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HIGH SILICON STRUCTURAL STEEL

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By H. W. Gillett

ABSTRACT

A German steel developed in 1925 and known as "Freund" steel has, within a year, aroused the interest of German structural engineers. Extensive tests were made upon the steel in Germany. Results of tests on specimens submitted to the Bureau of Standards agree with those of the German tests, showing the steel to combine the desirable properties of high yield point and high ductility. The steel is unusually high in silicon, containing about 1 per cent, and low in carbon, containing less than 0.15 per cent.

While quantity production of steel of exactly that composition seems not to have been undertaken outside Germany, quite complete metallurgical information has been available upon it for many years. Steels of similar composition, but a trifle higher in carbon, were commercially produced in the United States and in England 15 or 20 years ago.

Recent American practice in the manufacture of high yield point structural steel has tended toward the use of manganese as an alloying element. If the carbon content is lowered as the content of alloying element is increased, most of the desirable properties of the German steel could be obtained by the use of manganese or a combination of manganese and silicon instead of by silicon. From the sole basis of cost of the alloying element silicon should be nearly as cheap as, and in some conditions of the ferro-alloy market, cheaper than manganese and considerably cheaper than nickel. Hence, the attention of American steel makers is called to the possibilities in the use of silicon.

Published data on the alloying effect of silicon and of manganese are summarized, and tests made at the Bureau of Standards on the silicon steel given in detail, compared with published German tests, and with existing specifications.

Evidence is summarized which leads to the conclusion, contrary to some German claims, that no special type of furnace is required for the manufacture of the silicon steel.

Much interest is being shown in Germany concerning the attempt to introduce a "new" structural steel containing around 0.12 per cent carbon, 0.40 to 0.70 per cent manganese, and about 0.95 per cent silicon. As rolled, this steel has a tensile strength and yield point of about 70,000 and 50,000 lbs./in.^{2}, respectively, with an elongation of 25 per cent in 8 inches and reduction of area of 60 per cent. The object of this article is to summarize German comment, discuss the "newness" of the steel, and give data upon this German steel recently tested at the Bureau of Standards.

This steel is being advocated by the Berliner Aktiengesellschaft fur Eisengiesserei und Maschinenfabrikation, formerly the J. C. Freund

Co., whence the steel gets its name of "Freund" or "F" steel. This firm has produced the steel in a 3-ton Bosshardt furnace, of which there appear so far to be but two installations in Germany, and discussion rages there as to whether or not this particular furnace is required in order to produce steel of the above-mentioned properties

The Bosshardt furnace [1] is of the open-hearth type and is alleged by its German makers to operate at excessively high temperatures, 3,600 to 4,000° F. (2,000 to 2,200° C.). It has been explained that the entrance of air for combustion near the top of the furnace cools the silica roof sufficiently to maintain it, but no explanation has been adduced for the lack of prompt failure of the hearth at such temperatures. The American Bosshardt Furnace Co.[2] states that it does not vouch for these temperature figures, obtained by various "unstandard" methods, but believes that the furnace produces extremely hot and fluid steel.

Zerzog [3] says that it is a question how the refractories can stand up at the temperatures claimed, but since he makes the comment that the coal consumption is extraordinarily high, it seems probable that the furnace is really operated to give very high temperatures, whatever they may be.

The furnace was originally designed for the production of thin walled steel castings,[4] and one American installation has been made for that purpose. It is stated [5] that the typical heats made with it contain 0.12 to 0.16 per cent C, 0.24 to 0.46 per cent Si, 0.47 to 0.60 per cent Mn, 0.01 to 0.02 per cent P, 0.03 to 0.05 per cent S, and give 55,000 lbs./in.^{2} tensile strength.

One account [6] of Bosshardt furnace steel stated that the steel was not an alloy steel and contained very little sulphur and phosphorus with no oxygen whatever, even though made from unselected scrap, and Bunnell [7] even stated that it was "free from" sulphur, phosphorus, and oxygen.

S. H. Bunnell, of the American Bosshardt Furnace Co., sent some of the "Freund" steels, made in the Bosshardt furnace, to the Bureau of Standards for testing, stating that the characteristics of these steels were supposed to be the same as those of the soft steel generally produced in the Bosshardt furnace. He said that the high

[1] Bosshardt, E., German patent No. 291689, class 18b, group 14, Mar. 14, 1914, published May 5, 1916. U. S. Patent, 1164983, Dec. 21, 1915, application Dec. 28, 1914. Gradenwitz, A., New furnace for malleable castings, Iron Age, **111**, p. 1781; 1923. Bunnell, S. H., Special open-hearth steel castings, Iron Age, **115**, p. 901; 1925; Bunnell, S. H., makes steel from unselected scrap, Iron Trade Rev. **77**, p. 559; 1925. Anon, Freund Steel, Iron Age **116**, p. 936; 1925.

[2] Private communication.

[3] Zerzog, L., Der neuzeitliche Giessereibetrieb, Giess. Ztg. **23**, p. 218; 1926. See also, Ludwig, P., same, p. 274.

[4] Anon, Martinofen zur Herstellung von dunnwandigen, komplizierten Stahlformguss, Stahl und Eisen, **38**, p. 399; 1918.

[5] Avey, D. M., Heats steel hotter, Foundry, **54**, p. 88; 1926.

[6] Jonas, R., Ein neuer deutscher Stahl, Allegmeine Deutsche Zeitung, September 16, 1925.

[7] Bunnell, S. H., see footnote 1.

hearth temperature was thought to be responsible for the special characteristics, as analysis did not show any particular alloying element which would account for the toughness. He requested the aid of the Bureau of Standards in investigating the German claims and agreed to the customary stipulation that the bureau might publish the results however they might come out.

When informed that the analyses showed that the steel submitted was not an ordinary carbon steel but should be classed as a silicon alloy steel, he stated that the "Freund" steel was a development of the summer of 1925, and although it was made in the Bosshardt furnace at the Freund works in Berlin, it should be tested "to determine its qualities as a steel and without regard to the use of the patented Bosshardt furnace in its production."

Although the first German accounts [8] of "Freund" steel called it a "new" steel, Tetmajer [9] had shown in 1884 that steels of 0.11 to 0.18 per cent C, 0.90 per cent Mn, and 0.70 to 1.0 per cent Si (with the very high S and P characteristic of the steel of those days) had as good or better ductility and higher strength than steels of corresponding or even higher carbon content with 0.45 per cent Mn and negligible Si.

Hadfield [10] in 1889 described high silicon steels of some 5 or 6 points higher carbon than the Freund range, their properties agreeing well with those of "Freund" steels.

Turner [11] had shown the effect of silicon, up to 0.50 per cent, in 1888.

Paglianti [12] in 1912 gave test results agreeing very closely with those later given for "Freund" steel of nearly identical composition.

Bisset [13] in 1914 and Pomp [14] in 1925 fully described the properties of steels of about 1 per cent silicon, Bisset those 10 or 12 points higher in carbon than the "Freund" steels and Pomp those 6 or 7 points lower. By interpolation from the results of Bisset and Pomp the physical properties of steels of the "Freund" composition could have been closely predicted.

Bisset's results were based on large-scale experiments for the Bureau of Construction and Repair, United States Navy, at the Carnegie Steel Co. He states that the *Lusitania* and *Mauretania*

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[8] Ein neuer deutscher Stahl, Schafer, Bautechnik, **3**, 1925; p. 631. See also Rein, Bauingenieur, **6**, p. 844; 1925.

[9] Tetmajer, L., Zur Frage der Qualitatsbestimmung von Flussstahlschienen, Stahl und Eisen, **9**, p. 608; 1884. See also Guillet L, Les Aciers Speciaux, p. 91; 1904.

[10] Hadfield, R. A., On alloys of iron and silicon, J. Iron and Steel Inst., pt. 2, p. 222; 1889

[11] Turner, F., The influence of silicon on steel, J. Iron and Steel Inst., pt. 2, p. 302; 1888.

[12] Paglianti, P., Della influenza del Silico sulle proprieta del ferro omogenio, Met. Italiana, 4, p. 231; 1912, Metallurgie, **9**, p. 217; 1912. See also Charpy G., Cornu-Thenard, A., Researches on the iron, silicon, carbon alloys, J. Iron and Steel Inst., **91**, p. 276; 1915, Engineering, **100**, p. 173; 1915, for critical ranges of 0.07 to 15C, 1.0 Si steel.

[13] Bisset, G. A., Silicon steel, Iron Age, **86**, p. 442; 1910. See also Burgess, G. K., ref. 26, p. 1300.

