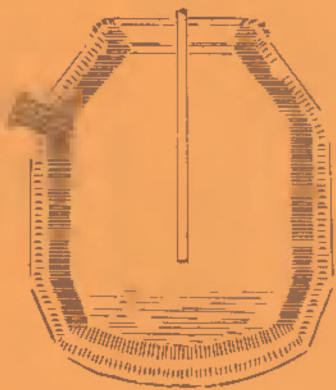
ELEVATED-TEMPERATURE PROPERTIES of BASIC-OXYGEN STEEL



ASTM DATA SERIES DS 40

Elevated-Temperature Properties of Basic-Oxygen Steel

Presented at the

NATIONAL MEETING ON STEEL

AMERICAN SOCIETY FOR TESTING AND MATERIALS

Mexico City, Mexico, Jan. 24-29, 1965

Reg. U. S. Pat. Off.

ASTM Data Series DS 40

Price $4.00; to Members $2.80

Published by the

AMERICAN SOCIETY FOR TESTING AND MATERIALS

1916 Race St., Philadelphia 3, Pa.

Library of Congress Catalog Card Number: 65-22073

The Society is not responsible, as a body, for the statements and opinions advanced in this publication.

Printed in Philadelphia, Pa.
July, 1965

Contents

Related ASTM Publications

Evaluation of Metallic Materials in Design for Low-Temperature Service, STP 302 (1962)

Elevated-Temperature Compression Testing of Sheet Materials, STP 303 (1962)

Comparison of the Properties of Basic Oxygen and Open Hearth Steels, STP 364 (1963)

FOREWORD

This symposium was presented during the National Meeting on Steel held in Mexico City, Mexico, Jan. 24-29, 1965, under the sponsorship of Committee A-1 on Steel.

DS39A-EB/Jul. 1965

Elevated-Temperature Properties of Basic-Oxygen Steel

By C. E. Spaeder, Jr.[1]

KEY WORDS: carbon steel, creep and creep-rupture properties, room- and elevated-temperature tensile properties, impact properties, transition temperature, strain aging, microstructural changes.

ABSTRACT: Because of the relatively limited amount of test data available on steels made by the basic-oxygen process and to supply information on which a decision could be made to include the basic-oxygen process in certain ASTM specifications, the ASTM authorized a Task Group to determine the properties of carbon steels made by this process.

The results of this investigation and information available from previous investigations indicate that the basic-oxygen A 201 and A 212 steels in the hot-rolled condition and in the normalized and tempered condition in comparison with these steels made by the open-hearth process have about the same tensile properties in the range 80 to 1000 F, notch toughness in the range −10 to 110 F, and creep and creep-rupture properties in the range 800 to 1000 F. In addition, the strain-aging characteristics, weldability, steel quality, and microstructures of the steels made by the two processes are similar.

REFERENCE: C. E. Spaeder, Jr., *Elevated-Temperature Properties of Basic-Oxygen Steel, ASTM STP 387*, Am. Soc. Testing Mats., 1965.

Because the basic-oxygen[2] process has gained prominence only in the past few years, the available data on mechanical properties of steels made by this process are relatively limited. Until sufficient data showed that the mechanical properties of the steel made by this process are equivalent to the properties of the same steel produced by the open-hearth or the electric-furnace process, ASTM deferred approval of the basic-oxygen steelmaking process in certain ASTM specifications.

Accordingly, the ASTM Committee A-1 on Steel authorized a Task Group[3] to determine the properties of carbon steels produced by the basic-oxygen process. For comparison, companion open-hearth heats of

[1] Research metallurgist, Stainless Steel Products, Applied Research Laboratory, United States Steel Corp., Monroeville, Pa.

[2] The basic-oxygen steelmaking process refers to the process in which molten steel is refined under a basic slag by directing a jet of high-purity oxygen onto the surface of the hot-metal bath.

each of the steels to be studied were included also in the investigation. The investigation comprised three separate projects: Project A, an investigation of ASTM A 285 (Grade C) steel; Project B, an investigation of ASTM A 201 (Grade A) and A 212 (Grade B) steels; and Project C, an investigation of ASTM A 442 (Grades 55 and 70) steels.[4]

Projects A and C included an investigation of steels made by both the open-hearth and basic-oxygen processes to determine their room- and elevated-temperature tensile properties, impact properties, steel quality (as measured by bend and homogeneity tests), weldability, microstructure, and strain-aging characteristics. The results of this investigation, which have already been reported [*1*],[5] indicate that the properties of the ASTM A 285 (Grade C) and ASTM A 442 (Grades 55 and 70) steels made by the basic-oxygen and open-hearth processes were equivalent. Project B was similar to Projects A and C except that it included a determination of the creep and creep-rupture properties of the A 201 and A 212 steels. ASTM A 201 and A 212 steels were selected for extensive investigation of the elevated-temperature properties because a large amount of data on the creep and creep-rupture properties of these steels made by the open-hearth process were available from previous investigations [*2*, *3*]. Hence, the creep and creep-rupture properties of the open-hearth A 201 and A 212 steels were not determined in this investigation.

