured area. The methods are applicable to coatings free of supplementary coatings such as oil, water or solvent-based polymers, or wax.

8. Standards for Analysis of Microstructure

8.1 Metallography

ASTM B 797
Standard Test Method for Surface Finger Penetration Depth of Interparticle Oxide Networks in Powder Forged (P/F) Steel Parts

General Description	Data Produced
This Method describes the metallographic examination of a cross-section of the surface and interior of powder forged steel parts. Surface finger oxide penetration is measured at 400x on polished but unetched specimens. Interparticle oxide network concentration is measured at 200x to 400x on polished and unetched specimens. The Method includes sampling, procedure, examples of metallographically prepared oxide finger penetration and oxide network concentration, and reporting.	Metallographic images.

Intended Application	Specimen Requirement	Limits
Oxide finger penetration and interparticle oxide networks are used to evaluate processing. Results of tests may be used to qualify parts.	Specimens should be from each critical area on a part. Polished surfaces shall be parallel to the forging direction. Edge rounding is to be avoided.	Not specified.

ASTM E 3
Standard Guide for Preparation of Metallographic Specimens

General Description	Data Produced
This Guide provides general guidelines for preparation of specimens for metallographic examination of structure. It provides guidance for coated materials and identifies other pertinent ASTM standards. The Guide includes specimen selection, size and cutting; cleaning and mounting; edge retention methods; grinding and polishing; procedures for porous or otherwise unusual materials.	Visual image of microstructure.

Intended Application	Specimen Requirement	Limits
Study of structure and composition of metals and alloys by light or electron microscopy.	Varies with subject of analysis.	Not specified.

ASTM E 562
Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count

General Description	Data Produced
This Method describes how to manually count points in a polished microstructure to enable the statistical estimation of the volume fraction of an identifiable constituent or phase. Point grids are provided and the procedure for using these grids or eyepiece reticle. The Method includes description of apparatus (including grid configurations), sample selection and preparation, procedure, calculation of volume percentage estimate and percent relative accuracy, reporting, precision and bias.	Count of grid points which can be used to calculate volume fraction.

Intended Application	Specimen Requirement	Limits
Quantitative analysis of microstructure.	Polished, opaque cross-section.	Precision and relative accuracy are a function of the procedure including sample preparation, point density of the grid, magnification used and calculation methods.

ASTM E 1920
Standard Guide for Metallographic Preparation of Thermal Sprayed Coatings

General Description	Data Produced
This Guide provides guidance for the preparation of thermal sprayed coatings. The Guide is general and does not address specific coating or substrate materials. Selection of specimens, sectioning, cleaning, mounting, grinding, polishing and reporting are included. Microstructural features which this guide addresses include: unmelted particles, linear detachment, porosity, contamination, coating thickness, interfacial contamination and integrity.	Visual image of the microstructure.

Intended Application	Specimen Requirement	Limits
Evaluation to ensure coating integrity and adherence to substrate.	Specimens to be mounted should be no larger than 12 mm x 25 mm (0.50 in. x 1.0 in.)	Quantitative analysis can be influenced by preparation technique.

ISO 3057
Non-Destructive Testing – Metallographic Replica Techniques of Surface Examination

General Description	Data Produced
This Standard specifies techniques of surface examination in which transparent nitrocellulose varnish or plastic material is used to record metallurgical and mechanical in homogeneities in a metal surface. The Standard includes surface preparation, including metallographic preparation techniques, application of the replicate, removal of the replicate, mounting and examination.	Visual information.

Intended Application	Specimen Requirement	Limits
Analysis of metallographic, fracture and service effected surfaces where access is restricted.	Surface must be clean, degreased and dry.	Not specified.

8.2 Porosity and Defect Measurement of Coatings

ASTM B 735
Standard Test Method for Porosity in Gold Coatings on Metal Substrates by Nitric Acid Vapor

General Description	Data Produced
This Method provides a means of determining the amount of porosity in gold coatings on electrical contacts. It is a severe, destructive test, applicable to curved surfaces. Test materials are suspended in a closed container which is at low relative humidity (60% max) and above a container of nitric acid. Adequate specimen exposure to nitric acid for times of over an hour, depending on gold thickness, is followed by oven drying and counting corrosion product sites using 10x magnification. Corrosion products are the result of nitric acid fume reaction with copper, nickel or their alloys used as substrates.	Number of corrosion sites in a given surface area for coatings less than 0.6 μm (25 μin.) in thickness. Gives quantitative descriptions of pore density up to about 100/cm^2.

Intended Application	Specimen Requirement	Limits
Designed to show if porosity level is greater or less than a value considered acceptable for a specific application.	Clean and dry complex shapes are acceptable.	The test is too severe for use on coatings less than 0.6 μm (25 μin.) in thickness. Not suitable for coatings less noble than gold or platinum, such as palladium and its alloys or gold-flashed palladium or its alloys. Not intended for prediction of electrical performance of contacts unless correlation with service performance is established. Tested parts are not to be put into service.

ASTM B 741
Standard Test Method for Porosity in Gold Coatings on Metal Substrates by Paper Electrography

General Description	Data Produced
This Method describes a technique for determining the porosity of gold coatings on electrical contacts which are made of copper, nickel, or their alloys. The test consists of pressing dye transfer paper which has been saturated with an appropriate electrolyte against the test piece and applying a low voltage across the paper, coating and substrate. Products of the reaction between the substrate and the electrolyte, through pores in the coating, stain the paper. The test takes about one minute. Procedures for preparing the electrolyte are given. Reaction stains on the paper are counted using 10x magnification. Highly sensitive.	Indicated spots per unit area or per contact.

Intended Application	Specimen Requirement	Limits
Intended to show whether the porosity level is greater than a level, which by experience, is deemed acceptable.	Clean and dry and generally flat or gently curved surfaces.	Intended to be quantitative for pore densities up to about 100/cm^2; qualitative above this level. Test is destructive; specimens should not be put into service.

ASTM B 765
Standard Guide for Selection of Porosity Tests for Electrodeposits and Related Metallic Coatings

General Description	Data Produced
This Guide provides general information on ASTM Standards for the detection, identification and measurement of porosity. The tests consist of exposing coated materials to corrosive environments where reaction of the corrodant with the substrate (basis metal or interlayer) through intrinsic porosity or gross defects or mechanical damage in the coating produces a corrosion product at the defect site. Some of the products occur on the coating and others on a gel or paper coating. Visual inspection is by unaided eye or by 10x microscopy.	Visual indication of defect in coating.

Intended Application	Specimen Requirement	Limits
Process control or assessment of protection afforded by the coating. Intrinsic porosity test methods apply to coatings of gold, silver, nickel, tin-nickel, tin, tin-lead, copper, palladium and chromium on substrates of copper and its alloys, nickel, iron or steel and silver; although not all coatings on all substrates. Tests for gross defects and mechanical damage apply to coatings of gold, nickel, tin-nickel, tin, tin-lead, palladium and silver on copper and its alloys, nickel, iron or steel and aluminum; although not all coatings on all substrates.	Varies with method, generally. Clean surfaces.	Does not apply to thermal sprayed, sputtered, ion bombardment or processes where particles are discretely deposited on a substrate. Does not apply to coatings with controlled porosity.

ASTM B 798
Standard Test Method for Porosity in Gold or Palladium Coatings on Metal Substrates by Gel-Bulk Electrography

General Description	Data Produced
This Method is an electrographic technique wherein the test piece is made the anode in a cell containing a semisolid electrolyte of gelatin, conducting salts and an indicator. Application of current causes substrate metal ions to pass through continuous pores in the coating. Cation reaction with the indicator produces a colored reaction productat pore sites. Individual sites are counted using low power magnification through the clear gel in the cell. The test is suitable for gold coatings on silver, nickel, or copper and its alloys and palladium on nickel, copper and its alloys. The test procedure includes electrolyte preparation. The test is conducted for 20 s at a current density of 0.78 mA/cm^2 (5 mA/in.^{2}), 2.0 V to 2.5 V, at 23 °C.	Count of pores per unit area or per contact.

Intended Application	Specimen Requirement	Limits
Intended for the inspection of electrical contacts by providing a quantitative description of porosity as number of pores per unit area or per contact.	Clean specimens free of debris.	This is a destructive test. Tested parts may not be used in service. Not sensitive to small pores. Useful for pore densities up to about 25/cm^2.

ASTM B 799
Standard Test Method for Porosity in Gold and Palladium Coatings by Sulfurous Acid/Sulfur-Dioxide Vapor

General Description	Data Produced
This is a destructive test wherein test pieces are exposed to sulfur dioxide emitted from sulfurous acid above which the pieces are suspended. Reaction of the sulfur dioxide with the substrate produces corrosion products at pores in the coating. Spots are counted with low power magnification. The method is suitable for coatings with greater than 95% gold or palladium on substrates of copper, nickel and their alloys. Tests should be conducted in a fume hood. Exposures of 2 h for gold thicknesses of 1.25 μm or greater; 90 min for thicknesses less than 1.25 μm. Exposures of 60 min are required for palladium coatings.	Count of pores per unit area or per contact.

Intended Application	Specimen Requirement	Limits
Intended for the inspection of electrical contacts by providing a quantitative description of porosity as number of pores per unit area or per contact.	Clean specimens free of debris.	Generally, corrosion products less than 0.05 mm (0.002 in.) in diameter are not counted. Suitable for pore densities up to about 100/cm^2.

ASTM B 809
Standard Test Method for Porosity in Metallic Coatings by Humid Sulfur Vapor ("Flowers-of-Sulfur")

General Description	Data Produced
This Method describes methods and equipment for determining (qualitatively) the porosity of metallic coatings on silver, copper or copper alloys, where the pores penetrate to the substrate. In this Method, the test piece is suspended above a source of sulfur vapor in an environment of controlled humidity at 50 °C for hours or days. Reaction of the sulfur with the substrate, at locations where coating porosity allows penetration, produces "flowers of sulfur". Visual examination is conducted at 10x magnification. Pore sizes less than 0.05 mm (0.002 in.) in diameter are not counted.	Visible indications of defects.