[14] Pomp, A., Einfluss des Siliziums auf die Festigkeitseigenschaften des Flussstahles bei Erhohter Temperatur. Mitt. Kais. Wilh. Inst. fur Eisenforschung, **7**, No. 58, pt. 9, p. 105; 1925, also Zeit. Ver. deutsch. Ing., **70**, p. 611, 1926.

were partly constructed of high-silicon steel and cites satisfactory French and British experience with it.

Hadfield [15] gives the analysis (about 0.25 C, 1.10 Si) and properties (see Table 1) of the silicon steel in the *Mauretania*, and states that such steels were satisfactorily made by two different English firms and in ingots up to 16 tons, while de Rusett [16] comments on the better elastic limit obtained in the high silicon high tensile ship steel with tensile strength and elongation practically the same as in high carbon, high tensile steel.

Barton [17] also comments on the high elastic limit of silicon steel for castings, states that the bend test is satisfactory, low-carbon steel with over 2 per cent silicon giving 180° cold bend, and says it can be satisfactorily made in either the acid or basic electric furnace. He gives logs of successful heats of around 0.30 C, 0.65 Mn, and 0.60 Si.

Since all these earlier silicon steels were made in furnaces other than the Bosshardt, it is not surprising to find that the recent tests of the Verein Deutscher Eisenhuttenleute [18] (in which high-silicon steels made in the Bosshardt furnace, and rolled at two different works, were tested by several German laboratories in comparison with similar steels made in the converter, the open-hearth, and the electric furnace) indicated that the properties are primarily due to the composition rather than to the furnace.

However, according to Schafer's recent article [19] the Deutsche Reichsbahn Gessellschaft is having installed at the Linke-Hoffman Lauchhammer A. G. a 10-ton Bosshardt for further comparative tests among that furnace, the open hearth and the converter.

Rein [20] points out that general use of the high-silicon steel depends on the reliability and economy of its preparation on a large scale. He expresses the hope of the German structural-steel industry that the price of silicon steel will allow its use for all structures, so that a single material may serve, instead of merely adding "F" steel to the two common German structural steels No. 37 and No. 48. He thinks that if a minimum yield point of 51,000 lbs./in.^{2} of the silicon steel can be regularly obtained, with the 22 per cent or better elongation, that a really perceptible improvement will have been made over the high-carbon steel No. 48, with its minimum elongation of 18 per cent.

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[15] Hadfield, R. A., Metallurgy and its influence on modern progress, Pub. D. Van Nostrand, p. 150, 1925; p. 114; 1926.

[16] de Rusett, E. W., The use of high tensile steel in the construction of the *Mauretania*, Engineering **83**, p. 873; 1907.

[17] Barton, L. J., Refining metals electrically, pp. 255; 285, 386; 1926.

[18] Die Eigenshaften hochsilizium haltigen Baustahls, Stahl und Eisen, **46**, p. 493, 1926; also Zeit. Ver. deutsch. Ing. **70**, p. 861, 1926; also abstract in Trans. Am. Soc. Steel Treating, **10**, p. 130, 1926; see also Schulz., E. H., Stahl und Eisen **46**, p. 880, 1926.

[19] Schaefer, F. Stahl, Bautechnik, **4**, p. 237, 1926.

[20] Rein, W., Silizium stahl als Baustahl, Bauingenieur, **7**, p. 426, 1926.

Graf [21] gives ranges of 36,000 to 43,000 and 40,500 to 47,500 lbs./in.^{2} for the yield points and 55,000 to 61,500 and 72,500 to 79,000 lbs./in.^{2} for the tensile strengths of Nos. 37, and 48, respectively, while Gehler [22] gives for steel No. 58, 44,500 lbs./in.^{2} yield point and 76,000 lbs./in.^{2} in tensile strength, with 25 per cent elongation, and the specifications, according to Bernhard [23] require 42,500, 82,500 and 18.

From the comments in these articles it would appear that high silicon steel is creating quite a furore in Germany, while the use of manganese as a strengthening element does not appear to be receiving much consideration there, although the analyses of Freund steels sometimes show up to about 0.90 per cent Mn, and one of the specimens (No. 60, heat No. 1,700) sent to the Bureau of Standards was stated to contain 0.09 per cent C, 1.33 per cent Mn, 0.94 per cent Si. Although analysis at the bureau showed 0.15 per cent C, 0.79 per cent Mn, 1.11 per cent Si, the bar evidently being wrongly marked, the stated composition is interesting as indicating that "Freund" steels may contain high manganese. In the available analyses of "Freund" steels there seems to appear a tendency toward higher manganese with lower silicon.

American practice in high strength structural steels seems to trend toward the use of higher carbon—say, 0.30 to 0.35 per cent—with manganese around 1 per cent, as in the Delaware River Bridge, or even higher.[24]

Lang [25] gives tests on 0.10 per cent carbon steel with 1.25 to 1.75 per cent manganese which show physical properties quite comparable to those of the silicon steels.

The definite trend toward higher manganese [26] indicates that increased use will be made of that cheap alloying element, and the question arises whether another relatively cheap element (silicon) also deserves wider use.

Many a vanadium, chromium, or other recognized alloy steel owes a good deal of its strength to its high manganese content, even though the manganese is seldom mentioned in naming the steel. As sole alloying element the influence of manganese has long been

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[21] Graf, O., Druckversuche mit profileisen, Beuingenieur, **7**, p. 277, 1926; see also Editorial, Present status of new high-strength steel, Eng. News. Rec., **94**, p. 273, 1925; see also Schellewald, Bearbeitungs versuche mit Hochwertiger Baustahls, Bauingenieur, **6**, p. 729, 1925; see also Kommerell, Ein Jahr Hochwertiger Baustahls St., 48, Baustahls Bauingenieur, **6**, p. 811, 1925.

[22] Gehler, W., Einige Leitsatze uber das Wesen und die Bedeutung des Hochwertigen Baustahles St., 58, Bauingenieur, **5**, p. 630, 1924.

[23] Bernhard, K., Deutscher Eisenbau Verband, Zeit, Ver. Deut. Ing., **68**, p. 1252, 1924.

[24] Cone, E. F., High manganese steel for locomotives, Iron Age, **114**, p. 824; 1924.

[25] Lang, G., Über den Einfluss des Mangans auf die Eigenschaften des Flusseisen, Stahl und Eisen, **31**, p. 181; 1911; Metallurgie, **8**, p. 15, 49; 1911.

[26] Strauss, J., Characteristics of some manganese steels, Trans. Am. Soc. Steel Treat., **4**, p. 665; 1923. Anon., A special manganese steel and its advantages, Iron Age, **117**, p. 336; 1926. Anon., Special carrying rails (0.65 C, 0.90 Mn), Iron Age, **117**, p. 1651; 1926. d'Arcambal, A. H., Effect of high-speed steel on machines (0.40 C, 1.0 Mn), Iron Age, **117**, p. 1202; 1926.

understood. Campbell [27] expressed its strengthening effect quantitatively in his well-known formula 30 years ago. The work of Neville and Cain [28] on the pure Fe-C-Mn alloys covers a considerable range of compositions and clearly shows the effect of changes in carbon or manganese for a given content of the other elements.

Hall, Nissen and Taylor [29] show (their Table 4, steels 1, 4, 7) that improvement in both strength and ductility is gained by raising the silicon and lowering the carbon in a steel with rather high manganese, not heat treated. Spring steel of about 0.60 C, 0.75 Mn, 2.0 Si is, of course, common for use in the heat-treated condition.

Webster [30] discusses in detail the effect of carbon, manganese, and phosphorus, and though he does not consider the quantitative effect of silicon, he calls attention to its strengthening effect, which is evidenced by a break in his curves due to the higher strength caused by the presence of higher silicon in certain classes of steels.

Hoyt [31] says that silicon has only a negligible effect up to 0.30 per cent, but cites Yensen and others on the strengthening effect of silicon when present in higher amounts, 1 per cent raising the tensile strength of forged electrolytic iron from 45,000 to 60,000 lbs./in.^{2} Transformer steel with carbon as low as possible and silicon—say, 2.5 to 5 per cent—is used for properties not at all connected with structural strength.