The present paper summarizes the results obtained under Project B on A 201 and A 212 steels made by the basic-oxygen and open-hearth processes. Because this paper is primarily concerned with the elevated-temperature properties of the basic-oxygen A 201 and A 212 steels, results other than the elevated-temperature properties are presented in the Appendix.

MATERIALS AND EXPERIMENTAL WORK

As shown in Table 1, the four steels used in the investigation are within the chemical composition limits required by the pertinent ASTM specification. These steels were made by Kaiser Steel Corp. in accordance with firebox-quality coarse-grain practice and were then processed to 1-in.-thick plate. One heat of each steel was produced by the basic-oxygen process, and one heat of each steel was produced by the open-hearth process. The 1-in.-thick plates were tested both in the hot-rolled condition and in the normalized (1625 F for 1 hr) and tempered (1150 F for 1 hr) condition.

From the midthickness of the 1-in.-thick plate, standard longitudinal tension specimens were machined from the basic-oxygen A 201 and

[3] The Task Group comprised the following members: C. L. Kent (chairman), H. E. Berger, J. E. Carney, G. T. Jones, J. R. LeCron, T. B. Linn, E. E. Powell, J. J. B. Rutherford, and L. H. Wilson. In addition, J. S. Worth, P. W. Marshall, M. Korchynsky, and R. F. Miller assisted the Task Group.

[4] The following companies participated in the investigation: The American Oil Co., Armco Steel Corp., Bethlehem Steel Co., Kaiser Steel Corp., Jones and Laughlin Steel Corp., Republic Steel Corp., Sharon Steel Corp., and United States Steel Corp.

[5] The italic numbers in brackets refer to the list of references appended to this paper.

A 212 steels. Transverse tension specimens were also prepared for the basic-oxygen A 212 steel. The room- and elevated-temperature tension tests on the basic-oxygen A 201 and A 212 steels were conducted at 75, 200, 400, 500, 600, 800, and 1000 F on 0.505-in.-diameter specimens with a 2-in. gage length. For the open-hearth A 201 and A 212 steels, the room- and elevated-temperature tension tests were conducted at these temperatures but on 0.250-in.-diameter specimens with a 1-in. gage length. Because elongation in 1 in. and reduction of area obtained on a 0.250-in.-diameter specimen are equivalent to the elongation in 2 in. and reduction of area of 0.505-in.-diameter tension specimens, the elongation and reduction-of-area values obtained for the basic-oxygen and open-hearth steels can be readily compared [*4*]. The tension tests were conducted in accordance with ASTM Recommended Practice for Short-Time Elevated-Temperature Tension Tests of Materials (E 21-58 T).

Longitudinal creep and creep-rupture test specimens were also machined from the midthickness of the 1-in.-thick plate both in the hot-rolled and in the normalized and tempered conditions. The creep and creep-rupture tests were conducted at 800, 900, and 1000 F on 0.252-in.-diameter specimens of the A 201 steel and on either 0.357- or 0.505-in.-diameter specimens of the A 212 steel. Both tests were conducted in accordance with Recommended Practice for Conducting Creep and Time for Rupture Tension Tests of Materials (E 139-58 T).

Metallographic studies were conducted on the steels before and after long-time creep and creep-rupture testing. The microstructures were examined after being etched both in nital and picral reagents to reveal primarily the ferrite and the pearlite structure, respectively.

RESULTS AND DISCUSSION

Tensile Properties of A 201 (Grade A) Steel:

The room- and elevated-temperature tensile properties are shown in Table 2 for basic-oxygen A 201 steels both in the hot-rolled and in the normalized and tempered conditions and in Table 3 for open-hearth A 201 steels in both conditions. The properties shown in Tables 2 and 3 are also shown graphically in Figs. 1-4. The modulus-of-elasticity data derived from the stress-strain curves are also presented in Table 2. In addition to the yield strength determined at 0.2 per cent offset of the stress-strain curve, the yield strength at 0.01 per cent offset was also determined for the basic-oxygen steel, Table 2. At the lower test temperatures (75, 200, and 400 F in the hot-rolled condition and 75, 200, 400, 500, and 600 F in the normalized and tempered condition), the yield strength determined at the 0.01 per cent offset was higher than the yield strength at the 0.2 per cent offset.

The higher values for the 0.01 per cent yield strength for these steels are due to the presence of both upper and lower yield points. The presence of an upper and lower yield point is due to an interaction of carbon and nitrogen with dislocations [5].

The curves showing the effect of test temperatures on the yield (0.2

per cent offset) and tensile strengths of the A 201 basic-oxygen and open-hearth steels are presented in Fig. 1 for the hot-rolled condition and in Fig. 2 for the normalized and tempered condition.