Intended Application	Specimen Requirement	Limits
Intended for determination of coating quality and thus as a measure of deposition process control. Particularly intended for determination of quality of underplates of nickel or nickel alloy in finish systems with 1.2 μm (50 μin.) thick or less top layers above the nickel.	Clean surfaces.	Highly sensitive to exposed copper but nickel underplates are not attacked below 100 °C and if free of pores will not allow identification of pores in an overplate. Not recommended for product performance prediction unless correlation with service experience is established.

ASTM E 2109
Test Methods for Determining Area Percentage Porosity in Thermal Sprayed Coatings

General Description	Data Produced
This document gives procedures for conducting porosity ratings on metallographic specimens of thermal sprayed coatings using both direct visual comparison to standard images and automatic image analysis equipment. Specimens are prepared per ASTM E 1920 without specification of coating or substrate material. Visual comparison images are provided together with descriptions of apparatus, sampling, specimen preparation, test procedures, statistical analysis methods, reporting, precision and bias.	Images analyzed manually or by automated techniques.

Intended Application	Specimen Requirement	Limits
Intended for monitoring effects of process variables and suitability for purpose.	Specimens should include approximately 25 mm (1.0 in.) of coating length. Multiple specimens may be prepared to evaluate homogeneity.	Precision and bias can be affected by specimen preparation and analysis technique.

9. Standards for Measurement of Composition and Crystal Structure

9.1 Composition

ASTM E 673 *Standard Terminology Relating to Surface Analysis*	
General Description	**Data Produced**
This is a compilation of definitions of over 150 terms used in surface analysis. The terms apply to Auger electron spectroscopy, X-ray photoelectron spectroscopy, ion-scattering spectroscopy, secondary ion mass spectrometry and energetic ion analysis.	Not specified.

Intended Application	Specimen Requirement	Limits
Surface analysis, generally.	Not specified.	Not specified.

ASTM E 1127
Standard Guide for Depth Profiling in Auger Electron Spectroscopy

General Description	Data Produced
This Guide gives detailed instructions for chemical analysis as a function of depth from a surface using Auger electron spectroscopy (AES). Guidelines are given for depth profiling using ion sputtering, angle lapping and cross-sectioning. Mechanical cratering and non-destructive depth profiling are described.	Chemical composition as a function of distance from the surface.

Intended Application	Specimen Requirement	Limits
Chemical analysis generally.	Instrument dependent size requirements, cleanliness.	Destructive analysis is conducted by ion sputtering for depths less than 1μm or angle lapping or mechanical cratering for depths greater than about 1 μm and subsequently using Auger Electron Spectroscopy (AES) at different distances from the surface. Nondestructive depth profiling with AES is based on varying the effective electron escape depth from the test piece and is limited to the outermost 2 nm to 5 nm.

ASTM E 1438
Standard Guide for Measuring Widths of Interfaces in Sputter Depth Profiling Using SIMS

General Description	Data Produced
This Guide provides a method for determining the width of interfaces from SIMS (secondary ion mass spectroscopy) sputtering data. Interface widths are calculated from plots of SIMS secondary ion intensity versus time. Procedure and apparatus are included.	SIMS intensity versus ion bombardment time where the time required for the signal of one of the major elements of the layer overlying the interface to be reduced from 84% to 16% of its average intensity in the overlying layer is used to calculate thickness.

Intended Application	Specimen Requirement	Limits
Primarily intended to provide a method for checking on proper or consistent instrument performance.	Not specified.	This method does not apply to analyses of data from specimens without interfaces such as ion-implanted material.

ISO 14606
Surface Chemical Analysis – Sputter Depth Profiling – Optimization Using Layered Systems as Reference Materials

General Description	Data Produced
This document gives guidance on the optimization of sputter depth profiling parameters using appropriate single layered and multilayered reference materials to optimize depth resolution in Auger electron spectroscopy (AES), X-ray photoelectron spectroscopy (XPS) and secondary ion mass spectroscopy (SIMS).	Instrument specific.

Intended Application	Specimen Requirement	Limits
Chemical analysis, generally.	Not specified.	Not specified.

ISO 14707
Surface chemical analysis – Glow discharge optical emission spectrometry (GD-OES) – Introduction to use

General Description	Data Produced
This document provides guidelines applicable to bulk and depth profiling GD-OES analyses. Principle of operation, apparatus description, procedure, steps for determination of quantitative analysis are included.	Instrument specific.

Intended Application	Specimen Requirement	Limits
Chemical analyses as a function of depth.	Flat round or rectangular specimens with a width of 10 mm to 100 mm.	The specimen area analyzed is typically 2.5 mm to 8 mm. Layer thicknesses amenable to GD-OES depth profiling range from a few nanometers to approximately 100 μm.

9.2 Crystal Structure

ASTM F 2024
Standard Practice for X-ray Diffraction Determination of Phase Content of Plasma Sprayed Hydroxyapatite Coatings

General Description	Data Produced
This Practice provides detailed guidance for the use of the Reference Intensity External Standard Model to determine the weight percent of the crystalline phases hydroxyapatite (HA), beta-tricalcium phosphate (B-TCP) and calcium oxide (CaO) in plasma sprayed HA on metallic substrates. The Practice was developed for plasma sprayed coatings with HA contents of at least 50% of the total coating. The Practice includes a description of the external standard technique, experimental procedure, reporting, precision and bias.	X-ray diffraction pattern which is compared to an external standard to quantitatively determine phase content.

Intended Application	Specimen Requirement	Limits
For detailed analysis of the form and purity of calcium phosphate to enable reproducible clinical trials of biological implants and for determination of effects of phases on biocompatibility.	Specimens for X-ray diffraction analysis should be flat, 2.5 cm x 2.5 cm x 0.6 cm (1 x 1 x 0.125 in.) to be analyzed on a substrate. The coating should be at least 44 μm thick to ensure opaqueness to the X-ray beam. Effective particle size and variation in surface roughness in the alpha-corundum external standard must be less than 5 μm.	Reproducibility is of the order of ± 3% for HA content of plasma sprayed coatings.

10. Standards for Residual Stress and Hardness Measurement

10.1 Residual Stress Measurement

ASTM E 837
Standard Test Method for Determining Residual Stresses by the Hole-Drilling Strain Gage Method

General Description	Data Produced
This Method gives the procedure for determining the residual stresses near the surface of an isotropic, linear-elastic material by measuring changes in strain, using a strain gage rosette, as affected by drilling a small hole in the material in the center of the rosette. Drilled hole diameters and depths are a function of rosette size. Procedure, instrumentation, stress calculation, specimen preparation, reporting, precision and bias are included.	Instrument readings converted to strain and via elastic modulus to stress.

Intended Application	Specimen Requirement	Limits
Determination of residual stresses which can affect the performance of a component or structure.	A clean, degreased surface for strain gage attachment. Abrading or grinding the surface may alter surface stresses.	Stresses should not vary significantly with depth and not exceed one-half the yield strength. Bias can be expected to not exceed ± 10% if conditions specified herein are followed. If a significant non-uniform stress distribution is unrecognized the error may be more than 10%, usually an under estimate of the maximum stress. Round robin testing showed a standard deviation of 14 MPa (2.0 ksi) for carbon steel and 12 MPa (1.7 ksi) for stainless steel, both about the mean values measured.

ASTM E 1426
Standard Test Method for Determining the Effective Elastic Parameter for X-ray Diffraction Measurements of Residual Stress

General Description	Data Produced
This Method describes how to determine the effective elastic parameter, E_{eff}, using mechanical loading techniques. E_{eff} is related to Poisson's ratio and relates macroscopic stress to the strain measured in a particular crystallographic direction in polycrystalline samples. The Method includes apparatus and specimen descriptions, calibration of the specimen, X-ray diffraction technique, calculation of E_{eff}, precision and bias.	Diffraction data related to stress through calculation.

Intended Application	Specimen Requirement	Limits
Used in the X-ray diffraction measurement of residual and applied stress.	Test specimens should be fabricated from material with microstructure as similar as possible to the material in which residual stress is to be measured. Guidelines for length to width to thickness ratios are provided for rectangular specimens in tensile or bending. Surfaces may be electropolished or as-rolled sheet or plate and of a size to accommodate strain gage(s).	Precisions of 2% to 3% were reported in a three laboratory round robin.

10.2 Indentation Hardness Measurements

ASTM A 833
Standard Practice for Indentation Hardness of Metallic Materials

General Description	Data Produced
This practice consists of using a hammer to manually strike a calibration bar which in turn strikes a Brinell ball that makes an impression in the test piece. The impact force on the calibration bar is assumed to be the same as the impact force on the test piece. The size of the Brinell ball indentation on the test piece and the calibration bar are compared to ascertain the hardness of the test piece. The hardness of the calibration bar is determined independently in a hardness testing machine. The Practice includes apparatus, test parts, verification of apparatus and calibration of comparative bars, procedure and reporting.	The diameter of the impression is measured with a microscope and used to calculate hardness.

Intended Application	Specimen Requirement	Limits
This Practice is intended for measurement of the hardness of large parts or stationary structures not suitable for hardness testing machine use.	The specimen should be of sufficient thickness such that a bulge does not form on the side opposite the impression, and that the test piece be stable with a surface sufficiently smooth to measure the impression with a microscope.	The comparative bar impression should not exceed 4.2 mm. Accuracy can be improved if the comparative bar has a hardness within thirty Brinell (HB) numbers of the part tested.

ASTM B 277
Standard Test Method for Hardness of Electrical Contact Materials

General Description	Data Produced
This Method identifies other ASTM standards suitable for measurement of hardness of electrical contacts. Those standards include E 10, E 18, E 384. Aspects of those standards which affect measurement of electrical contacts are identified. The Method includes sampling, procedure, reporting, precision and bias.	Hardness numbers read from a testing machine.

Intended Application	Specimen Requirement	Limits
Measurement of hardness of metallic electrical contacts.	Specimens should be thick enough to not flow during indentation or of phase sizes sufficiently large that microhardness measurements do not represent an average hardness.	Precision and bias are as identified in referenced standards.

ASTM B 294
Standard Test Method for Hardness Testing of Cemented Carbides

General Description	Data Produced
This Method addresses measurement of hardness of cemented carbides using the Rockwell A scale in the range of Rockwell A80 and above. This generally follows ASTM E 18. The Method includes apparatus, test specimens, procedure, reporting, precision and bias, and information of standard test blocks and indenter selection.	Hardness numbers read from a testing machine.