Thus, while the fact has long been known that by reducing carbon and raising manganese or silicon, or both, steels are obtained which are superior in ductility for a given strength to those obtainable by the use of higher carbon it has been customary to accomplish this end by the use of nickel in steels to be used as rolled or annealed, while for steels to be normalized or quenched and tempered, nickel, chromium, or vanadium [32] are used when the properties of carbon steels need to be somewhat exceeded. Hoyt [33] advocates obtaining strength in structural steel to be used without heat-treatment by carbon rather than by manganese on account of the lack of notch-toughness when 1 per cent manganese is exceeded.

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[27] Campbell, H. H., The manufacture and properties of iron and steel, 1896 ed., pp. 261, 289, 316; 1907 ed., p. 381.

[28] Neville, R. P., and Cain, J. R., Preparation and Properties of Pure Iron Alloys, I, Effects of C and Mn on the Mechanical Properties of Pure Iron, B. S. Sci. Paper No. 453, 1922. See also Aitchison, L., Engineering steels, p. 143; 1921. See also Abbott, R. R., A comparison of the properties of a nickel, a carbon, and a manganese steel before and after heat treatment, Trans. Am. Soc. Mech. Eng., **37**, p. 39; 1915.

[29] Hall, J. H., Nissen, A. E., and Taylor, K., Heat treatment of cast steel, Trans. Am. Inst. Min. and Met. Eng., 62, p. 353; 1920.

[30] Webster, W. R., Application in rolling of effects of C, P, and Mn on mechanical properties of steel, Trans. Am. Inst. Min. and Met. Engrs., **67**, p. 220; 1922. Continued discussion on the physics of steel, Trans. Am. Inst. Min. and Met. Engrs., **69**, p. 715; 1923.

[31] Hoyt, S. L., Metallography, Part II, Metals and common alloys, pp. 241, 243, 356.

[32] McWilliams, A., and Barnes, E. J., Influence of 0.2 per cent Vanadium on steels of varying carbon content, J. Iron and Steel Inst., **83**, p. 294; 1911.

[33] See footnote 31.

Navy specifications[34] have for 10 years covered steel of 80,000, lbs./in.^{2} in tensile strength, and either carbon, nickel or silicon steel may be supplied under those specifications.

While all these have been in use[35] for structural steel, the relatively small amount of silicon structural steel produced commercially in America seems to have been of higher carbon and lower silicon content than the "Freund" composition. The recent tentative A. S. T. M. specifications[36] for structural silicon steel cover a composition of not over 0.40 per cent carbon and not less than 0.20 per cent silicon, with manganese not specified.

Various specifications for structural steel are given in Table 1. In this and the other tables the figures have been rounded off to the nearest 500 pounds, or 0.5 per cent.

Burgess[35] points out that silicon is a cheap alloying element, imparting strength and high elastic limit, but that since the specification for silicon structural steel allows the properties to be attained by either high manganese or high silicon, the composition of the steel will be adjusted by the makers, depending on the relative prices of the ferro-alloys.

Although little use has been made of them, the properties of the low-carbon silicon steels have been well established by the various investigators hereinbefore cited, representative figures for such steels and other types of structural steels being assembled in Tables 2 and 3.

The specimens of "Freund" steel supplied to the Bureau of Standards for test were insufficient in number or amount thoroughly to establish by themselves the properties of this class of steel, but the results are in general accord with recent data in German publications. The properties of "Freund" steels are given in Table 4.

Much of the German discussion of these steels has centered about the high ratio (88 per cent, with 80 per cent claimed as minimum) of yield point to tensile strength indicated by some of the earlier tests made at the Staatliche Materialprufungsamt, Berlin, Dahlem (Table 4, B, No. 16); but the later tests have shown a much more normal lower ratio, and the initial claims are not substantiated on that score. It is really the combination of yield point and elongation that makes these steels attractive.

The earliest publicity for the "Freund" steels claimed[37] a very marked reduction in weight, of railroad cars, for example, through their use, but it is obvious that this claim related to a comparison

[34] Navy Specification 48S5b, June 1, 1916, steel plates for hulls.

[35] Burgess, G. K., The study of steels for engineering structures, Trans. Am. Soc. Civil Eng., **86**, p. 1292; 1923.

[36] Proceedings, Am. Soc. for Testing Materials, **25**, Pt. I, p. 514; 1925.

[37] The Engineer, **140**, p. **349** 1925. See also ref. 8.

of the yield point of the steel with that of the German mild structural steel "St. 37," and not to the density of the steel itself, since the specimens tested at the Bureau of Standards [38] showed an average density of 7.78 against 7.84 for ordinary structural steel.

The phosphorus content of the "F" steels is said [39] to be intentionally high for its strengthening effect. (See Table 4, B, Nos. 4, 6, 18, 19.) German analyses show 0.05 to 0.30 per cent nickel and do not mention chromium or copper, while the three samples analyzed at the Bureau of Standards [40] contained no nickel, but did contain chromium up to 0.15 per cent and copper up to 0.22 per cent. The analyses in Table 4 certainly dispose of the extraordinary claim that

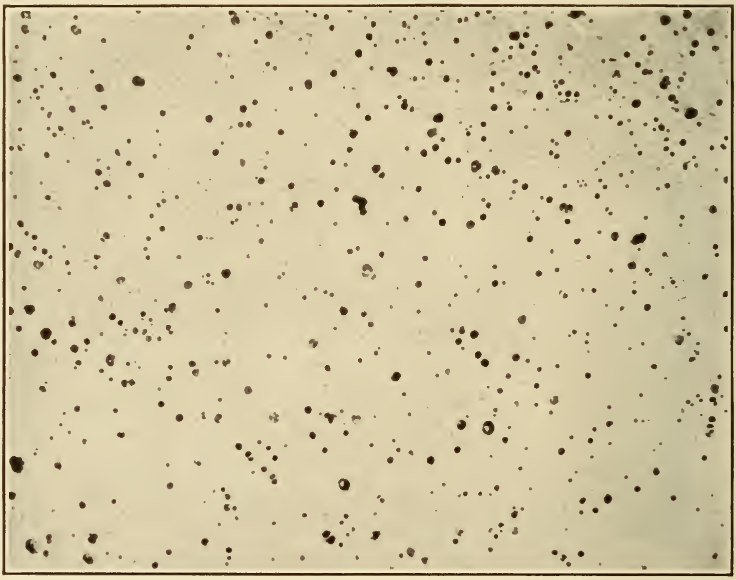

Fig. 1.—*Heat 1622, mark 4, Freund steel, unetched.* × *100. Transverse section*

the Bosshardt furnace automatically eliminates phosphorus and sulphur.

The claim that the furnace eliminates oxygen through its high temperature was examined by the Verein Deutscher Eisenhuttenleute [41] on Nos. 10 to 15 of Table 4, B (heats 1982 to 2002). About 0.02 to 0.035 per cent oxygen was found by the hydrogen reduction method and about 0.02 to 0.04 per cent by the Oberhoffer residue method, these amounts being stated to be of the same order as are usually found by those methods in ordinary German open-hearth steels.

[38] By E. L. Peffer. [39] See footnote 19, p. 124. [40] By H. A. Bright. [41] See footnote 18, p. 124.

At the Bureau of Standards heat 1626 (No. 7, Table 4, B) was examined [42] by the vacuum fusion method [43] and found to contain about 0.015 per cent oxygen; that is, about the amount usually present in ordinary steels as shown by that method of analysis.

Metallographic examination [44] of unetched specimens show the "Freund" steels to be very dirty. Figures 1 to 3 and 6 to 8 show representative unetched sections.

Sulphides were finely divided and scattered. Notwithstanding the high silicon content, few of the inclusions appeared to be silicates.

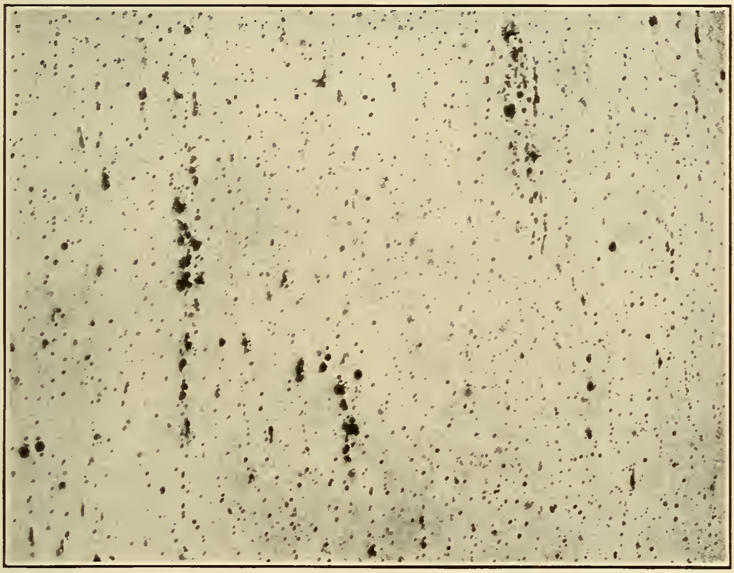

Fig. 2—Heat 1622, mark 4, Freund steel, unetched. × *100. Longitudinal section*

Considerable alumina, as shown by arrows in Figures 3 and 8, appeared to be present, hence spectrographic examination was made [45] for aluminum and from the intensity of the aluminum lines and the relation of intensities to aluminum content it was estimated that 0.02 to 0.03 per cent aluminum (probably largely as Al_2O_3) was present in all the six specimens.