A comparison of the yield and tensile strengths for the basic-oxygen A 201 steel with the properties for the open-hearth A 201 steel, Figs. 1 and 2, indicates that their tensile properties are about the same with the exception that the yield strength of the hot-rolled open-hearth steel is somewhat higher than that of the basic-oxygen steel. Because of the scatter in tensile properties observed for most steels, the difference in the yield strength for the hot-rolled basic-oxygen and open-hearth A 201 steels is not significant.

As shown in Figs. 1 and 2, the tensile strength decreases first as the test temperature is increased from room temperature to 200 F, then increases to a maximum at 400 F, whereupon it decreases again with increasing temperature. The maximum tensile strength usually observed in the range 400 to 600 F is due to strain aging [6]. The temperature at which the maximum tensile strength occurs for a particular steel depends primarily on the strain rate during tension testing.

The yield-strength curves, Figs. 1 and 2, indicate that the yield strength decreased with increasing temperature above 400 F. However, in the range room temperatures to 400 F, the effect of temperature on the yield strength was not consistent. This inconsistent behavior is probably associated with strain aging.

The effect of temperature on the elongation and reduction of area for the two steels in the hot-rolled condition is shown in Fig. 3 and for both steels in the normalized and tempered condition in Fig. 4. These properties of the basic-oxygen A 201 and open-hearth A 201 steels do not differ significantly in the range 80 to 1000 F.

The elongation and reduction-of-area curves, Figs. 3 and 4, show minima at about 400 F, that is, at the same temperature at which the maximum in the tensile-strength curve occurs. For example, the elongation of the hot-rolled basic-oxygen A 201 steel, Fig. 3, decreases from 42 per cent at 75 F to 22 per cent at 400 F. As the test temperature is increased further the elongation increases to 52 per cent at 1000 F, the highest test temperature.

Tensile Properties of A 212 (Grade B) Steel:

The longitudinal and transverse room- and elevated-temperature tensile properties of the basic-oxygen A 212 steel in the hot-rolled condition and in the normalized and tempered conditions are shown in Tables 4 and 5. Shown in Table 6 are the longitudinal room- and elevated-temperature tensile properties for the open-hearth A 212 steel in the same conditions. The longitudinal tensile properties of basic-oxygen and open-hearth A 212 steel are shown graphically in Figs. 5-8.

The yield and tensile strength of the basic-oxygen A 212 steel both in the hot-rolled and in the normalized and tempered conditions are somewhat higher than those of the open-hearth steel. However, these differences are within the scatter normally observed in tensile-property data and are not considered significant.

The maximum tensile strength was observed in the expected temperature range (500 to 600 F) for the hot-rolled basic-oxygen and open-hearth A 212 steels. The maximum occurred at 500 F, Fig 5. For the normalized and tempered condition, Fig. 6, the temperature of the maximum was 600 F for the basic-oxygen steel and 500 F for the open-hearth steel. The yield-strength curves for the basic-oxygen and open-hearth A 212 steels in the hot-rolled condition, Fig. 5, reveal a maximum at about 500 F. This behavior probably is associated with strain aging. For the normalized and tempered basic-oxygen and open-hearth A 212 steels, Fig. 6, the yield-strength curves decrease continuously with increasing temperature.

The effect of temperature on the elongation and reduction of area for the two steels is depicted in Fig. 7 for the hot-rolled condition and in Fig. 8 for the normalized and tempered condition. For both conditions the elongation and reduction-of-area values for the open-hearth steel tended to be somewhat higher than those for the basic-oxygen steel. The higher ductility values for the open-hearth steel would be expected because of its lower yield and tensile strengths compared with those of the basic-oxygen steel.

The elongation and reduction-of-area curves show a minimum at about 500 F, approximately the same test temperature at which the maximum in the tensile-strength curve occurs.

Creep and Creep-Rupture Properties:

The results of creep and creep-rupture tests conducted in this investigation on basic-oxygen steels only are compared with the results previously reported by Miller [*2, 7*] and Worth [*3*].

Miller's paper contains 1000 F creep and creep-rupture test data for ASTM A 201 (Grade B) steel produced in accordance with both fine-grain and coarse-grain practice. These data were obtained on 1-in.-thick plate in the hot-rolled and stress-relieved condition. Worth's paper contains 800, 900, and 1000 F creep and creep-rupture test data for ASTM A 212 (Grade B) steel produced in accordance with coarse-grain practice. These data were obtained on 1-in.-thick plate in both the hot-rolled and stress-relieved condition and in the normalized and tempered condition along with 800, 900, and 1000 F creep and creep-rupture test data for 3-in.-thick plate in the normalized and tempered condition.