Intended Application	Specimen Requirement	Limits
Measurement of hardness as an indication of wear resistance and toughness.	Minimum thickness of 1.6 mm (0.0625 in.), surface roughness with Ra less than or equal to 0.2 μm (8 μin.), surfaces flat and parallel to one part per hundred for general practice, radius of curvature not less than 15 mm. Mounted carbides are to be removed from steel bodies.	The repeatability limit is 0.3 HRA (Hardness, Rockwell A scale). The repeatability standard deviation is 0.1 HRA. The reproducibility limit between or among laboratories is 0.4 HRA. The reproducibility standard deviation is 0.14 HRA.

ASTM B 578
Standard Test Method for Microhardness of Electroplated Coatings

General Description	Data Produced
This Method provides guidance for the measurement of microhardness of the cross-section of electroplated metallic coatings using a Knoop indenter at test loads of 0.245 N (25 gf) or 0.981 N (100 gf), for soft (50 to 300 HK) and hard (greater than 300 HK) coatings. The Method includes special requirements, preparation of test specimens, procedure (based on ASTM E 384), reporting, use of test coupons and precision and bias.	Measurement of indent diagonals interpreted as microhardness.

Intended Application	Specimen Requirement	Limits
Property measurement for acceptance or suitability for purpose.	Metallographic specimen with 38 μm thick (min) soft coating and 25 μm thick (min) hard coating overplated with 12 μm coating of similar hardness as test coating.	Precision and bias are not provided. Reference hardness specimens of electroformed nickel with certified hardness readings are available from the National Institute of Standards and Technology (NIST).

ASTM B 647
Standard Test Method for Indentation Hardness of Aluminum Alloys by Means of a Webster Hardness Gage

General Description	Data Produced
This method addresses the use of the Webster, Model B, portable handheld hardness gage. This gage provides a numerical hardness value reflecting the penetration of a hardened steel indenter into the test piece. The Method includes apparatus, test parts or specimens, calibration of the device, procedure, reporting, precision and bias. The device is operated like a pair of pliers.	Webster hardness number as read from gage.

Intended Application	Specimen Requirement	Limits
Intended for the *in-situ* determination of hardness of fabricated parts and test specimens for production control.	Material between 1 mm (0.040 in.) and 6 mm (0.250 in.) in thickness and with a clear flat area of 25 mm x 25 mm (1 in. x 1 in.) at an edge, with surfaces essentially parallel, clean and lightly polished and 3 mm (0.125 in.) from edge of part or specimen.	Useful for material in the range of 3003-0 to 7075-T6; e.g., Rockwell 5 HRE (Hardness Rockwell E scale) to 110 HRE.

ASTM B 648
Standard Test Method for Indentation Hardness of Aluminum Alloys by Means of a Barcol Impressor

General Description	Data Produced
This Method addresses the use of a Barcol Impressor, Model 934-1, a portable device, to measure the hardness of aluminum alloys. The device is operated by applying hand pressure on the housing and measuring the penetration of a hardened steel indenter into the test piece. The Method includes apparatus, test parts or specimens, calibration, procedure, reporting, effect of curvature and precision and bias.	Barcol hardness number as read from gage.

Intended Application	Specimen Requirement	Limits
Intended for the *in-situ* determination of hardness of fabricated parts and test specimens for production control.	Test material should be clean and smooth at least 1.5 mm (0.0625 in.) thick and large enough to ensure a minimum distance of 3 mm (0.125 in.) in any direction from the indenter point to the edge.	Greater variation than standard fixed frame hardness testers. Three readings on homogeneous materials are needed to maintain a variance-of-average of 0.28 at an 80 Barcol reading. Six readings at a 50 Barcol reading are required for the same variance-of-average.

ASTM B 724
Standard Test Method for Indentation Hardness of Aluminum Alloys by Means of a Newage, Portable, Non-Caliper-Type Instrument

General Description	Data Produced
This Method addresses the use of a Newage portable hardness instrument which provides readout values numerically equivalent to Rockwell B scale as determined by ASTM E 18. The depth of penetration of a carbide tipped indenter between preload and full load is an indication of the hardness value. The Method includes apparatus, hazards, test piece requirements, instrument calibration, test procedure, interpretation of results, precision and bias.	Hardness numbers are read from the instrument and are related to but not necessarily identical to Rockwell B when conducted in accordance with ASTM E 18. Values obtained with the Newage instrument are reported as HRBN (Hardness Rockwell BN scale).

Intended Application	Specimen Requirement	Limits
Intended for quality assurance and production control. It is not intended to be an independent material-acceptance test.	Intended for thicknesses greater than 1.50 mm (0.0625 in.) which does not deflect during test and which does not produce a bulge on its reverse side. Surface should be clean, free of mechanical damage or processing defects. A surface finish of 3.2 μm or finer is recommended.	Single operator, single instrument, same day relative precision for HRBN of aluminum alloy with HRB of 55 was ± 1.4, with HRB of 75 it was ± 1.1, and with HRB of 84 it was ± 0.8. More extensive repeatability and reproducibility information are included.

ASTM C 1326
Standard Test Method for Knoop Indentation Hardness of Advanced Ceramics

General Description	Data Produced
This Method, in great detail, describes the measurement of the Knoop hardness of advanced ceramics using a calibrated machine to force a diamond indenter into a polished surface of the material and measuring the long diagonal of the indentation with an optical microscope. The Knoop indentation is shallower than a Vickers indentation and may be useful in evaluating coating hardness. The Method includes identification of factors which can interfere with the measurement, apparatus and specimen descriptions, indentation measurement, hardness calculation, reporting, precision and bias.	Hardness calculated from the ratio of the applied load to the projected area of the permanent impression in the test piece.

Intended Application	Specimen Requirement	Limits
One of many properties used to characterize ceramics.	Specimens should have a surface roughness less than 0.1 μm rms and be ten times as thick as the indentation depth, generally at least 0.50 mm. Porosity can affect the measurement.	Precision and bias depend on adherence to the procedure and instrument and material factors.

ASTM C 1327
Standard Test Method for Vickers Indentation Hardness of Advanced Ceramics

General Description	Data Produced
This Method provides detailed guidance on the measurement of the Vickers hardness of advanced ceramics, complementing ASTM C-1326-99 which addresses the use of a Knoop indenter. The Method includes descriptions of apparatus, factors which affect measurements, specimen requirements, procedure and measurement, hardness calculation, illustrations of acceptable and unacceptable indentations, reporting, precision and bias.	Hardness calculated from the ratio of the applied load to the area of contact of the four faces of the undeformed indenter.

Intended Application	Specimen Requirement	Limits
Measurement of one property used to characterize advanced ceramics.	Generally, specimens should be over 0.50 mm thick with a surface roughness of less than 0.1 μm rms, unless examination of surface treatment or coating precludes grinding and polishing.	Precision and bias depend on adherence to procedure, material and instrument factors. Within laboratory hardness repeatabilities of indentations made at 9.81 N on tungsten carbide test blocks showed 1.2% coefficient of variation and between laboratory repeatabilities of 6.1% for indents made by the organizing laboratory.

ASTM E 10
Standard Test Method for Brinell Hardness of Metallic Materials

General Description	Data Produced
The Brinell hardness number (HBW) is determined by measuring the indentation of a tungsten carbide ball of known diameter at a specified load into the test piece using a testing machine. The method is suitable for materials with a Brinell hardness (HBW) not exceeding 650. Three test methods are included: Test Method A- test procedure; Test Method B- verification of testing machines; Method C- calibration of standardized test blocks.	Hardness is calculated from and is proportional to the quotient obtained by dividing the test force by the curved surface area of the indentation.

Intended Application	Specimen Requirement	Limits
Provides empirical data which can be correlated with strength, wear resistance or other properties and may be useful in quality control and material selection.	The test piece should not exhibit bulging on the reverse side opposite the indentation; generally interpreted as requiring a thickness of ten times the indentation depth. The center of the indentation should be at least 2.5 times the diameter of the indentation and the surface should be smooth enough to see the edge of the indentation.	Precision and bias for the test method are not specified. Conversion to other hardness scales is to be avoided.

ASTM E 18
Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

General Description	Data Produced
The Rockwell hardness of a material is determined by measuring the indentation of a diamond spheroconical or tungsten carbide or steel spherical indenter under specified conditions into a surface in two operations (loads) and to measure the difference in depth of the indentation under the specified conditions of preliminary and total test forces. The Rockwell superficial hardness test is the same but with lower loads. Three test methods are included: Test Method A- General Description and Test Procedure; Test Method B- Verification of Machines; Method C- Calibration of Standardized Test Blocks.	Hardness number read from testing machine.

Intended Application	Specimen Requirement	Limits
This is an empirical test which provides hardness data which may correlate with strength or other properties and may be useful in quality control and material selection. This test is considered satisfactory for acceptance of commercial shipments.	Information is provided on test piece thickness and surface condition. Generally, thickness should be greater than ten times the depth of indentation with a diamond indenter and 15 times the depth of indentation with a ball indenter.	None specified.

ASTM E 92
Standard Test Method for Vickers Hardness of Metallic Materials

General Description	Data Produced
The Vickers hardness is determined using a calibrated machine to force a square base diamond pyramid indenter into the test piece with a predetermined force and measuring the diagonals of the impression with an optical microscope after the force is removed. The Vickers hardness number, HV, is related to the applied force and the surface area of the permanent impression. Three test methods are included: Method A – General Method and Test Procedure; Method B – Verification of Testing Machine; Method C – Calibration of Standard Hardness Test Blocks.	Hardness number calculated from applied force and measured impression.

Intended Application	Specimen Requirement	Limits
This test provides hardness data which may be used for correlations with material properties.	The thickness of the test piece should be at least 1.5 times the length of the diagonal. The surface shall be prepared such that the ends of the diagonals are clearly defined. The center of an indentation shall not be closer than 2.5 times the diagonal of the impression from the test piece edge.	Under optimum conditions of procedure and equipment, the accuracy can be expected to be the equivalent of 4% of the Vickers hardness number of the standardized reference test blocks.