Specimens were carburized for 10 hours at 925°, polished, etched, and examined [46] for "abnormality" in the McQuade-Ehn test. The carburized layers were unusually shallow, the grain extremely fine, and slight traces of coalescence were found in the cementite.

[42] By R. J. Kranauer.

[43] Jordan, L., and Eckman, J. R., Gases in Metals II, Determination of oxygen and hydrogen in metals by fusion in vacuum. B. S. Sci. Paper, No. 514; 1925.

[44] By S. Epstein and W. A. Tucker.

[45] By Dr. W. R. Meggers.

[46] By S. Epstein.

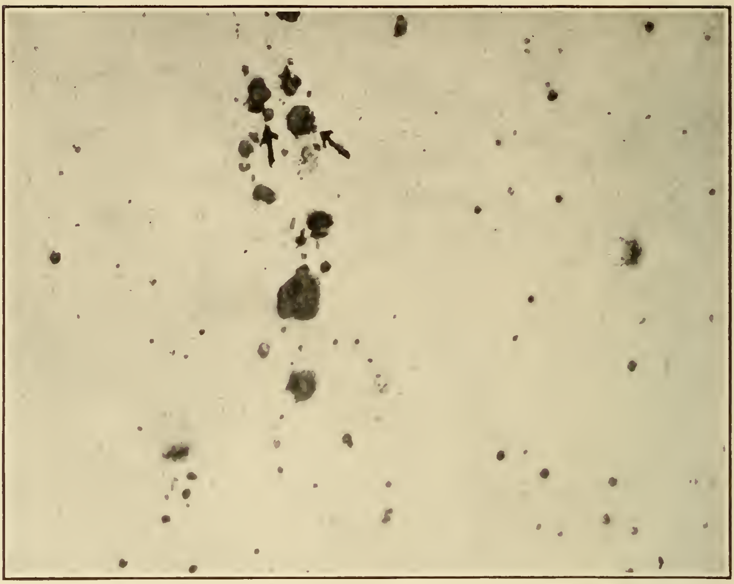

Fig. 3.—*Heat 1622, mark 4, Freund steel, unetched.* × *500. Longitudinal section*

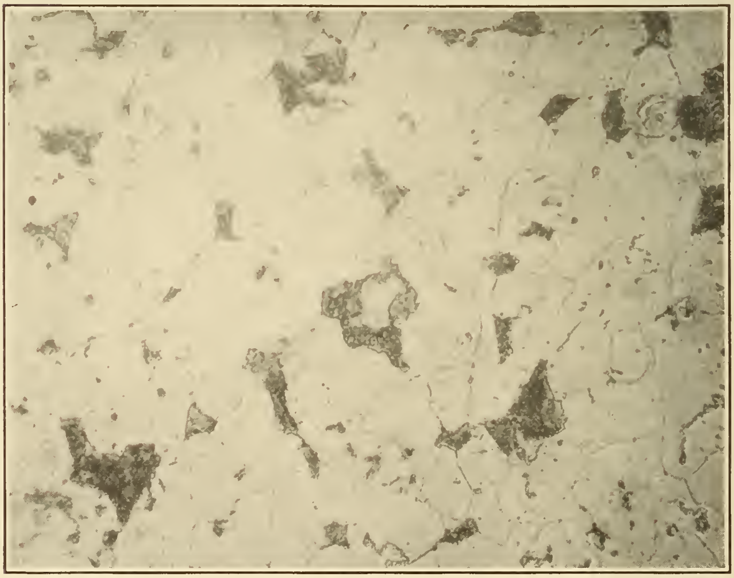

Fig. 4.—*Heat 1622, mark 4, Freund steel, as rolled.* × *500. Etched 5 per cent picric acid in alcohol*

From experience with the usual carburizing steels, steels of this high aluminum content would have been expected to be abnormal, but, instead, these steels should probably be classed as "fine-grained normal," scarcely as definitely normal, and certainly not strongly abnormal.

The presence of so many inclusions would be expected to give reduced ductility were transverse tensile tests made and would be dangerous were the steels to be used under repeated stress. But, as Burgess [47] remarks, repeated stress is negligible in structural steels and inclusions that would be fatal in rail steel may not be definitely harmful in structural steel.

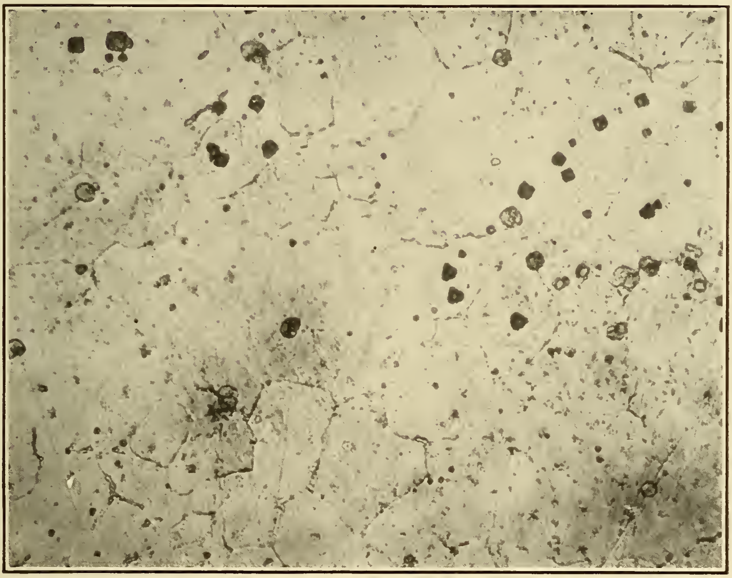

FIG. 5.—*Heat 1662, mark 4, Freund steel, annealed. × 500. Etched 5 per cent picric acid in alcohol*

Schafer [48] says that the "Freund" steels contain more inclusions than the German high-carbon structural steel No. 48, the inclusions increasing, as well as becoming less plastic at rolling temperatures, as the silicon content increases. He thinks that a silicon content of 1 per cent should not be exceeded. In the report [49] of the tests by the Verein Deutscher Eisenhuttenleute, however, it is stated that only a very small amount of nonmetallic inclusions was found, though coarse inclusions were found around the pipe.

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[47] See footnote 35, p. 127. [48] See footnote 19, p. 124. [49] See footnote 18, p. 124.

The high silicon steels are reported to contain deeper pipes than ordinary steels, and while the number of rim holes was decreased, a couple of the ingots showed some surface unsoundness and developed some surface cracks on rolling.

In very large sections, according to the Verein Deutscher Eisenhuttenleute tests, the yield point and ductility may both be low (see Table 4, B, Nos. 28, 29b, 29c, 34). In thin sheet the yield point is high and ductility low. The tests do not make clear whether these variations with section were connected with the finishing temperatures or with rate of cooling. No data have been presented to show

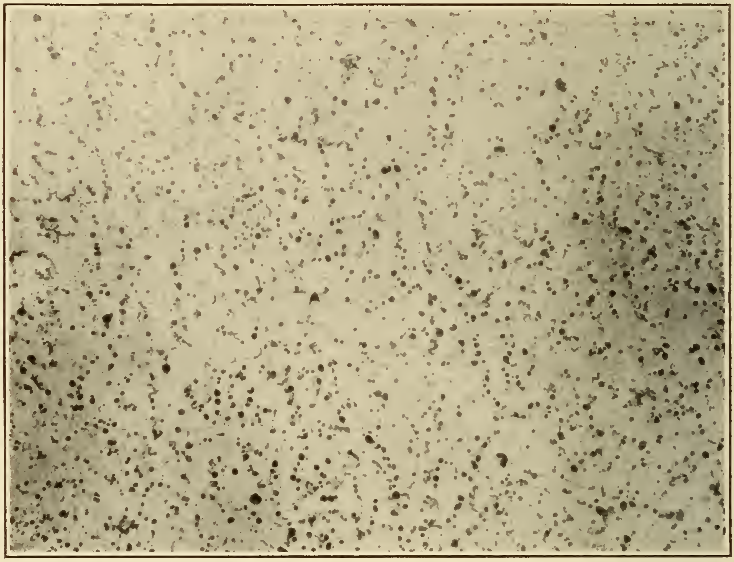

Fig. 6.—*Heat 1626, mark 14, unetched. × 100. Freund steel. Transverse section*

whether the steel can be appreciably hardened by quenching, available data [50] dealing with steel of higher carbon content.