ASTM A 201 Steel: The 800, 900, and 1000 F creep and creep-rupture test data for the hot-rolled and for the normalized and tempered A 201 steels made by the basic-oxygen process are shown in Tables 7 and 8 and are plotted in Fig. 9-12. The 1000-hr creep-rupture strength for the hot-rolled A 201 steel at 800, 900, and 1000 F are 29,000, 16,000, and 9200 psi, respectively (Fig. 9). About the same properties were exhibited by the normalized and tempered A 201 steel (Fig. 10); the 800, 900, and 1000 F creep-rupture strengths are 30,000, 16,000, and 9000 psi, respectively.

Stress versus minimum creep-rate curves for the A 201 steel in the hot-rolled condition and in the normalized and tempered condition are shown in Figs. 11 and 12. For the 800, 900, and 1000 F, the stresses for a creep rate of 0.0001 per cent per hr for the hot-rolled steel are 23,000, 6600, and 3700 psi, respectively, compared with 23,000, 8500, and 4600 psi for the normalized and tempered steel. Many of the strain-versus-time curves from which the minimum creep rates were derived exhibited changes in slope during second-stage creep [*8*]. These changes in slope made it difficult to establish accurate minimum creep rates; hence, the observed differences in creep strength for the hot-rolled and for the normalized and tempered A 201 steels probably do not represent true differences in the creep strength of the steels.

The 1000 F creep and creep-rupture test data for six heats of A 201 (Grade B) open-hearth steel are plotted along with the data obtained on the A 201 basic-oxygen steel (Grade A) in the present investigation, Fig. 13. The only difference between the A 201 Grades A and B steels is the somewhat higher room-temperature yield and tensile strengths of Grade B. The time-to-rupture and minimum creep data for the basic-oxygen A 201 (Grade A) steel may be, therefore, compared with the data for the open-hearth A 201 (Grade B) steel. For both steelmaking processes the creep and creep-rupture data are within a single scatter band, an indication that the creep and creep-rupture properties of the basic-oxygen and open-hearth A 201 steels are the same at 1000 F.

ASTM A 212 Steel: The 800, 900, and 1000 F creep and creep-rupture test data for the hot-rolled and for the normalized and tempered A 212 steel are shown in Tables 9 and 10 and are plotted in Figs. 14-16. For the hot-rolled steel, at 800, 900, and 1000 F, the 1000-hr creep-rupture strengths are 37,000, 20,000, and 11,000 psi, respectively, (Fig. 14), compared with 41,000, 25,000, and 11,000 psi, respectively, for the normalized and tempered material (Fig. 15). For the same steel made by the same process and heat-treated in the same way, the differences in creep-rupture strength between the A 212 steel in the hot-rolled and in the normalized and tempered conditions are not considered significant.

The stress versus minimum creep-rate curves for the A 212 steel in the normalized and tempered and in the hot-rolled conditions, Fig. 16, were derived from combined data for these conditions. The limited number of test points available made it impossible to accurately define a curve when the data for each condition were plotted separately. The stresses for a creep rate of 0.0001 per cent per hr for the hot-rolled and for the normalized and tempered A 212 steel at 800, 900, and 1000 F are 25,000, 10,000, and 4300 psi, respectively.

A comparison between the 800, 900, and 1000 F creep-rupture test data for the basic-oxygen and the open-hearth A 212 steels, Fig. 17, reveals a single scatterband for both steelmaking practices.

Similarly, a single scatterband is obtained when plotting the creep-test data for the A 212 steel (tested at 800, 900, and 1000 F) made by the basic-oxygen and the open-hearth steelmaking processes, Fig. 18. Thus, the creep and creep-rupture properties of A 212 steel made by the basic-oxygen and by the open-hearth steelmaking processes are equivalent.

Summary of the Creep and Creep-Rupture Properties of the Basic-Oxygen ASTM A 201 and A 212 Steels: The results of these creep and creep-rupture tests are summarized in Table 11. These data indicate that the creep and creep-rupture strengths for the A 212 steel are generally superior to that of the A 201 steel. For example, the 1000-hr creep-rupture strengths for the hot-rolled A 201 steel at 800, 900, and 1000 F are 29,000, 16,000, and 9200 psi, respectively, whereas the 1000-hr creep-rupture strength for the hot-rolled A 212 steel are 37,000, 20,000, and 11,000 psi, respectively. The higher creep and creep-rupture strengths of the A 212 steel are expected because of the higher carbon content of the A 212 steel.

Metallographic Studies:

The microstructure of the hot-rolled A 201 steel before and after creep-rupture testing are shown in Figs. 19 and 20. The photomicrographs shown in Fig. 19 were obtained on samples that were etched in picral reagent, and those in Fig. 20 were obtained on the same samples after being repolished and etched in nital reagent.

The initial microstructure of the steel consisted of ferrite and pearlite, Fig. 19*a*. After long-time testing (4478.1 hr) at 800 F, Fig. 19*b*, some of the fine detail in the pearlite lamella is lost because of some agglomeration of the carbide platelets. The microstructure after 900 F (3663.1 hr) testing, Fig. 19*c*, is similar to the 800 F microstructure except that agglomeration has progressed to much greater extent than at 800 F. After long-time testing at 1000 F (3816 hr), Fig. 19*d*, spheroidization and graphitization have occurred. The formation of graphite [9] in carbon steel of similar carbon content has been observed previously at 1000 F.