ASTM E 103
Standard Test Method for Rapid Indentation Hardness Testing of Metallic Materials

General Description	Data Produced
This Method is an alternative to ASTM E 10 and employs commercially available portable testers. This is not considered a standard Brinell hardness test method. The Method includes: Part A – General Description and Test Procedure; Part B – Verification of Testing Machines; Part C – Calibration of Reference Test Blocks.	Varies with device.

Intended Application	Specimen Requirement	Limits
The method is used where hardness measurements must be made rapidly; as in inspection of production output.	The thickness of the test piece must be at least 10 times the depth of the indentation and the surface must be clean and in such condition that test results are not compromised. The center of the indentation should be at least 2.5 times the depth of the indentation from the edge of the test piece.	Test results are not comparable between equipment from different manufacturers.

ASTM E 110
Standard Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers

General Description	Data Produced
This is a short, general description of portable devices which attach to the test piece and use spring or hydraulic force, rather than dead weights, to apply the load necessary to make a Brinell, Rockwell or Vickers type indentation.	Varies with device.

Intended Application	Specimen Requirement	Limits
These devices are used principally for testing articles too large or awkward to be evaluated in conventional, stationary hardness testing machines.	Not specified.	Precision of the method is not established because of the wide variety of portable testers. Precision of a given test can be determined.

ASTM E 140
Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness and Scleroscope Hardness

General Description	Data Produced
This document contains nine conversion tables relating hardness scales for steels (primarily), stainless steels, copper, cartridge brass, unalloyed white cast iron and wrought aluminum alloys. Equations for conversion between scales are included.	Varies with method, generally read off instrument.

Intended Application	Specimen Requirement	Limits
These tables should be used when it is impossible to test a material under the conditions specified.	Varies with method.	Converted values should be considered approximate.

ASTM E 384
Standard Test Method for Microindentation Hardness of Materials

General Description	Data Produced
E 384 is the Standard Test Method on which several other methods are based. It provides the basic information for Knoop and Vickers indentation tests at loads in the range of 1 gf to 1000 gf. This method includes formulas for calculation of hardness numbers, description of apparatus, specimen requirements, procedure, reporting, factors affecting precision and bias, verification methods for testing machines and indenters, calibration of standardized hardness test blocks, results of interlaboratory tests of microindentation measurement, recommendations for light force testing, HK and HV values for a 1 gf test load.	Optical measurement of diagonal used with applied force to calculate hardness.

Intended Application	Specimen Requirement	Limits
Hardness can be correlated with material properties such as strength and wear resistance. Microindentation tests can be applied to test pieces too small for conventional macro-indentation tests or for the examination of phases or aspects of a material.	Preferably flat polished specimens free of defects or material which can affect measurement of indentation diagonals, particularly tips. Specimens should be prepared in accordance with ASTM E 3.	Precision and bias depend on adherence to test procedure, instrumental and material factors and measurement errors. The Method includes results of interlaboratory tests and analysis of test parameter variations which produce a 1% error in hardness.

ISO 3878
Hardmetals – Vickers Hardness Test

General Description	Data Produced
This is a succinct Standard describing the method for determining the Vickers hardness of hardmetals. Hardmetals are not defined. The test force applied shall be in the range of 9.807 N (HV 1) to 490.3 N (HV 50), the preferred force being 294.2 N (HV 30).	Optical measurements of indentation dimensions (diagonals) used to calculate a hardness number.

Intended Application	Specimen Requirement	Limits
Hardness measurements, generally.	Polished, clean surface free of contaminants, lubricants and oxides. The test piece shall be at least 1 mm thick and the thickness of material removed from the surface shall not be less than 0.2 mm.	The device for diagonal (d) measurement shall have the following accuracy: $d < 100$ μm; ± 0.2μm 100 m < d < 200 μm; ± 1.0μm $d > 200$ μm; ± 0.5 μm The arithmetical mean of the hardness values measured shall be reported to the nearest 10 HV.

ISO 4498-2
Sintered Metal Materials, Excluding Hard Metals – Determination of Apparent Hardness
Part 2: Case-hardened ferrous materials, surface enriched by carbon or carbon and nitrogen

General Description	Data Produced
This brief Standard specifies methods of hardness testing surfaces of sintered metals which have non-uniform hardness to a depth of 5 mm below the surface and "therefore applies to materials in which the hardness is obtained essentially by surface enrichment by carbon and nitrogen, for example by carburizing, carbonitriding, nitrocarburizing or sulphidizing." Vickers (HV 5) or Rockwell (HR 15 N) hardness tests are specified. Five indentations are to be made and reported hardness shall be the arithmetical mean of the four highest readings rounded to the nearest whole number.	Readings as obtained for Vickers or Rockwell hardness measurements specified in ISO/ R 146, Verification of Vickers hardness testing machines; ISO/R 1024, Rockwell superficial hardness test (N and T scales) for steel; and ISO 6507/1, Metallic materials-Hardness test-Vickers test-Part 1: HV 5 to HV 100.

Intended Application	Specimen Requirement	Limits
Not specified.	The sintered metal surface shall be clean, smooth and flat.	Not specified.

ISO 4545
Metallic Materials – Hardness Test – Knoop Test
Part 1: Test method

General Description	Data Produced
This Standard specifies the method for conduct of a Knoop hardness test for metallic materials at forces up to and including 9.807 N. The document accompanies ISO 4546, Metallic materials-Hardness test-Verification of Knoop hardness testing machines and ISO 10250 Metallic materials- Tables of Knoop hardness values for use in tests made on flat surfaces. Descriptions of apparatus, test pieces, test procedure and reporting are included.	Optical measurements of indentation dimensions used to calculate a hardness number.

Intended Application	Specimen Requirement	Limits
Microhardness measurements, generally.	Polished, clean surface free of contaminants and oxides.	There is no general process of accurately converting Knoop hardness values into other hardness scales or tensile strength. A strict comparison of hardness values is only possible at identical test forces.

ISO 6507-1
Metallic Materials – Vickers Hardness Test
Part 1: Test method

General Description	Data Produced
This Standard specifies the method for conduct of a Vickers hardness test at test forces of: greater than or equal to 49.03 N; greater than or equal to 1.961 N and less than 49.03 N; and, greater than or equal to 0.09807 N and less than 1.961 N. This Standard accompanies ISO 6507-2 Metallic materials – Vickers hardness test – Part 2: Verification of testing machines and ISO 6507-3, Metallic materials – Vickers hardness test –Part 3: Calibration of reference blocks.	Optical measurements of indentation dimensions used to calculate a hardness number.

Intended Application	Specimen Requirement	Limits
Microhardness measurements where lengths of indentation diagonals are between 0.020 mm and 1.400 mm.	Polished, clean surface free of contaminants and oxides.	Uncertainty is dependent on two categories of parameters, the testing machine and the application of the method. Uncertainty may approach 10% of the measured hardness value.

ISO 14577-1
Metallic Materials – Instrumented Indentation Test for Hardness and Materials Parameters
Part 1: Test method

General Description	Data Produced
ISO 14577 – Part 1 specifies the method for instrumented indentation measurement of Martens hardness (HM), indentation hardness (HIT), indentation modulus (EIT), indentation creep (CIT), indentation relaxation (RIT), plastic and elastic parts of the indentation work. In this method, displacement of the indenter (indentation) and force are measured during the complete cycle of increasing and removal of the load. Optical measurement of the indent is not necessary. Ranges of application are: macro ($2N \leq F \leq 30$ kN), micro ($2N \geq F$; $h \geq 0.2$ μm), nano ($h \leq 0.2$ μm), where F is the applied force and h is the depth of the indent. This Standard is accompanied by Part 2 – Verification and calibration of testing machines and Part 3 – Calibration of testing blocks.	Indentation force and indenter displacement with time used to calculate material properties.

Intended Application	Specimen Requirement	Limits
Determination of material properties.	The contact area should be free of fluids or lubricants and dust particles. Surface finish has a significant effect on test results due to asperity contact at very shallow indentation depths. The standard provides guidelines of permissible roughness for different materials and test forces. The test piece thickness should be at least 10x the indentation depth or 3x the indentation diameter, whichever is greater. Coating thickness should be considered to be the test piece thickness.	Type A uncertainties include: zero point assignation, measurement of force and displacement, fitting of the force removal curve, thermal drift rate, and contact area due to surface roughness. Type B uncertainties include force and displacement, testing machine compliance, indenter area function calibration values, calibration drift due to uncertainty in temperature of testing machine and time since last calibration, and tilt of test surface.

ISO 14705
Fine Ceramics (Advanced Ceramics, Advanced Technical Ceramics) – Test Method for Hardness of Monolithic Ceramics at Room Temperature

General Description	Data Produced
This Standard describes the methods for determining the Vickers or Knoop hardness of monolithic fine ceramics at room temperature by microscopical measurement of diagonals of indentations made with diamond indenters using a loading device which controls appliedload and load duration. The Standard includes definitions and physical principles for each method; sample calculations based on applied load and measured indentation diagonal lengths, diamond indenter requirements, measurement procedures including examples of acceptable and unacceptable indentations, and illustrations of crosshair measurements of indentation diagonals.	Optical measurements of indentation dimensions used with the measured indentation load to calculate a hardness number.

Intended Application	Specimen Requirement	Limits
Intended for measurement of hardness of ceramics where indentation is formed by micro cracking and micro fracture, besides plastic deformation.	Polished, smooth, clean surface free of contaminants and oxides. Vickers and Knoop test piece thickness shall be at least 0.5 mm; and, for Vickers, at least 1.5 times the diagonal of the indentation and 2 times the crack length.	Vickers indentations are less likely to cause cracks in fine ceramics than Knoop indentations. Conversion between these hardness scales shall not be made. Distance between centers of Vickers indentations and the test piece edge shall be at least 2.5 times the mean diagonal of the indentation and 5 times the mean length of the crack from indentation tips. The distance between the centers of adjacent indentations shall be at least 4 times the mean diagonal of the indentation and 5 times the mean length of the crack. Five valid indentations are required. Knoop indentations should be at least 1.5 times the long diagonal distance from the test piece edge. Knoop indentations should be separated by at least 1.5 times the long diagonal length.