According to Paglianti's [51] data (Table 3, B) notch toughness falls off between 1.25 and 1.75 per cent Si. Bissett's data, however, would indicate that the falling off did not occur below 1.45 per cent Si. Pilling [52] finds it necessary to exceed 2 per cent Si in 0.09 per cent C steel before brittleness is found even at −100° C. The "Freund" steels examined at the Bureau of Standards [53] (Table 4, B, Nos. 4 to 9) were tough. Schafer states that the notch toughness is above

[50] Colbeck, E. W., and Hanson, D., The hardening of silico-manganese steels, J. Iron and Steel Inst. **109**, p. 377; 1924.

[51] See footnote 12, p. 123.

[52] Pilling, N. B., Low temperature brittleness in silicon steels, Trans. Am. Inst. Min. and Met. Eng., **49**, p. 780; 1923.

[53] By G. W. Quick and R. D. France.

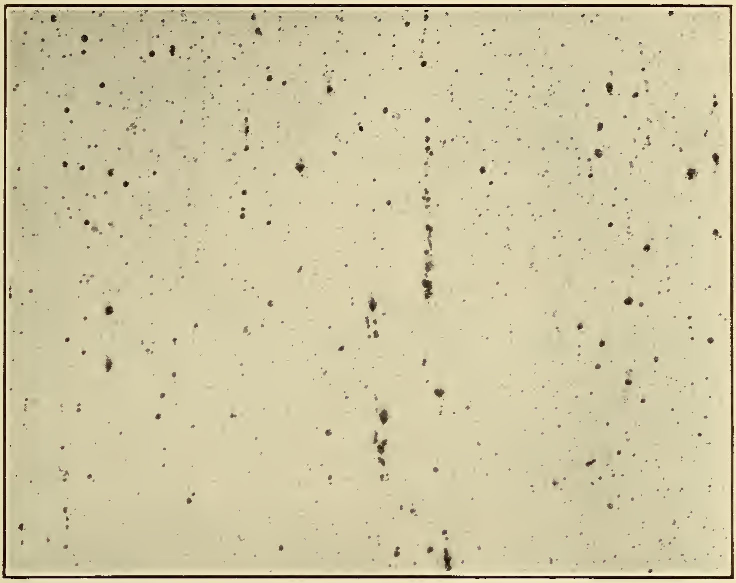

FIG. 7.—*Heat 1639, mark 22, unetched. × 100. Freund steel. Longitudinal section*

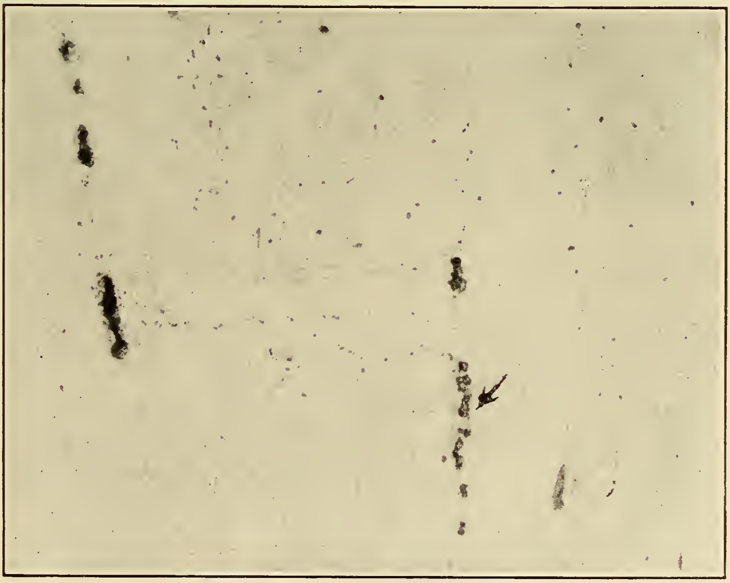

FIG. 8.—*Heat 1639, mark 22, unetched. × 100. Freund steel. Longitudinal section*

that of the high carbon German steel No. 48, over the range −70 to 300° C., and at the higher temperatures is even above that of the medium carbon German steel No. 37. Bend tests are reported to be very satisfactory as would be expected from the ductility.

Schafer says that heating to 630° C. does not alter the tensile strength or yield point. The effect of annealing (temperature not stated) as found in the German tests is shown in Table 4, A. Schafer states that there is no graphitization on annealing the Freund steels.

Annealing at 800° C. for one hour, with furnace cooling, brought the Brinell hardness of the specimens tested at the Bureau of Stand-

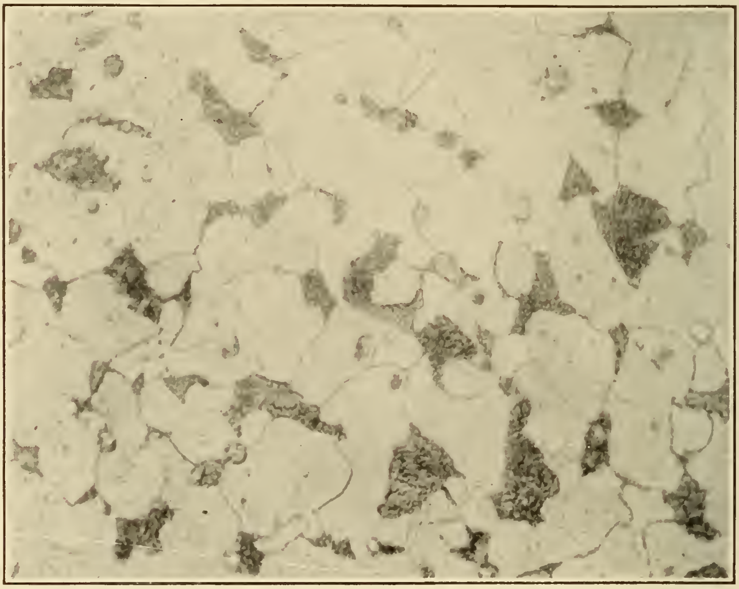

Fig. 9.—*Heat 1626, mark 14, Freund steel as rolled. × 500. Etched 5 per cent picric acid in alcohol*

ards from 137 to 131, 151 to 138, and 152 to 146, representative structures as rolled and as annealed being shown in Figures 4 to 5 and 9 to 10.

Table 4, B, and Table 3, B (Nos. 34 to 38), give the analyses and mechanical properties of some 25 different lots of "Freund" steels ranging from 0.10 to 0.15 per cent C, and 0.67 to 1.50 per cent Si, with 48,500 lbs./in.^{2} as the lowest yield point, 68,500 lbs./in.^{2} as the lowest tensile strength, elongation never below 22 per cent and generally above 25 per cent in 8 inches, and reduction of area never below 45 per cent, generally above 60 per cent. If we compare these properties with the specifications for the properties of structural steels in Tables 1 and 2, the combination of yield point and ductility is seen to be better than can be expected in higher

carbon steels of normal manganese content and approaches that of nickel steels.

It is evident from Tables 2, B, and 3, A, that the properties of the "Freund" steels can be closely attained with steels, of, say, 0.15 per cent C, 1.50 per cent Mn; 0.25 per cent C, 1.00 per cent Mn; or 0.25 per cent C, 0.75 per cent Si; with the single exception that the reduction of area may not, when the carbon is as high as 0.25 per cent, be quite up to that of the 0.12 per cent C, 1.00 per cent Si, "Freund" composition.