The same microstructures are shown in Figs. 20*a*, *b*, *c*, and *d* but etched with nital reagent; these photomicrographs show the development of a substructure in the ferrite after long-time testing at 800, 900, and 1000 F. The formation [*10*] of a substructure is often observed after creep-rupture testing and is due to dislocation climb during high-temperature deformation.

The microstructures of the normalized and tempered A 201 steel before and after long-time creep-rupture testing at 800, 900, and 1000 F, Figs. 21*a*, *b*, *c*, and *d*, were about the same as those of the hot-rolled material.

Microstructural studies were conducted on the hot-rolled and normalized and tempered A 212 steel, Figs. 22 and 23. As was true for the A 201 steel, the microstructure of the steel before exposure consisted of ferrite and pearlite, Figs. 22*a* and 23*a*. Some of the ferrite is present in a Widmanstätten pattern. For the hot-rolled material, long-time exposure at 800 F (2878.8 hr) and 900 F 876 hr) resulted in some agglomeration of the carbides in the pearlite, Figs. 22*b* and *c*. As would be expected, the tendency for agglomeration was much greater at 900 F than at 800 F. After long-time testing of the hot-rolled material at 1000 F (1354.5 hr), Fig. 22*d*, appreciable agglomeration had occurred. However, compared with the hot-rolled material, the extent of the agglomeration is much less for the normalized and tempered material after 4500 hr at 800, 900, and 1000 F, Figs. 23*b*, *c*, and *d*. The difference in the tendency to agglomerate is due to the large difference in the amount of deformation that occurred during creep and creep-rupture testing. The normalized and tempered A 212 steel specimens were tested for longer times but at relatively low stresses resulting in little deformation (these tests were designed to obtain creep data only), whereas the hot-rolled steel specimens were tested at stresses resulting in rupture. Because deformation accelerates microstructural changes, more agglomeration of the hot-rolled A 212 steel is expected.

As was true for the A 201 steel, by repolishing and etching these A 212 steel specimens in nital reagent, a substructure was observed in the hot-rolled specimens after long-time testing at 800, 900, and 1000 F. As would be expected, because of the small amount of deformation that occurred during the creep tests, no substructure was detected in the normalized and tempered A 212 steel.

A comparison of the microstructures of the A 201 and A 212 steels after long-time exposure indicates that the changes in microstructure were greater for the A 201 steel. For example, despite the higher carbon content (0.29 per cent) of the A 212 steel compared with that (0.15 per cent) of the A 201 steel, no graphite was formed in the A 212 steel. The differences in the microstructural changes may be the result of the differences in the exposure condition for the A 212 steel. As was already mentioned, the hot-rolled A 201 steel was tested for longer times than the hot-rolled A 212 steel. Although the exposure times were similar for the normalized and tempered material, the A 201 steel was tested under high stresses that resulted in extensive deformation, whereas specimens of the A 212 steel were tested under low stresses, and, consequently, the amount of deformation was very small.

Supplementary Testing:

The Appendix shows the results of supplementary tests conducted by Kaiser Steel Corp. on the basic-oxygen and open-hearth A 201 and A 212 steels used in the investigation of the elevated-temperature properties of these steels. The results presented in the Appendix may be summarized as follows:

1. The longitudinal and transverse room-temperature tensile properties of the basic-oxygen and open-hearth A 201 and A 212 steels in the hot-rolled and in the normalized and tempered conditions are shown in Tables 12 and 13. These results show that the steels investigated exhibit the tensile properties required by the pertinent ASTM specifications. A

comparison of the tensile properties of the two steels made by the basic-oxygen process with those of the open-hearth steels indicates that the tensile properties are essentially the same.

2. The results of standard longitudinal and transverse Charpy V-notch impact tests conducted in the range —10 to 110 F are shown graphically in Figs. 24-39. From the curves presented in these figures showing the effect of test temperature on the energy absorbed and the per cent shear fracture, the transition temperatures at the 15 ft-lb energy absorption level and at 50 per cent shear fracture were obtained. These transition temperatures are shown in Table 14 for the A 201 steel and in Table 15 for the A 212 steel. A comparison of the transition temperatures for the basic-oxygen with the open-hearth A 201 and A212 steels in the hot-rolled condition and in the normalized and tempered condition indicates that the transition temperatures generally are not markedly affected by the steelmaking process. The generally lower transition temperatures of these steels in the normalized and tempered condition compared with the hot-rolled condition are a result of the smaller grain size of the normalized and tempered material.

3. The results of ferrite and austenite grain-size measurements for the A 201 and A 212 basic-oxygen and open-hearth steels, Table 16, are typical for these steels made in accordance with coarse-grain practice. The ferrite-grain size of the hot-rolled A 201 and A 212 steels is larger than that of the steels in the normalized and tempered condition. The differences in grain size for the two conditions are due to grain refinement that occurred when these steels were normalized.