SAE J417
Hardness Tests and Hardness Number Conversions
(SAE Information Report)

General Description	Data Produced
Approximate conversion values giving relationships between Vickers, Brinell, Rockwell, and Scleroscope hardness values and approximate corresponding tensile strengths of steels are included. Information on surface preparation, specimen thickness, effect of curved surfaces and recommendations for Rockwell surface hardness testing for case hardened parts are also included. Test methods for Vickers, Brinell, Rockwell, Rockwell Superficial and Shore are provided. *See ASTM E 140-02.*	Data may be read from instrument test to enable calculation of hardness.

Intended Application	Specimen Requirement	Limits
Material evaluation, generally.	Requirements for surface smoothness and cleanliness, specimen thickness, proximity to edges and surface treatment vary with method.	Conversion from one hardness scale to another should be conducted with caution, particularly for surface treated materials.

10.3 Other Hardness Measurement Methods

ASTM G 171
Standard Test Method for Scratch Hardness of Materials Using a Diamond Stylus

General Description	Data Produced
This method describes determination of the scratch hardness, the resistance of a solid surface to penetration by a moving stylus of given tip radius under a constant normal force and speed. The method is applicable to metals, ceramics, polymers and coated materials and may be indicative of resistance to surface damage. It is not intended to measure coating adhesion or for use with other than the specific hemispherically tipped conical styli described. Included are apparatus, calibration, procedure, calculation of scratch hardness number and stylus drag coefficient, reporting, and factors affecting precision and bias. Measurement of the scratch width and the normal force applied to the stylus are used to calculate the "scratch hardness number".	Scratch width is measured and with normal force used to calculate scratch hardness number.

Intended Application	Specimen Requirement	Limits
Intended to complement quasi-static hardness measurements. In principle, it is a more appropriate measure of the resistance of a material to damage processes like two body abrasion.	The surface of the test piece should not be such that scratch edges are indistinct or such that the stylus skips. The surface should be free of preparation artifacts. Surfaces of 0.02 μm to 0.05 μm Ra are typical of polished surfaces.	Interlaboratory tests on repeatability and reproducibility showed between laboratory scratch hardness of brass to be 1.13 (± 0.08) GPa with 200 g load and 200 μm radius diamond stylus. Does not measure a single material property. Correlations of scratch hardness number with other material characteristics depends on the extent to which the response of the surface in use is controlled by the same combination of properties which determine the scratch hardness number.

ASTM E 448
Standard Practice for Scleroscope Hardness Testing of Metallic Materials

General Description	Data Produced
This Practice describes the scleroscope apparatus for measuring hardness and the procedure for its use. The practice applies to Scleroscope Models C and D manufactured by the Shore Instrument and Manufacturing Company. Basic operation consists of dropping a diamond-tipped "hammer" onto the test piece and measuring the rebound of the hammer. The rebound height is a measure of hardness, reported as a Scleroscope hardness number HSc or HSd. The Practice includes: Part A – General Description of Instruments and Test Procedure; Part B – Verification of Scleroscope Hardness Instruments; Part C – Calibration of Standardized Hardness Test Blocks.	A Scleroscope hardness number is read from the instrument. The instrument scale is determined by dividing into 100 units the rebound of the hammer from a quenched to maximum hardness and untempered tool steel test block of AISI W-5.

Intended Application	Specimen Requirement	Limits
The Scleroscope can be used in situations where instrument portability is required.	Small specimens may be evaluated by clamping in a stand. Large specimens may be evaluated by mounting the instrument in a stand. Thin strips 0.13 mm to 0.38 mm (0.005 in. to 0.015 in.), depending on the material may be tested in the stand. Model C may be used free hand for testing specimens with a minimum mass of 2.3 kg (5 lb.). Surface finish is important. A No. 125 machined surface, minimum, is required for metals of "intermediate" hardness. Indentations can be made within 6 mm (0.250 in.) of an edge when proper clamping is used. Test should not be made on magnetized material.	Under optimum conditions, accuracy can be expected to be 3 Scleroscope points from the mean of the spread in Scleroscope hardness numbers marked on standardized reference test blocks.

SAE J864
Surface Hardness Testing with Files
(SAE Recommended Practice)

General Description	Data Produced
This Practice describes the technique for subjective evaluation of the hardness of iron and steel parts. The Practice includes required apparatus, condition of the surface to be tested, procedure and sources of files.	Subjective feel of operator.

Intended Application	Specimen Requirement	Limits
The method is useful in production control for identification of inconsistent surface conditions and where conventional indentation testing of hardness of sintered parts is inappropriate.	Smoothness of test piece and "prover" (standard for comparison) should be same.	Not quantitative.

11. Standards for Mechanical Properties and Adhesion of Coatings

11.1 Mechanical Properties

ASTM B 489
Standard Practice for Bend Test for Ductility of Electrodeposited and Autocatalytically Deposited Metal Coatings on Metals

General Description	Data Produced
This Practice describes a test procedure for determination of the ductility of electrodeposited or autocatalytically deposited metal coatings on metal substrates by bending strips of test material over round mandrels of successively smaller diameter. Mandrel diameters are from 6 mm to 50 mm, in 3 mm steps. Mandrels are held in a vise and specimens bent with coating outward until legs are parallel. If examination at 10x does not reveal cracks in the coating, a new specimen is bent over the next smaller mandrel.	Elongation is calculated from measured deposit and substrate thickness and diameter of smallest diameter mandrel which did not cause cracking.

Intended Application	Specimen Requirement	Limits
Intended to determine coating resistance to cracking during distortion.	Flat 10 mm wide and not less than 150 mm long, cut from plated or coated article, no closer than 25 mm from edges. Alternative substrates allowed where base metal thickness and temper affect bending test.	Largest source of error is detection of crack initiation.

ASTM B 490
Standard Practice for Micrometer Bend Test for Ductility of Electrodeposits

General Description	Data Produced
This Practice describes a method of measuring the ductility of electrodeposits with low ductility. This is a semi-quantitative method wherein a foil of the test material is bent between the closing jaws of a micrometer until cracks appear or fracture occurs.	Elongation is calculated from measured foil thickness and distance between jaws when cracks are formed.

Intended Application	Specimen Requirement	Limits
A useful method for controlling some electroplating solutions and evaluating response to moderate stress, as in bolting parts together.	Deposits are removed from a substrate and are typically 25 μm to 40 μm thick foils. Specimens are cut from the center of the foil removed from the substrate.	Elongations calculated using either formula provided bears no simple relation to ductility obtained from tension or other tests.

ASTM F 1044
Standard Test Method for Shear Testing of Calcium Phosphate Coatings and Metallic Coatings

General Description	Data Produced
This Method describes shear testing of calcium phosphate and metallic coatings applied to metallic substrates. It assesses adhesion of coatings to substrates or the cohesive strength of a coating, parallel to the substrate surface. Two tests are described: (1) for calcium phosphate or metal coatings- a coated and an uncoated surface bonded together by thermo- mechanical means or by a polymeric adhesive are loaded in shear using a tensile machine; (2) for metal coatings only-a lap shear test on porous coated area utilizing polymeric adhesive or bone cement and a test jig in a tensile machine. Gripping device details are included.	Load at separation is used to calculate adhesive or cohesive strength.

Intended Application	Specimen Requirement	Limits
Recommended for shear testing under uniaxial stress. Useful for comparative evaluations and for certain quality control. Aids development of load bearing medical implant applications.	Aligned interface test method substrates should have a nominal cross-sectional area of 2.84 cm^2. Lap shear specimens should have substrates 7.62 cm x 2.54 cm (3 in. x 1 in.) with a 2.54 cm x 2.54 cm (1 in. x 1 in. overlap test area).	Does not provide intrinsic property values for utilization directly in making calculations. Minimum bulk shear strength of 34.5 MPa (5000 psi) is required. Testing to be conducted at room temperature. Repeatability testing of plasma sprayed titanium alloy with mean shear strength of 29.6 MPa (4292 psi) was found to have a standard deviation of 4.81 MPa (698 psi). Reproducibility standard deviation was found to be 5.03 MPa (729 psi).

ASTM F 1147
Standard Test Method for Tension Testing of Calcium Phosphate and Metallic Coatings

General Description	Data Produced
This Method addresses tension testing of calcium phosphate and metallic porous coatings on dense metal substrates. It assesses adhesion to substrates or internal cohesion of a coating in tension normal to the surface plane. A coated specimen is bonded to an uncoated grip with polymeric adhesive (calcium phosphate and metal) or by sintering (metal). Loading is performed in a testing machine and an axial force pulls the parallel faces of specimen substrates apart. Similar to ASTM C 633.	Load at separation is used to calculate adhesive or cohesive strength.

Intended Application	Specimen Requirement	Limits
Useful for comparing adhesive or cohesive strengths of coatings or effects of processing methods.	Substrates should have a nominal cross-sectional area of 5.07 cm^2.	Does not provide an intrinsic material value for utilization directly in making calculations. Polymeric adhesive must have a minimum bulk tensile strength of 34.5 MPa (5000 psi). Sintered Co-Cr-Mo coatings on the same substrate alloy demonstrated a mean tensile strength of 29.8 MPa (4325 psi). These coatings had a repeatability standard deviation of 4.23 MPa (613 psi) and a reproducibility standard deviation of 5.32 MPa (772 psi).Test intended for room temperature use. Eccentric loading introduces bending stresses in the coating.

ASTM F 1160
Standard Test Method for Shear and Bending Fatigue Testing of Calcium Phosphate

General Description	Data Produced
This test method describes the determination of the shear and bending fatigue performance of plasma sprayed coatings intended for medical implants. The procedure was developed and is pertinent to plasma sprayed titanium and plasma sprayed hydroxyapatite coatings. The shear fatigue mode evaluates the cohesive and adhesive properties of the coating on the metallic substrate. The bending mode evaluates adhesion as well as the effect of the coating on the substrate. The Method includes descriptions of test equipment and specimens, adhesives for bonding coating to test fixture (shear), test procedure, stress calculations, reporting precision and bias.	Cycles to failure at a predetermined stress, a predetermined number of visible cracks at a specified magnification, a crack of certain dimensions, or complete separation of the coating from substrate.

Intended Application	Specimen Requirement	Limits
To aid in the development of material for use in load bearing implant applications as a guide to the selection of coated materials under conditions of repeated stress.	Shear test specimens must have a cross-sectional area of nominally 2.85 cm^2 (0.44 $in.^2$) to which the coating is applied. Bending fatigue specimens of various designs are allowed but general requirements pertaining to failure in the test section and constant stress in flat tapered beam designs.	Not intended for evaluation of components or devices.