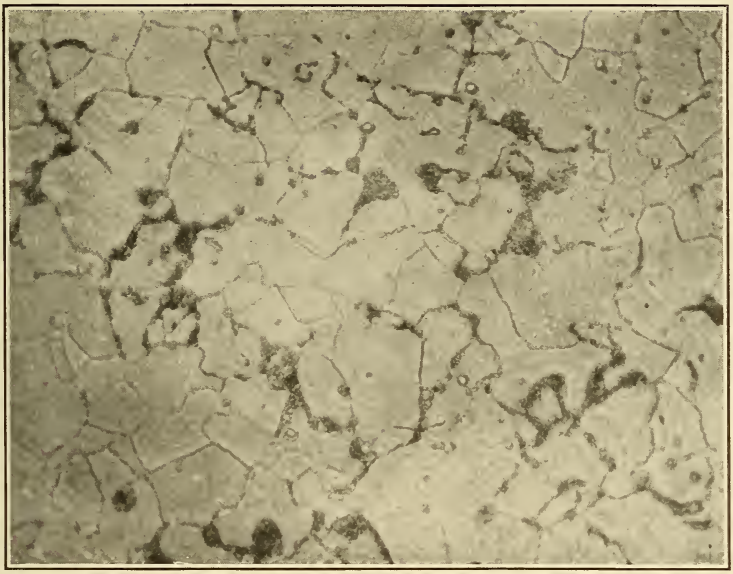

FIG. 10.—*Heat 1626, mark 14, Freund steel, annealed.* × 500. *Etched 5 per cent picric acid in alcohol*

It is evident that silicon, at least when present in amount above 0.50 per cent, should be classed as a true alloying element. Its effect in raising the yield point is quite marked. If users of structural steel are to base design upon yield point rather than upon tensile strength, and if a higher yield point than that of medium carbon steel is sought without notable loss in ductility, increase in manganese or silicon or both, together with a lowering of carbon, seems to offer a cheaper method than the use of nickel. The single figure cited in Table 2, E, would indicate that another cheap element (copper) should not be neglected.

It appears that for the optimum combination of yield point and toughness carbon will have to be held lower and controlled within narrower limits with silicon as alloying element than with manganese.

Sisco points out [54] that in production of electric steel below 0.15 per cent C, desulphurization is more difficult than in higher carbon steels, and that it is hard to produce such steel without overoxidation.

It would appear that the use of silicomanganese with its lower carbon content, instead of ferromanganese, would aid in holding the final carbon content down and make it simple to obtain the needed balance among carbon, manganese, and silicon.

Since the data in Tables 3, B, and 4, C, show that the properties claimed for "Freund" steels have been obtained with those compositions in various furnaces other than the special Bosshardt furnace, attention may be centered on the composition rather than on the furnace.

Whether such steel can be produced here at a low enough cost to allow it to compete would have to be determined by trial under American conditions, but the metallurgist of one American mill states that he sees no reason to expect any particular difficulty in the making or rolling of such steel.

The relative advantages of manganese and of silicon as alloying elements will depend somewhat upon their relative prices. American steel makers might find it worth while to be prepared to utilize silicon for making high yield point structural steel, in periods when ferromanganese is high and ferrosilicon low, as previously pointed out by Burgess.[55]

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[54] Sisco, F. T., The Manufacture of Electric Steel, p. 177, 1924.

[55] See footnote 35, p. 127.

TABLE 1.—*Structural steel specifications*

No.	Steel for—	Chemical composition [1] C	Mn	Si	Ni	Cr	Minimum yield point [2]	Minimum tensile strength	Elongation in 8 inches [3]	Reduction of area [3]	Source of data
							Lbs./in.²	*Lbs./in.²*	*Per cent*	*Per cent*	
1	Rivets for bridges						25,000	46,000	32½		A. S. T. M. A-7-24 and F. S. B. 351.
2	Bridges						30,000	55,000	27		Do.
3	Rivets for buildings						25,000	46,000	30½		A. S. T. M. A-9-24.
4	Buildings						30,000	55,000	25½		Do.
5	Rivets for cars						22,500	45,000	33		A. S. T. M. A-11-24 and F. S. B. 373.
6	Cars						25,000	50,000	30		Do.
7	Ships						29,000	58,000	26		A. S. T. M. A-12-21.
8	Rivets for ships						27,500	55,000	27		A. S. T. M. A-13-24.
9	Structures	Under 0.44		Over 0.18			45,000	80,000	18½	30	A. S. T. M. A-94-25T (tentative).
10	Hull plates							80,000	20		United States Navy 48S5b, 1916.
11	Ni rivet	Under 0.30	Under 0.60		Over 3.25		45,000	70,000	21½	40	Fed. Spec. Bd. 372.
12	Ni plates, shapes, bars	Under 0.45	Under 0.70		Over 3.25		50,000	85,000	17½	25	Do.
13		Under 0.40	Over 0.30	Under 0.15	Over 1.20	Also present	50,000	85,000	19	30	Burgess, footnote 35, p. 127
14		0.45	0.50-0.60				45,000	85,000	17½		Burgess, Penn Steel Co.
15	Bridges, buildings, ships							62,500	20		Burgess, British.
16							26,500	48,500	25		D. I. Norm. German steel No. 34.
17							29,000	52,500	20		D. I. Norm. German steel No. 37.
18							37,500	68,500	20		Footnotes 22, 23, and 24, p. 125, German steel No. 48.
19							45,500	85,000	18		Footnotes 22, 23, and 24, p. 125, German steel No. 58.
20							48,500	68,500	22	45	Table 4 (minimum figures "Freund" steel).

[1] P and S limits not included in Table 1. [2] Usually specified as 50 or 55 per cent of tensile strength. [3] Figures given correspond to minimum tensile strength.

TABLE 2.—*Properties of structural steels*

A. CARBON STEELS

No.	Chemical composition						Yield point	Tensile strength	Elongation per cent in 8 inches (unless noted)	Reduction of area	Condition as rolled (unless noted)	Source of data
	C	Mn	Si	Ni	Cr	Cu						
							Lbs./in.[2]	*Lbs./in.*[2]				
1	0.12	0.44	Trace.				36,000	50,000	44 in 2 inches	72		S. and P. Comm., A. S. T. M. Rivet Steel average.[1]
2	.25	.50	0.01				36,000	62,500	37½ in 2 inches	57		Petrenko.[2]
3	.34	.57	.22				46,500	79,000	25	52		B. S. test Delaware River Bridge, G6-1P.
4	.42	.58	.24				46,500	87,000	20	31		B. S. test Delaware River Bridge, G7A-1P.
5	0.50–0.65						46,500	83,500	22			de Rusett, footnote 16, p. 124.
6							36,000–43,500	55,000–61,500				Graf, footnote 21, p. 125. German No. 37.
7							40,500–47,500	72,500–79,000				Graf, footnote 21, p. 125. German No. 48.
8							44,500	76,000	25			Gehler, footnote 22, p. 125. German No. 58.

B. MANGANESE STEELS

No.	C	Mn	Si	Ni	Cr	Cu	Yield point	Tensile strength	Elongation per cent in 8 inches (unless noted)	Reduction of area	Condition as rolled (unless noted)	Source of data
9	0.10	1.27	0.31			0.15	54,500	71,500	28 [3]	68		Lang, footnote 25, p. 125.
10	.25	.85					56,000	83,000	30 in 2 inches			Aitchison.[4]
11	.20	.90					54,000	80,500	34 in 2 inches	60		B. E. S. C.[5]
12	.34	1.61	.01			.02	61,000	88,000	30 in 2 inches	58½	Annealed	Abbott, footnote 28, p. 126.
13	.34	1.69	.31				54,000	100,000	26 in 2 inches	52		Cone, footnote 24, p. 126.
14	.33	.94	.30				50,500	87,500	23	53		B. S. test Delaware River Bridge, G7-A1.
15	.31	.96	.29				52,500	90,500	25	48		B. S. test Delaware River Bridge, G5-A1.

C. NICKEL STEELS

No.	C	Mn	Si	Ni	Cr	Cu	Yield point	Tensile strength	Elongation per cent in 8 inches (unless noted)	Reduction of area	Condition as rolled (unless noted)	Source of data
16	0.19	0.70		3.48			49,000	76,000	23½ in 2 inches	67	Annealed	Krebs.[6]
17	.34	.55	0.19	3.17		0.05	55,000	82,000	31 in 2 inches	59	do	Abbott, footnote 28, p. 126.
18	.38	.58		3.45			60,000	100,000	18	33½		Burgess, footnote 35, p. 127, St. Louis Bridge.