4. The results of tension and impact tests on the hot-rolled basic-oxygen and open-hearth A 201 and A 212 steels that had been strain-aged are shown in Table 17. The strain-aging treatment consisted of elongating the steel 10 per cent at room temperature and aging the steel at 450 F for 2 hr. A comparison of the tension and impact test results indicates that the strain-aging characteristics of the steels made by the basic-oxygen or open-hearth process are about the same.

5. The results of welding-qualification tests conducted in accordance with the procedures outlined by the American Soc. Mechanical Engrs. (ASME) Boiler and Pressure Vessel Code, Section IX, Welding Qualifications, are shown in Table 18. The results of macroetch, tension, and bend tests on plates welded by the manual shielded-metal arc process with American Welding Soc. (AWS) E7018 electrodes indicate that the performance of such a weld in the basic-oxygen A 201 and A 212 steels is satisfactory by the ASME standards and equivalent to that customarily observed with these steels made by the open-hearth process.

6. The results of homogeneity and bend tests conducted in accordance with ASTM General Requirements for the Delivery of Rolled Steel Plates of Flange and Firebox Qualities (A 20-63T) indicate that the material met all the qualification requirements set forth by this specification. The results of the homogeneity and bend tests are shown in Figs. 40-42.

SUMMARY AND CONCLUSIONS

An investigation has been conducted to compare the mechanical properties of steels made by either the basic-oxygen or open-hearth process. The results of this investigation and information available from previous investigations indicate that the basic-oxygen A 201 and A 212 steels in the hot-rolled condition and in the normalized and tempered condition in comparison with the steels made by the open-hearth process have about the same tensile properties in the range 80 to 1000 F, notch toughness in the range —10 to 110 F, and creep and creep-rupture properties in the range 800 to 1000 F. In addition, the strain-aging characteristics and the weldability of the A 201 and A 212 steels made by the two processes are similar.

REFERENCES

[1] *Comparison of the Properties of Basic-Oxygen and Open Hearth Steels, ASTM STP 364,* Am. Soc. Testing Mats., 1963.

[2] R. F. Miller, "The Strength of Carbon Steels for Elevated-Temperature Applications," *Proceedings,* Am. Soc. Testing Mats., Vol. 54, 1954, pp. 964-986.

[3] J. S. Worth, "Report of Project SP-4 to Steam Power Panel of the ASME-ASTM Joint Committee on the Effect of Temperature on the Properties of Metals," *Paper No. 59-MET-12,* Am. Soc. Mechanical Engrs., 1959.

[4] G. E. Dieter, Jr., *Mechanical Metallurgy,* McGraw-Hill Book Co., Inc., New York, N.Y., 1961, p. 253.

[5] A. H. Cottrell, *Theoretical Structural Metallurgy,* Edward Arnold, Ltd., London, 1955, pp. 242-243.

[6] G. V. Smith, *Properties of Metals at Elevated Temperatures,* McGraw-Hill Book Co., Inc., New York, N.Y., 1950, pp. 337-338.

[7] *Elevated Temperature Properties of Carbon Steels, ASTM STP 180,* Am. Soc. Testing Mats., 1955.

[8] D. L. Newhouse, Discussion of R. F. Miller paper, Ref. *2.*

[9] C. D. Dickinson, R. Jackowski, and J. W. Freeman, Discussion of R. F. Miller paper, Ref. *2.*

[10] G. Schoeck, "Theories of Creep," *Mechanical Properties of Materials at Elevated Temperatures,* J. H. Dorn, editor, McGraw-Hill Book Co., Inc., New York, N.Y., 1961, pp. 85-87.

TABLE 1—CHEMICAL COMPOSITION REPORTED BY KAISER STEEL FOR ASTM A 201 (GRADE A) AND A 212 (GRADE B) STEELS INVESTIGATED, PER CENT.

Heat	Steel	Steelmaking Process	C	Mn	P	S	Si	Cu	Ni	Cr	V	Mo	Al	N
						LADLE ANALYSES								
310453	A 201	basic oxygen	0.13	0.51	0.007	0.019	0.19	0.07	...	...	...	...	...	...
42835	A 201	open hearth	0.14	0.54	0.009	0.025	0.19	0.07	...	...	...	...	...	...
209939	A 212	basic oxygen	0.28	0.78	0.016	0.014	0.25	0.08	...	...	...	...	...	...
88244	A 212	open hearth	0.26	0.76	0.009	0.025	0.22	0.08	...	...	...		...	...
						CHECK ANALYSES								
314053	A 201	basic oxygen	0.15	0.51	0.008	0.022	0.19	0.13	0.01	0.010	0.005	0.005	0.005	0.004
42835	A 201	open hearth	0.15	0.50	0.011	0.031	0.19	0.07	0.01	0.028	0.005	0.005	0.005	0.007
209939	A 212	basic oxygen	0.29	0.80	0.009	0.016	0.25	0.12	0.01	0.011	0.005	0.005	0.005	0.006
88244	A 212	open hearth	0.29	0.78	0.018	0.027	0.23	0.07	0.02	0.027	0.005	0.005	0.005	0.007
						ANALYSIS[a] REQUIRED BY PERTINENT ASTM SPECIFICATION								
	A 201	....	0.20 max	0.80 max	0.035 max	0.04 max	0.13 to 0.33							
	A 212	....	0.31 max	0.80 max	0.035 max	0.04 max	0.13 to 0.33							

[a] Firebox-quality steel.