ASTM F 1501
Standard Test Method for Tension Testing of Calcium Phosphate Coatings

General Description	Data Produced
This Method is very similar to F 1147-99, differing in that it does not include metallic coatings.	Load at separation is used to calculate adhesion or cohesion strength.

Intended Application	Specimen Requirement	Limits
Intended to provide a comparative evaluation of cohesive or adhesive properties or quality control.	Cross-section of specimen to which coating is applied should be nominally 5.07 cm^2 (0.78 $in.^2$). Coating thickness, substrate composition, surface or other features should be representative of the intended application.	The Method does not provide an intrinsic value for utilization directly in making calculations such as determining the ability of a coating to withstand specified environmental stresses.

11.2 Adhesion

ASTM B 571 *Standard Practice for Qualitative Adhesion Testing of Metallic Coatings*	
General Description	**Data Produced**
This Practice provides general guidance for evaluating the adhesion of, primarily, electroplated coatings to substrates. Methods described include: bend tests, burnishing tests, chisel-knife tests, draw tests, file tests, grind-saw tests, heat-quench tests, impact tests, peel tests and scribe-grid tests. A table of adhesion tests appropriate for various coating materials is provided as well as a temperature test guide for various coatings and substrates.	Varies with test method.

Intended Application	**Specimen Requirement**	**Limits**
Production control and acceptance inspection.	Varies with test method, but generally should reflect condition of material in intended application.	Qualitative nature of the tests precludes precision and bias statements.

ASTM C 633
Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings

General Description	Data Produced
This Method describes the measurement of the degree of adhesion of a coating to a substrate or the cohesive strength of a coating when subjected to a tensile force normal to the surface. The test consists of adhesively bonding test fixtures to the underside of the substrate and to the top side of the coating and applying tensile loading in a testing machine. The test is performed at ambient temperatures due to elevated strength limitations of common adhesives. The degree of cohesion or adhesion is calculated by dividing the maximum load sustained by the cross-sectional area of the specimen. The Method includes testing machine and fixture descriptions, adhesive material and test specimen requirements, procedure, calculation and interpretation of results and reporting.	Adhesive or cohesive strength.

Intended Application	Specimen Requirement	Limits
Recommended for quality control, acceptance testing, process/procedure and material development. Not intended to provide an intrinsic value for calculation purposes.	Coatings should be at least 0.38 mm (0.015 in.) thick applied to test fixtures of not less than 23 mm (0.9 in.) and not more than 25 mm (1.0 in.) in diameter.	Application of this test should have tolerances and interpretation of adherence set and agreed upon by purchaser and manufacturer.

ASTM D 4541
Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

General Description	Data Produced
This Method covers the measurement of the force and, by calculation, the stress (pull-off strength) of coatings. A loading fixture is affixed to a coating on a substrate using an adhesive. The fixture, with adhesive bonded coating attached, is pulled from the substrate using a portable device which can be mechanically or hydraulically loaded. The device gradually applies force normal to the surface until the coating is detached. The pull-off strength is calculated based on the maximum indicated load, instrument calibration data and original surface stressed. Four commercially available instruments are described. The Method includes: Apparatus, Test Preparation, Test Procedure, Calibration and Interpretation of Results, Reporting, Precision and Bias. The principle of operation is similar to ASTM C 633.	Pull-off strength calculated from instrument readings and measured area of separation.

Intended Application	Specimen Requirement	Limits
Intended to determine acceptance per specified properties as measured by this method.	The Method is not specifically intended for a given material. Referenced documents address testing of paints and varnishes.	Nature of failure must be reported, i.e., whether in adhesive, coating system or substrate. Precision of measurements determined in intra- and inter- laboratory studies show coefficient of variation of types I, II, and III instruments to be 12.2% for intralaboratory measurement and 20.6% for interlaboratory measurement.

Industry Standard Scratch Adhesion Test	
General Description	**Data Produced**
This Practice provides a quantitative value of coating adhesion for standard PVD (physical vapor deposition) coatings. A diamond stylus 0.2 mm in diameter is run against the surface at fixed speed of 100 mm/min and a load increasing at the rate of 100 N/min. Two values are recorded: the load at which delamination of the coating is first observed, and the load at which the coating is completely removed from the wear track.	Quantitative adhesion.

Intended Application	Specimen Requirement	Limits
Production control and acceptance inspection.	Flat, highly polished sample.	Results are very dependent on substrate.

12. Standards for Measurement of Corrosion, Wear and Thermal Properties

12.1 Bare

ASTM C 177 *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus*	
General Description	**Data Produced**
This Method establishes the criteria for measurement of the one dimensional steady state heat flux through flat, homogeneous specimens. General guidelines for design of the apparatus and testing are given The test consists of heating one side of a flat specimen with a resistance heater in a carefully insulated arrangement and limiting heat flux to the thickness of the specimen with temperatures measured on both sides of the specimen. This is a primary method of measurement. ASTM C 1043, C 1044 and C 1045 accompany this Method. The apparatus may be designed to operate in controlled environments or at elevated or reduced temperatures.	Heat input and specimen temperatures are measured and used to calculate thermal transmission properties per ASTM C 1045.

Intended Application	**Specimen Requirement**	**Limits**
Laboratory measurement of heat flux which enables calculation of conductivity.	Specimen size is determined by heater size and other experimental considerations.	Specimen conductance should be less than 16 W/(m^{2}K). Layer structures with inhomogeneities normal to the heat flux direction can be measured. Inhomogeneities in the heat flux direction can yield results that are location specific and are inappropriate for this apparatus.

ASTM C 1043
Standard Practice for Guarded-Hot-Plate Design Using Circular Line-Heat Sources

General Description	Data Produced
This Practice covers the design of a circular line-heat-source guarded hot plate for use in accordance with ASTM test Method C 177-Test Method for Steady State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot Plate Apparatus. The Practice provides: guidance in determining the mean temperature of the meter plate, information and calculation procedures for (1) control of edge heat loss or gain, (2) location and installation of line-heat sources, (3) design of the gap between the meter and guard plates, (4) location of heater leads for the meter plate.	Provides detailed design data for fabrication of a device which performs in accordance with ASTM C 177.

Intended Application	Specimen Requirement	Limits
Supports fabrication of a guarded hot plate for measurement of thermal transmission properties.	Specimen size is determined by heater size and other experimental considerations.	The line-heat-source guarded hot plate has been used over a mean temperature range of -10 °C to +65 °C with circular metal plates and a single line-heat source in the meter plate. However, the practice does not preclude (1) lower or higher temperatures, (2) line-heat sources other than circular, (3) plate geometries other than circular, (4) the use of plated fabricated from ceramics, composites or other materials, (4) the use of multiple line-heat sources in both the meter and guard plates.

ASTM C 1044
Standard Practice for using a Guarded-Hot-Plate Apparatus or Thin-Heater Apparatus in the Single-Sided Mode

General Description	Data Produced
This Practice covers the determination of the steady-state heat flow through the meter section of a specimen when a guarded hot plate apparatus or thin-heater apparatus is used in the single-sided mode. This Practice supplements ASTM C 177 or ASTM C 1114 for testing a single specimen. Procedure, heat flow calculation, and sources of experimental error are included.	Thermal transmission properties are determined in accordance with ASTM C 177.

Intended Application	Specimen Requirement	Limits
Supports operation of the guarded hot plate apparatus in the single sided mode for the determination of thermal transmission properties.	Specimen size is determined by heater size and other experimental considerations.	The Practice requires that the cold plates of the apparatus have independent temperature controls.

ASTM C 1045
Standard Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions

General Description	Data Produced
This Practice gives a uniform procedure for calculating thermal transmission properties of a material or system from data generated by steady state, one dimensional test methods used to determine heat flux and surface temperatures. It is intended to eliminate the need for similar calculation sections in ASTM C 177 and other Standards and allow concentration on measurement details rather than calculation details.	Apparent thermal conductivity is obtained as a function of temperature with data obtained from ASTM C 177 or other test methods.

Intended Application	Specimen Requirement	Limits
Supports operation of the guarded hot plate apparatus in the single sided mode for the determination of thermal transmission properties.	Specimen size is determined by heater size and other experimental considerations.	ASTM C 177 shall be considered the final authority for materials having flat geometry; C 335 shall be used for materials having a cylindrical geometry.

ASTM E 1461
Standard Test Method for Thermal Diffusivity by the Flash Method

General Description	Data Produced
This comprehensive test Method details measurement of thermal diffusivity using the laser flash method. In brief, the material of concern is heated on one side (front face) with a laser or flash lamp and the temperature rise on the opposite side (back face) is measured. Thermal conductivity can be calculated using diffusivity results, specific heat capacity and density. Document includes interferences, detailed description of apparatus requirements, specimen requirements, calibration and verification, procedure, calculation, precision and bias statement. Measurements may be conducted at elevated temperature or in other non-ambient conditions using an appropriate environmental chamber.	Temperature and time data measured on the back face of the specimen is used to calculate thermal diffusivity.

Intended Application	Specimen Requirement	Limits
General measurement of thermal diffusivity of homogeneous solids. The method has been used for composite and layered materials.	Specimens are typically a circular disk with a front face area less than the energy beam, usually 6 mm to 18 mm in diameter. Thicknesses are typically 1 mm to 6 mm. Sample faces should be flat and parallel within 5% of their thickness with uniform surfaces. Translucent or reflective materials may be coated.	Non-homogenous materials may have heat flow patterns which may render diffusivity values inaccurate, but still useful for limited comparisons. Precision of ± 5% can be attained for diffusivity.

ISO 8302
Thermal Insulation – Determination of Steady-State Thermal Resistance and Related Properties – Guarded-Hot-Plate Apparatus

General Description	Data Produced
This is an extensive Standard detailing the use of the guarded hot plate to measure the steady-state heat transfer through flat slab specimens and the calculation of heat transfer properties. This is an absolute, or primary, method of measurement since only measurements of length; temperature and electrical power are required. A flat specimen, which may be layered, is heated on one side and temperature on the opposite side is measured. All measurements are conducted in an apparatus which controls heat flow. The technique is sensitive to specimen dimensions, finish and homogeneity. The limit for thermal resistance may be as low as 0.02 m^2 K/W but accuracy over the full range may not be achieved. The Standard includes detailed information on instrumentation and calculation of heat transfer properties. Temperature limits are not specified.	Test data consists of measured specimen dimensions, temperatures on either side of the test specimen and electrical power input. These data are used to calculate thermal resistance.