D. NICKEL-CHROMIUM STEELS

19	0.35	0.70		1.40	0.45		56,000	90,000	13		Annealed and then normalized.	Burgess, footnote 35, p. 127, Memphis Bridge.
20	.33	.62		1.52	.50		59,000	103,000	26 in 2 inches	61		Krebs.[6]
21	.44	.63	0.24	3.50	.19		80,000	121,000	20 in 2 inches	49½		Petrenko.[2]

E. COPPER STEEL

22	0.38	0.57				0.86	61,000	92,500	25 in 2 inches	52½		Hayward and Johnston.[7]

F. SILICON STEELS

23			0.65–1.11				48,500	83,500	22			de Rusett, footnote 16, p. 124.
24	0.27	0.72	1.12				62,500–67,000	92,000–105,000	25 to 30[3]	45–52		Hadfield, footnote 15, p. 124.
25	.24	.71	1.10				61,000	87,000	22½ in 2 inches	59	Normalized	B. S. and B. M. Heat No. 1198.[8]
26	.39	.58	.66				61,500	95,500	25 in 2 inches	46	do	B. S. and B. M. Heat No. 1104.
27	.22	.39	.83				49,000	76,500	29	60		Bisset, footnote 13, p. 123.
28	.24	.49	1.44				58,000	88,000	25	50		Do.
29	.18	.21	.70				56,000	76,500	29½ in 2 inches	54½		Hadfield, footnote 10, p. 123.
30	.11	.36	.95				53,500	69,000	28	55		Paglianti, footnote 12, p. 123.
31	.07	.32	1.17				47,500	67,500	29½ in 3 inches	71½		Pomp, footnote 14, p. 123.
32	.13	.57	1.05		0.08	0.18	56,500	76,000	25	63		B. S. average "Freund."

1 Joint Committee on Investigation of P and S in steel, Preliminary report effect of sulphur on rivet steel, Proc. A. S. T. M., **22** (1), 1922, p. 94; Figure 5, p. 108.
2 Petrenko, S. N., Comparative slow bend and impact notched bar tests on some metals, Trans., A. S. S. T., **8**, p. 519; 1925.
3 Test length not stated.
4 Aitchison, L., Engineering Steels, p. 143; 1921.
5 British Eng. Stds. Assn. Report Steel Research Committee No. 75, October, 1920.
6 Krebs, F. W., The cold drawing of bar steel, Mech. Eng., **48**, p. 448; 1926.
7 Hayward, C. R., and Johnston, A. B., Effect of presence of small amount of copper in medium carbon steel, Trans. A. I. M. E., **58**, p. 722; 1918.
8 Gillett, H. W., and Mack, E. L., Experimental production of some alloy steels, Bureau of Mines Bull. No. 199, 1922; Burgess, G. K., and Woodward, R. W., Manufacture and properties of steel plates containing zirconium and other elements, B. S. Tech. Paper No. 207, Table 11; 1922.

TABLE 3.—*Effect of variations in carbon, manganese, and silicon on the mechanical properties of steels*

A. MANGANESE STEELS

No.	Source	C	Mn	Si	Cu	P	S	Proportional limit	Yield point	Tensile strength	Elongation per cent in 2 inches (unless noted)	Reduction of area	Impact	Brinell	Condition
								Lbs./in.²	*Lbs./in.²*	*Lbs./in.²*		*Per cent*			
1	Neville and Cain, footnote 28, p. 126.	0.15	1.00–1.35	Trace.	------	Trace.	Trace.	31,000	----------	53,000	34	76	--------	--------	Annealed and then normalized.
2		.20	1.00–1.35	Trace.	------	Trace.	Trace.	40,000	----------	61,000	29	72	--------	100	Do.
3		.25	1.00–1.35	Trace.	------	Trace.	Trace.	46,000	----------	67,000	26	70	--------	105	Do.
4		.30	1.00–1.35	Trace.	------	Trace.	Trace.	56,000	----------	75,000	23	66	--------	110	Do.
5		.35	1.00–1.35	Trace.	------	Trace.	Trace.	60,000	----------	80,000	20	61	--------	115	Do.
6	Lang, footnote 25, p. 125	.12	.29	0.32	0.13	0.063	0.046	----------	46,000	62,500	28 [1]	53½	[2] 23.2	110	As rolled.
7		.10	.79	.31	.12	.040	.052	----------	49,000	64,500	28 [1]	66	[2] 33.4	119	Do.
8		.10	1.27	.31	.15	.099	.045	----------	54,500	71,500	28 [1]	68	[2] 26.4	132	Do.
9		.10	1.77	.31	.15	.103	.056	----------	60,000	82,500	26 [1]	54½	[2] 25.1	156	Do.
10		.09	2.47	.29	.12	.110	.051	----------	63,500	103,000	19 [1]	39½	[2] 2.7	211	Do.

B. SILICON STEELS

No.	Source	C	Mn	Si	Cu	P	S	Proportional limit	Yield point	Tensile strength	Elongation per cent in 2 inches (unless noted)	Reduction of area	Impact	Brinell	Condition
11	Turner, 1888, footnote 11, p. 123. No. 1	0.16	0.55	0.01	------	0.060	0.050	----------	49,000	66,000	23 in 10 inches	49	--------	--------	As rolled.
12	No. 7	.13	.48	.31	------	.057	.028	----------	47,500	66,000	25 in 10 inches	56½	--------	--------	Do.
13	No. 9	.15	.49	.32	------	.081	.049	----------	50,000	74,000	16½ in 10 inches	36	--------	--------	Do.
14	No. 11	.18	.45	.50	------	.121	.094	----------	59,000	82,000	19½ in 10 inches	35	--------	--------	Do.
15	Hadfield, 1889, footnote 10, p. 123. A1	.14	.14	.18	------	.05	.08	----------	49,000	74,000	30	54½	--------	--------	Do.
16	B2	.18	.21	.70	------	------	------	----------	56,000	76,500	29½	54½	--------	--------	Do.
17	C3	.19	.28	1.60	------	------	------	----------	62,500	84,000	31	50½	--------	--------	Do.
18	D4	.20	.25	2.11	------	.04	.06	----------	69,500	88,500	18½	28	--------	--------	Do.
19	Bisset, 1910, footnote 13, p. 123. 540	.22	.39	.83	------	.012	.020	----------	49,000	76,500	29 in 8 inches	60	[3] 38	--------	Do.
20	541	.24	.46	.74	------	.015	.021	----------	52,500	82,500	26 in 8 inches	55	[3] 30.6	--------	Do.
21	543	.22	.42	.90	------	.026	.024	----------	49,000	77,500	28½ in 8 inches	53½	--------	--------	Do.
22	542	.24	.49	1.44	------	.030	.022	----------	58,000	88,000	25 in 8 inches	50½	[3] 33.5	--------	Do.
23	Paglianti, 1912, footnote 12, p. 123. 1	.12	.41	.24	------	.033	.064	----------	45,500	62,500	30 in 8 inches	57½	[4] 26.7	130	Do.
24	2	.10	.30	.37	------	.041	.049	----------	47,500	61,000	29½ in 8 inches	57	[4] 36.0	131	Do.
25	3	.11	.23	.67	------	.044	.044	----------	49,500	65,000	28½ in 8 inches	58	[4] 34.2	144	Do.
26	4	.11	.36	.95	------	.040	.043	----------	53,000	69,000	28 in 8 inches	55	[4] 31.5	150	Do.
27	5	.15	.50	1.25	------	.043	.047	----------	60,000	78,500	28 in 8 inches	45	[4] 28.5	165	Do.
28	6	.15	.56	1.73	------	.045	.040	----------	63,500	80,000	26 in 8 inches	40	[4] 12.0	180	Do.
29	7	.12	.29	2.35	------	.040	.058	----------	67,000	83,500	23 in 8 inches	39½	[4] 10.5	182	Do.

30	Pomp, 1925, footnote 14, p. 123.	A	.05	.25	.39		.014	.049		40,500	58,000	29½ in 3 inches	72	[5] 6.5	117	Do.
31		B	.07	.32	1.17		.013	.034		47,500	67,500	29½ in 3 inches	71½	[5] 3.1	130	Do.
32		C	.05	.35	1.73		.014	.030		54,500	72,500	29½ in 3 inches	64	[5] 3.4	140	Do.
33		D	.06	.16	2.39		.010	.016		53,500	76,500	24½ in 3 inches	53½	[5] .9	181	Do.
34 [6]	Schafer, 1926, "Freund" steels.				.67					53,000–54,500	71,500–72,000	25 to 30 in 8 inches.	63–64			Do.
35 [6]					.91					52,000–55,000	71,000–72,000	25 to 28 in 8 inches.	45–59			Do.
36 [6]					1.08					58,000–61,000	76,500–82.000	22 to 26 in 8 inches.	46–54			Do.
37 [6]					1.39					56,500	74,000	26	61			Do.
38 [6]					1.50					53,000–59,500	73,500–79,500	22 to 26 in 8 inches.	43–32			Do.