TABLE 2—LONGITUDINAL ROOM- AND ELEVATED-TEMPERATURE TENSILE PROPERTIES REPORTED BY THE AMERICAN OIL CO. FOR ASTM A 201 STEEL (GRADE A) MADE BY THE BASIC-OXYGEN PROCESS, HEAT 310453.

Test Temperature, F	Yield Strength 0.01% Offset, psi	Yield Strength 0.2% Offset, psi	Tensile Strength, psi	Elongation in 2 in., per cent	Reduction of Area, per cent	Modulus of Elasticity, millions of psi
			HOT-ROLLED CONDITION			
75	34 300	33 100	60 700	42	65	31.4
200	31 500	30 500	58 700	29	62	29.0
400	31 400	29 900	74 200	22	48	27.7
500	26 200	26 700	73 800	32	52	27.3
600	19 400	23 000	66 000	38	63	28.0
800	14 200	21 700	47 800	47	74	25.6
1000	12 000	17 800	28 600	52	72	18.6
			NORMALIZED AND TEMPERED CONDITION			
75	39 200	38 000	61 200	42	67	33.0
200	35 800	34 000	59 000	31	64	30.0
400	33 800	30 400	72 100	24	56	30.0
500	30 400	29 000	71 000	36	60	25.6
600	22 500	22 400	65 600	40	65	25.8
800	15 700	19 800	47 400	46	77	24.2
1000	11 200	16 300	27 900	64	85	19.2

NOTE—1. These results are the averages of duplicate tests.

2. The steel was normalized at 1625 F for 1 hr and then tempered at 1150 F for 1 hr.

3. The modulus of elasticity was determined from the stress-strain curve.

TABLE 3—LONGITUDINAL ROOM- AND ELEVATED-TEMPERATURE TENSILE PROPERTIES REPORTED BY JONES & LAUGHLIN STEEL CORP. FOR ASTM A 201 STEEL (GRADE A) MADE BY THE OPEN-HEARTH PROCESS, HEAT 42835.

Test Temperature, F	Yield Strength 0.2% Offset psi	Tensile Strength, psi	Elongation in 1 in., per cent	Reduction of Area, per cent
		HOT-ROLLED CONDITION		
75	32 600	60 100	38	65
200	33 300	58 900	24	64
400	33 300	77 400	22	51
500	32 800	74 000	28	51
600	29 800	68 100	33	61
800	29 500	48 500	40	73
1000	21 100	30 300	51	70
		NORMALIZED AND TEMPERED CONDITION		
75	36 500	61 100	45	68
200	34 000	59 900	28	63
400	35 000	75 900	22	50
500	28 300	74 100	30	53
600	25 300	68 300	35	61
800	22 400	48 600	47	76
1000	17 200	30 600	50	81

NOTE—1. These results are based on single tests.
2. The steel was normalized at 1625 F for 1 hr and then tempered at 1150 F for 1 hr.

TABLE 4—LONGITUDINAL ROOM- AND ELEVATED-TEMPERATURE TENSILE PROPERTIES REPORTED BY ARMCO STEEL CORP. FOR ASTM A 212 STEEL (GRADE B) MADE BY THE BASIC-OXYGEN PROCESS, HEAT 209939.

Test Temperature, F	Yield Strength 0.2% Offset, psi	Tensile Strength, psi	Elongation in 2 in., per cent	Reduction of Area, per cent
		HOT-ROLLED CONDITION		
75	40 400	87 500	30	53
200	38 300	81 800	27	53
400	44 300	92 500	18	38
500	45 600	95 700	14	30
600	43 200	94 800	21	30
800	39 400	76 800	27	63
1000	31 600	49 900	28	66
		NORMALIZED AND TEMPERED CONDITION		
75	46 900	84 100	32	56
200	43 800	78 700	30	56
400	42 000	90 100	19	41
500	40 700	91 800	18	37
600	38 700	92 600	26	44
800	34 100	73 600	29	67
1000	27 100	47 300	37	84

NOTE—1. The above values are the averages of duplicate tests.
2. The steel was normalized at 1625 F for 1 hr and then tempered at 1150 F for 1 hr.