Intended Application	Specimen Requirement	Limits
The Standard is intended to provide the means for determining the steady state heat transfer properties of flat slab specimens. Specimen size requirements may limit the utility of this method for evaluation of materials typically manufactured for some high temperature applications.	Specimens should typically be homogeneous. Homogeneous porous specimens should have inhomogeneities smaller than one-tenth of the specimen thickness. Specimen dimensions should be 0.2 m to 1 m diameter or square. Samples should be representative of the bulk material, which may determine specimen size. Specimen flatness is important. Specimen thickness is limited by contact resistances and thickness measurement accuracy.	Accuracy is a function of apparatus design, instrumentation and specimen type. When this standard is followed, the method is capable of measuring heat transfer properties accurate to within ± 2% when the mean temperature of the test is near room temperature. Accuracy of ± 5% should be obtainable anywhere within the full operating range of the apparatus. Reproducibility should be better than ± 1%.

SAE AMS-STD-753
Corrosion-Resistant Steel Parts: Sampling, Inspection and Testing for Surface Passivation
(Aerospace Material Specification)

General Description	Data Produced
This Standard is adopted from Mil-STD-753C. It describes methods of sampling and testing for surface passivity of steels with chromium contents in excess of 10.5%. Five test methods are listed for the determination of free iron or other anodic surface contaminants: water immersion, high humidity, copper sulfate, potassium ferricyanide-nitric acid solution and salt spray (ASTM B 117). Determination of presence of free iron is by visual inspection.	Evidence or indication of no surface contaminants.

Intended Application	Specimen Requirement	Limits
The standard is intended to test for the effectiveness or need for passivation.	No surface contaminants.	The copper sulfate test is not recommended for use on martensitic 400 series alloys or lower chromium grades (less than 16%) of ferritic 400 series alloys.The potassium ferricyanide test is more sensitive to the presence of free iron than the copper sulfate test and is recommended for use only on austenitic AISI 200 and 300 series alloys when the determination of trace amounts of free iron is required.

12.2 Coated

ASTM B 651
Standard Test Method for Measurement of Corrosion Sites in Nickel Plus Chromium or Copper Plus Nickel Plus Chromium Electroplated Surfaces with Double-Beam Interference Microscope

General Description	Data Produced
This Method allows the measurement of average dimensions and number of corrosion sites in decorative coatings electroplated onto steel. Corrosion pit lateral dimensions are measured optically with magnifiers or microscopes. Depths are measured with an interference microscope. Coating thickness is measured on a metallographically prepared cross-section. The Method includes descriptions of the apparatus, specimen preparation, procedures for measurement of crack and pit depth and average number, reporting, precision and bias.	Numeric values for number of pits and cracks as well as pit and crack dimensions.

Intended Application	Specimen Requirement	Limits
For comparing the relative corrosion resistance of different electroplating systems and for comparing the corrosiveness of different environments.	Clean surfaces.	Precision can be as good as ± 1μm. Bias can be as good as ± 1μm.

ASTM F 326
Standard Test Method for Electronic Measurement for Hydrogen Embrittlement from Cadmium-Electroplating Processes

General Description	Data Produced
This Method describes the use of a metal-shelled vacuum probe to evaluate electrodeposited cadmium characteristics, principally porosity, relative to hydrogen permeation. The Method includes detailed descriptions of the apparatus, reagents, preparation and calibration of the apparatus, procedure and calculations. It is useful particularly when hydrogen embrittlement, as of high strength steels, may be an issue due to limits of hydrogen bake-out after plating caused by cadmium plate low permeability.	Hydrogen pressure and cell current used to calculate hydrogen permeability of cadmium plate.

Intended Application	Specimen Requirement	Limits
The test provides a quantitative "control number" for cadmium plate porosity which can be used as a process control or as a process development research tool. This method is used in conjunction with stress rupture or other tests when intended to control a critical process.	Unpainted bare steel prepared as in production process of interest.	The Method specifies an "acceptable zone" of time in seconds for hydrogen pressure to drop to half its value during post plate baking.

ASTM F 1978
Standard Test Method for Measuring Abrasion Resistance of Metallic Thermal Spray Coatings by Using the Taber Abraser

General Description	Data Produced
This Method quantifies the loss of mass of plasma sprayed coatings when evaluated on the Taber Abraser with a 250 g mass. The specimen is rotated under a pair of abrasive wheels which gives rolling and rubbing wear. The Method includes description of the apparatus and supplier, specimen, procedure, calculation of mass loss per rotational cycle, reporting and information on precision and bias determined in an interlaboratory study.	Cumulative mass loss.

Intended Application	Specimen Requirement	Limits
Characterizing coatings used on surgical implants.	Flat specimens either round with a 10 cm diameter and at least 0.16 cm (0.0625 in.) thick; or 10 cm (4 in.) squares, same thickness, both with a 0.64 cm (0.250 in.) hole in the center. Coatings representative of that used in the intended implant. Six specimens, generally, required per material.	Flat, rigid specimens which do not react significantly with rinsing water and do not have phase transformations or chemical reactions between room temperature and 100 °C in air. An interlaboratory study (ILS) of a 100 cycle test showed a repeatability of 0.012 g and a reproducibility of 0.017 g for a material with an average weight loss of 0.504 g. More extensive ILS data is provided.

ISO 4536
Metallic and Non-Organic Coatings on Metallic Substrates – Saline Droplets Corrosion Test (SD Test)

General Description	Data Produced
This standard describes the procedure for evaluation of coatings, particularly conversion coatings, to ascertain corrosion resistance. A spray of aqueous saline solution is applied to test specimens to create discrete droplets on the surface. Specimens are evaluated visually after exposure in a chamber with relative humidity controlled according to a specification.	Data produced may be visual appearance after test or after removal of corrosion product, number and distribution of corrosion defects, time lapsed before signs of corrosion are observed.

Intended Application	Specimen Requirement	Limits
Intended for the evaluation of corrosion resistance where the droplets may be a more severe condition than a continuous moving moisture film.	Clean specimens which can be of complex shapes.	Criteria for evaluation of test results will be given in a product specification. Results of this test should not be regarded as a guide to corrosion resistance in all environments.

ISO 4538
Metallic coatings – Thioacetamide Corrosion Test (TAA test)

General Description	Data Produced
This Standard is intended to assess the corrosion resistance of metal surfaces in atmospheres containing volatile sulphides. Test specimens are exposed to vapors from thioacetimide in an atmosphere of 75% relative humidity maintained by the presence of a saturated solution of sodium acetate. The test is conducted in a chamber for a duration of generally less than 2 weeks with visual inspection hourly or daily. Descriptions of apparatus and procedures are included.	Product specifications determine evaluation criteria which may be appearance after test, time to first signs of corrosion, or number and distribution of corrosion defects. Methods for assessment of defects are specified in ISO 1462.

Intended Application	Specimen Requirement	Limits
Intended to accompany a coating or product specification for assessment of tarnish-preventing treatments on silver or copper and the detection of discontinuities in precious metal coatings on these materials.	Product specification may specify test sample or product to be tested. Samples shall be clean and cut edges protected.	Type and number of test specimens, exposure period, failure criteria are not included in this Standard but should be included in the product specification.

ISO 8993
Anodized Aluminum and Aluminum Aloys – Rating System for the Evaluation of Pitting Corrosion – Chart Method

General Description	Data Produced
This Standard describes the method for a rating system that defines levels of pitting corrosion. Test materials are cleaned to reveal corrosion pits. Cleaned surfaces are compared to illustrative charts included in the standard. Seven alphabetic levels of percentage of area of defects are illustrated in the charts, each with six sub-levels. Designations range from an "A" rating for no defects to an "H1" to "H6" rating for greater than 0.5% area of defects. This Standard is similar in purpose to ISO 8994.	Data consists of a visual or electronic comparison with charts included in the Standard.

Intended Application	Specimen Requirement	Limits
The rating system is applicable to pitting corrosion resulting from accelerated tests, exposure to corrosive environments and practical service tests.	Corrosion products or deposits are removed from the subject surface by abrasion with a fine pumice slurry, dipping in 30% nitric acid for 5 min to 10 min, or by dissolving the anodic coating in a hot phosphoric acid-chromic acid mixture.	Only accounts for pitting corrosion of the basis metal resulting from penetration of the protective anodic coating.

ISO 8994
Anodized Aluminum and Aluminum Alloys – Rating System for the Evaluation of Pitting Corrosion – Grid Method

General Description	Data Produced
This Standard describes the method for a rating system that defines levels of pitting corrosion. Test materials are cleaned to reveal corrosion pits. A transparent grid of at least 5,000 mm^2 with 5 mm x 5 mm grid squares is placed over the area of interest and the percentage of squares containing a pit determined. The percent containing pits is converted to a rating number. Grid ratings range from 0 for no grid squares with pits to 40 for 5.01% and greater of grid squares with defects. This Standard is similar in purpose to ISO 8993.	Data consists of a count to determine percent of grid squares with defects.

Intended Application	Specimen Requirement	Limits
The rating system is applicable to pitting corrosion resulting from accelerated tests, exposure to corrosive environments and practical service tests. The system is frequently used for rating short term corrosion tests of thin anodic coatings used in the automotive industry.	Corrosion products or deposits are removed from the subject surface by abrasion with a fine pumice slurry, dipping in 30% nitric acid for 5 min to 10 min, or by dissolving the anodic coating in a hot phosphoric acid-chromic acid mixture.	Only accounts for pitting corrosion of the basis metal resulting from penetration of the protective anodic coating.