[1] Test length not stated.
[2] mkg/cm².
[3] Izod ft.-lbs., size specimen not stated.
[4] mkg/cm.
[5] Charpy 10 by 11 mm. mkg/cm².
[6] C=0.08 to 0.13; Mn=0.42 to 0.56; P=0.023 to 0.051; S=0.024 to 0.038.

TABLE 4.—*Properties of high silicon steels made in various furnaces*

A. "FREUND" STEELS ANNEALED

No.	Heat No.	Mark	Size	C	Mn	Si	P	S	Cu	Cr	Ni	Proportional limit	Yield point	Tensile strength	Elongation per cent in 8 inch	Reduction of area	Brinell	Impact	Density	Number specs averaged	Source of data
												Lbs./in.[2]	*Lbs./in.*[2]	*Lbs./in.*[2]							
1	1985		1 inch by 2 inch and 1.2 inch round.	0.10	0.48	0.92	0.040	0.026					45,000	65,000	30	67				8	V. d. E., footnote 18, p. 124.
2	1991		2 inch by 0.4 inch and 0.6 inch by 0.4 inch round.	.11	.56	.67	.043	.037					43,000	63,500	30½	66				8	Do.
3	2002		1 inch by 2 inch and 1.2 inch round.	.13	.66	.93	.047	.026					47,500	72,500	30	64½				8	Do.

B. "FREUND" STEELS AS ROLLED

No.	Heat No.	Mark	Size	C	Mn	Si	P	S	Cu	Cr	Ni	Proportional limit	Yield point	Tensile strength	Elongation per cent in 8 inch	Reduction of area	Brinell	Impact	Density	Number specs averaged	Source of data
4	1622	2	1.2 inch round [1]	0.11	0.72	0.92	0.076	0.046	0.16	0.05		[2] 55,500	56,000	76,000	24¾	63		[3] 86			B. S. tests.
5	1622	4	do	.11	.72	.92	.076	.046	.16	.05		[2] 51,500	56,000	74,000	25½	63	137	[3] 61	7.782		B. S. tests, B. S. analysis.
6	1625	11	do	.11	.54	1.12	.072	.040				[2] 57,500	58,000	76,500	26	64½		[3] 58	7.773		B. S. tests, maker's analysis.
7	1626	14	do	.13	.35	1.23	.057	.039	.16	.03		[2] 53,500	56,000	77,000	25½	61	151	[3] 58	7.763		B. S. tests, B. S. analysis.
8	1639	22	do	.12	.46	.89	.030	.022				[2] 49,000	54,000	73,000	25¾	61		[3] 83	7.796		B. S. tests, maker's analysis.
9	1700	60	do	.15	.79	1.11	.048	.025	.22	.15		[2] 51,000	58,500	79,500	23½	67	152	[3] 72	7.777		B. S. tests, B. S. analysis.
10	1982		1 inch by 2 inch and 1.2 inch round.	.10	.66	.89	.039	.026			.12		49,500	71,500	28½	63				27	V. d. E., footnote 18, p. 124.
11	1985		do	.10	.48	.92	.040	.026			.16		48,500	69,500	29½	65½				28	Do.
12	1986		2.8 inch by 0.8 inch	.10	.56	1.10	.062	.037			.14		52,500	74,500	28	65				24	Do.
13	1991		2 inch by 0.4 inch and 0.6 inch by 0.4 inch.	.11	.56	.67	.043	.037			.20		54,500	72,500	26	62				16	Do.
14	1995		2.8 inch by 0.8 inch	.14	.88	.77	.057	.031			.25		52,000	76,500	27	65				18	Do.
15	2002		1 inch by 2 inch and 1.2 inch round.	.13	.66	.93	.047	.026			.31		51,000	76,500	27	58½				26	Do.

16	------	------	------	----	----	----	----	----	----	----	----	----	66,500	75,500	27	63	----	----	----	18	V. d. E., footnote 18, p. 124; early tests by Staatlichen Materialprufüngsamt.
17	------	------	------	.10	----	1.00	----	----	----	----	----	----	49,000–55,000	70,000–73,000	23½–28	50–60	----	----	----	4	V. d. E., footnote 18, p. 124; early tests.
18	------	------	1.3 inch by 1.3 inch and 1.2 inch round.	.11	.48	.80	.032	.019	----	----	.05	----	56,000	75,000	27	67½	140	[4] 27½	----	----	V. d. E., footnote 18, p. 124; tests by Kais. Wilh. Inst. Eisenforschung.
19	------	3	do	.11	.75	.83	.100	.042	----	----	.10	----	55,000	75,500	27	59	147	[4] 17½	----	----	Do.
20	------	19	do	.10	.65	.93	.077	.048	----	----	.10	----	55,500	74,000	26½	65	145	[4] 17½	----	----	Do.
21	------	26	do	.09	.61	.73	.045	.030	----	----	.10	----	50,500	69,500	28½	68½	135	[4] 25½	----	----	Do.
22	------	015	do	.11	.77	.79	.052	.030	----	----	.10	----	55,500	75,000	28	69½	146	[4] 26½	----	----	Do.
23	------	016	do	.10	.77	.80	.051	.035	----	----	.10	----	55,000	74,000	27½	70	145	[4] 26½	----	----	Do.
24	------	020	do	.11	.74	.89	.045	.026	----	----	.10	----	51,000	74,000	27½	69½	142	[4] 24	----	----	Do.
25	------	024	do	.10	.42	.80	.016	.027	----	----	.10	----	48,500	68,500	28	67	131	[4] 26	----	----	Do.
26	------	080	do	.10	.65	.97	.040	.030	----	----	.10	----	57,000	75,500	28½	70	141	[4] 25	----	----	Do.

C. "FREUND" COMPOSITIONS MADE IN OTHER THAN BOSSHARDT FURNACES

27	Converter	------	0.75 inch round	0.10	0.53	0.75	0.062	0.028	----	----	----	----	57,000	77,500	22	----	----	----	----	----	V. d. E., footnote 18, p. 124.
28	do	------	4.3 inch to 6.7 inch square.	.07	.74	.80	.059	[5] .028	----	----	----	----	47,500	70,000	23½	43½	----	----	----	----	Do.
29a	O. H	------	0.87 inch round	.12	.46	1.00	.028	.030	----	----	----	----	54,500	70,500	22½	48	----	----	----	----	Do.
29b	O. H., edge	------	3.2 inch round	.12	.46	1.00	.028	.030	----	----	----	----	42,500	68,500	24½	48½	----	----	----	----	Do.
29c	O. H., center	------	do	.12	.46	1.00	.028	.030	----	----	----	----	39,000	67,000	24	38	----	----	----	----	Do.
30	O. H	------	2.4 inch by 0.5 inch	.10	.54	.74	.028	.030	----	----	----	----	48,000	68,500	28½	60	----	----	----	----	Do.
31	do	------	2.5 inch by 0.37 inch	.13	.53	.83	.022	.031	----	----	----	----	55,500	72,500	27	61	----	----	----	----	Do.
32	do	------	1.6 inch by 0.6 inch	.10	.69	.83	.020	.030	----	----	----	----	51,500	71,000	28½	63	----	----	----	----	Do.
33	do	------	1 inch by 0.24 inch	.09	.87	1.10	.040	.020	----	----	----	----	60,500	77,000	27½	56½	----	----	----	----	Do.
34	do	------	Sleepers	.09	.67	.82	.016	.035	----	----	----	----	39,000	67,000	22½	36½	----	----	----	----	Do.
35	Electric	------	0.9 inch round	.13	.56	.74	----	----	----	----	----	----	59,500	75,500	27½	68½	----	----	----	----	Do.
36	do	------	do	.13	.62	1.00	----	----	----	----	----	----	63,000	77,000	22	64	----	----	----	----	Do.

[1] Steels 4–9 made from 20 per cent pig, 80 per cent unsorted scrap. Poured at about 2,700 ° F. (1,500° C.), into 5.5 inch by 5.5 inch ingots 4 feet long. Ingots rolled to 1.2 inches diameter.
[2] Proportional limit with Ewing extensometer.
[3] Izod foot-pounds, specimens did not break completely apart in Izod test.
[4] mkg/cm ^{2}; 90 by 12 by 10 mm; 2 mm notch.
[5] Also 0.17 per cent Al.

WASHINGTON, July 14, 1926.