ISO 4540
Metallic Coatings – Coatings Cathodic to the Substrate – Rating of Electroplated Test Specimens Subjected to Corrosion Tests

General Description	Data Produced
This Standard specifies a method of evaluating the condition of electroplated test specimens that have been exposed to corrosive environments for test purposes. The method is applicable only to decorative and protective coatings that are cathodic to the substrate; i.e., nickel plus chromium or copper plus nickel plus chromium on steel or zinc die castings. The method provides a rating system that assigns a rating which (a) describes the appearance as affected by corrosion of the substrate and, (b) describes the appearance as affected by corrosion of the coating itself. Levels of protection rating from 10 (no defects) to 0 (greater than 50% area covered with defects) are assigned by comparing the test piece with dot charts and photographs included in the standard.	Visual examination and comparison with included charts and photographs gives numeric ratings. The rating number assigned to the ability to protect the substrate is called the "protection" rating. The number assigned to describe the overall appearance is called the "appearance" rating.

Intended Application	Specimen Requirement	Limits
Intended to describe the condition of electroplated coatings.	Specimens are typically 10 cm x 15 cm test panels. Specimens should not be cleaned before inspection if possible.	Not intended for use with anodic sacrificial coatings such as zinc and cadmium on steel. Defects to be taken into account include only those that can be seen by the unaided eye.

ISO 4541
Metallic and Other Non-Organic Coatings – Corrodkote Corrosion Test (CORR test)

General Description	Data Produced
This Standard provides guidance on assessment of corrosion resistance of metallic coatings by the Corrodkote procedure. The procedure consists of preparing a slurry of copper nitrate trihydrate, iron chloride hexahydrate and ammonium chloride with ceramic grade kaolin. The saturated kaolin is brushed onto the test surface. The slurry layer (0.08 mm to 0.2 mm thick) is allowed to dry before the test specimen is placed in a humidity chamber with temperature controlled to 38 °C. Test cycle time is typically 16 h. Slurry is reapplied after each cycle. After humidity chamber exposure, specimens are cleaned, removing corrosion products. The points of coating failure are identified by exposure to a medium which is corrosive to the basis metal, such as ISO 3768, but not the coating. Evaluation typically consists of visual appearance after testing, appearance after removal of corrosion products, number and distribution of corrosion defects assessed per ISO 1462, for example.	Descriptions of appearance of surface and quantitative evaluation by a method such as ISO 1462.

Intended Application	Specimen Requirement	Limits
The method and evaluation criteria may be used in product or purchase specifications. The method is primarily applicable to copper-nickel-chromium or nickel- chromium electroplated parts.	Type and number of specimens are determined by relevant product or purchase specification. Specimens should be solvent cleaned before testing with a material which is non-corrosive and does not create a protective film. Specimens may be cut from sheet material but cut edges should be protected.	Test results should not be regarded as a direct guide to the corrosion resistance of the tested materials in all environments. Relative ranking in the test may not be the same as ranking in service.

ISO 9227
Corrosion Tests in Artificial Atmospheres – Salt Spray Tests

General Description	Data Produced
This Standard specifies the procedure for determining the corrosion resistance of metallic materials, including those with inorganic or organic coatings. The test consists of spraying neutral salt solution (NSS), or acetic acid salt (ACSS) solution, or copper accelerated acetic acid solution (CASS) on specimens in a salt spray cabinet with controlled temperature and determining extent of corrosion after a predetermined exposure time. The Standard provides details of solution preparation and a salt spray cabinet design. Reference specimens are required for each test. Supercedes ISO 3768.	Test data consists of appearance before and after removing corrosion products, number and distribution of corrosion defects which may be assessed by ISO 1462 or ISO 4540, elapsed time before appearance of corrosion, mass change, change in mechanical properties, alteration revealed by microscopic examination.

Intended Application	Specimen Requirement	Limits
The Standard is intended to assess the corrosion resistance of metallic materials with or without permanent or temporary corrosion protection. The Standard may be included in a specification. Useful for detecting discontinuities such as pores and other defects in certain metallic, anodic oxide and conversion coatings. The NSS applies to metals and their alloys, certain metallic coatings (anodic and cathodic), certain conversion coatings, certain anodic oxide coatings, and organic coatings on metallic materials. The AASS is useful for testing decorative coatings of copper+nickel+ chromium or nickel+ chromium. The CASS is useful for testing decorative coatings of copper+nickel+ chromium or nickel+ chromium. It is also useful for testing anodic coatings on aluminum.	Detailed requirements for reference specimens of CR4 grade steel according to ISO 3574 are provided. Test specimen number, size, shape and arrangement in the spray cabinet shall be agreed upon by participating parties. Specimens shall be cleaned in such a way as to remove contaminants but not affect the surface adversely.	Test results shall not be regarded as a direct guide to the corrosion resistance of tested materials in all environments. Test performance should not be taken as a direct guide to performance in service.

ISO 10289
Methods for Corrosion Testing of Metallic and Other Inorganic Coatings on Metallic Substrates – Rating of Test Specimens and Manufactured Articles Subjected to Corrosion Tests

General Description	Data Produced
This Standard supersedes ISO 1460 and provides guidance for rating coatings that provide corrosion protection to a substrate or provide visual effects. The performance rating includes a protection rating and an appearance rating. The protection rating is a simple numerical rating while the appearance rating may include specific defects along with a numerical rating designating the intensity. Types of defects are identified, the method of inspection of defects are identified.	Visual observation of corrosion sites or products which are given numeric values.

Intended Application	Specimen Requirement	Limits
Intended for evaluation of the condition of test materials or articles exposed to corrosive test conditions or other purposes.	Product specification may specify test sample or product to be tested. Samples shall be clean and cut edges protected.	Generally qualitative assessment.

SAE J400
Test for Chip Resistance of Surface Coatings
(SAE Recommended Practice)

General Description	Data Produced
This Practice describes the use of a "Gravelometer" which projects sized gravel against a flat test panel to assess the resistance to chipping of organic surface coatings used in automotive applications. Equipment is described and equipment supplier identified. Test procedure including evaluation based on an SAE Chipping Rating Standard (EA-400) is provided.	Assessment of coating material damage.

Intended Application	Specimen Requirement	Limits
This test provides a means of evaluating automotive coatings and coating systems and has been correlated with field results.	Test panels should be 10.16 cm x 30.48 cm (4 in. x 12 in.) and typically 20 gage (0.091 cm (0.0359 in.)) material with typical preliminary surface treatment such as phosphatizing or anodizing.	Exact counting and visual comparison techniques are used to establish a rating which should not differ by more than one number-letter rating in a test sequence.

13. Surface Engineering Measurement Standards

13.1 ASME (American Society of Mechanical Engineers) Standards

B46.1	Surface Texture (Surface Roughness, Waviness, and Lay) American National Standard	63

13.2 ASTM International (American Society for Testing and Materials) Standards

A 90/A 90M	Standard Test Method for Weight (Mass) of Coating on Steel Articles with Zinc or Zinc-Alloy Coatings	125
A 309	Standard Test Method for Weight and Composition of Coating on Terne Sheet by the Triple Spot Test	126
A 428/A 428M	Standard Test Method for weight (Mass) of Coating on Aluminum Coated Iron or Steel Articles	127
A 630	Standard Test Methods for Determination of Tin Coating Weights for Electrolytic Tin Plate	128
A 754/A 754M	Standard Test Method for Coating Weight (Mass) of Metallic Coatings on Steel by X-ray Fluoresence	129
A 802/A 802M	Standard Practice for Steel Castings, Surface Acceptance Standards, Visual Examination	57
A 833	Standard Practice for Indentation Hardness of Metallic Materials	155
A 896	Standard Practice for Conducting Case Studies on Galvanized Structures	75
A 902	Standard Terminology Relating to Metallic Coated Steel Products	10
B 137	Standard Test Method for Measurement of Coating Mass Per Unit Area on Anodically Coated Aluminum	130
B 244	Standard Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy-Current Instruments	99
B 277	Standard Test Method for Hardness of Electrical Contact Materials	156

C 1043	Standard Practice for Guarded-Hot-Plate Design Using Circular Line-Heat Sources	192
C 1044	Standard Practice for using a Guarded-Hot-Plate Apparatus or Thin-Heater Apparatus in the Single-Sided Mode	193
C 1045	Standard Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions	194
C 1326	Standard Test Method for Knoop Indentation Hardness of Advanced Ceramics	162
C 1327	Standard Test Method for Vickers Indentation Hardness of Advanced Ceramics	163
D 4417	Standard Test Methods for Field Measurement of Surface Profile of Blast-Cleaned Steel	51
D 4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers	189
D 5723	Standard Practice for Determination of Chromium Treatment Weight on Metal Substrates by X-ray Fluorescence	132
E 3	Standard Guide for Preparation of Metallographic Specimens	137
E 10	Standard Test Method for Brinell Hardness of Metallic Materials	164
E 18	Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials	165
E 92	Standard Test Method for Vickers Hardness of Metallic Materials	166
E 103	Standard Test Method for Rapid Indentation Hardness Testing of Metallic Materials	167
E 110	Standard Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers	168
E 140	Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness and Scleroscope Hardness	169

13.3 ISO (International Organization for Standards) Standards

1456	Metallic Coatings – Electrodeposited Coatings of Nickel Plus Chromium and of Copper Plus Nickel Plus Chromium	76
1458	Metallic Coatings – Electrodeposited Coatings of Nickel	77
1460	*See* 10289	208
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2064	Metallic and Other Inorganic Coatings – Definitions and Conventions Concerning the Measurement of Thickness	124
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2082	Metallic Coatings – Electroplated Coatings of Cadmium on Iron or Steel	79
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2361	Electrodeposited Nickel Coatings on Magnetic and Nonmagnetic Substrates – Measurement of Coating Thickness – Magnetic Method	118

13.4 Military and Industry Standards

13.5 SAE (Society of Automotive Engineers) Standards

J121	Decarburization in Hardened and Tempered Unified Thread Fasteners (SAE Recommended Practice)	48
J122	Surface Discontinuities on Nuts (SAE Recommended Practice)	49
J123	Surface Discontinuities on Bolts, Screws, and Studs in Fatigue Applications (SAE Recommended Practice)	49
J349	Detection of Surface Imperfections in Ferrous Rods, Bars, Tubes and Wires (SAE Information Report)	59
J358	Nondestructive Tests (SAE Information Report)	37
J359	Infrared Testing (SAE Information Report)	37
J400	Test for Chip Resistance of Surface Coatings (SAE Recommended Practice)	209
J417	Hardness Tests and Hardness Number Conversions (SAE Information Report)	177
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