TABLE 5—TRANVERSE ROOM- AND ELEVATED-TEMPERATURE TENSILE PROPERTIES REPORTED BY ARMCO STEEL CORP. FOR ASTM A 212 (GRADE B) STEEL MADE BY THE BASIC-OXYGEN PROCESS, HEAT 209939.

Test Temperature, F	Yield Strength 0.2% Offset, psi	Tensile Strength, psi	Elongation in 2 in., per cent	Reduction of Area, per cent
	HOT-ROLLED CONDITION			
75	43 900	86 800	29	50
200	41 800	81 700	26	51
400	44 100	90 800	17	36
500	44 000	92 800	13	32
600	43 500	93 800	22	30
800	40 600	76 400	25	60
1000	32 300	48 700	27	61
	NORMALIZED AND TEMPERED CONDITION			
75	42 200	83 100	33	53
200	42 400	78 200	29	54
400	41 900	89 300	18	37
500	42 200	92 100	18	35
600	39 700	91 600	25	42
800	40 200	72 000	28	63
1000	30 000	46 700	36	81

NOTE—1. The above results are the averages of duplicate tests.
2. The steel was normalized at 1625 F for 1 hr and then tempered at 1150 F for 1 hr.

TABLE 6—LONGITUDINAL ROOM- AND ELEVATED-TEMPERATURE TENSILE PROPERTIES REPORTED BY JONES & LAUGHLIN STEEL CORP. FOR ASTM A 212 STEEL (GRADE B) MADE BY THE OPEN-HEARTH PROCESS, HEAT 88244.

Test Temperature, F	Yield Strength 0.2% Offset psi	Tensile Strength, psi	Elongation in 1 in., per cent	Reduction of Area, per cent
	HOT-ROLLED CONDITION			
75	39 100	78 000	29	58
200	36 300	74 200	26	57
400	39 200	88 100	17	37
500	42 900	91 000	20	33
600	37 400	83 600	27	43
800	34 300	65 100	29	64
1000	27 800	41 600	28	49
	NORMALIZED AND TEMPERED CONDITION			
75	43 900	76 800	32	59
200	42 300	71 600	28	59
400	40 100	85 600	19	45
500	34 300	88 500	23	43
600	30 300	80 200	29	54
800	30 900	64 900	34	70
1000	24 600	39 900	41	74

—NOTE—1. These results are based on single tests.
2. The steel was normalized at 1625 F for 1 hr and then tempered at 1150 F for 1 hr.

TABLE 7—CREEP AND CREEP-RUPTURE TEST DATA REPORTED BY U. S. STEEL FOR HOT-ROLLED BASIC-OXYGEN ASTM A 201 STEEL, HEAT 310453.

Test Temperature, F	Stress, psi	Time to Rupture, hr	Elongation in 1 in., per cent	Reduction of Area, per cent	Minimum Creep Rate, per cent per hr
800	40 000	5.7	34	61	...
	35 000	140.1	38	69	...
	35 000	194.4	31	58	0.049
	30 000	1784.8	40	67	0.00294
	25 000	4478.1	40	73	0.00042
900	25 000	25.3	51	80	...
	20 000	216.0	52	80	0.038
	15 000	1942	56	75	0.0081
	13 000	3663.1	50	74	...
	10 000	(4000)	test in progress		0.00094
	7 000	...[a]	...	...	0.00020
1000	15 000	40.5	65	87	...
	12 000	219.3	70	82	0.061
	9 000	1204.6	62	75	...
	7 000	3816	56	67	0.00126
	5 000	(6340)	test in progress		0.00050
	3 500	...[a]	...	...	0.00008

[a] Test discontinued after 4000 hr.

TABLE 8—CREEP AND CREEP-RUPTURE TEST DATA REPORTED BY U. S. STEEL FOR NORMALIZED AND TEMPERED BASIC-OXYGEN ASTM A 201 STEEL, HEAT 310453.

Test Temperature, F	Stress, psi	Time to Rupture, hr	Elongation in 1 in., per cent	Reduction of Area, per cent	Minimum Creep Rate, per cent per hr
800	40 000	50	30	54	...
	35 000	249.2	30	60	0.025
	30 000	2159.9	36	70	0.00194
	25 000	3900	46	74	0.00044
900	25 000	59.3	43	73	...
	20 000	278.8	48	77	0.0271
	15 000	1610	45	73	0.0118
	12 000	4740.7	50	72	0.00095
	10 000	4000	test in progress		0.00036
1000	15 000	25	60	83	...
	10 000	594.6	67	77	0.014
	7 000	3989.6	50	66	0.00284
	5 000	5973	test in progress		0.000105

NOTE—The steel was normalized at 1625 F for 1 hr and then tempered at 1150 F for 1 hr.

TABLE 9—CREEP AND CREEP-RUPTURE TEST DATA REPORTED BY BETHLEHEM STEEL CO. AND AMERICAN OIL CO. FOR HOT-ROLLED BASIC-OXYGEN ASTM A 212 STEEL, HEAT 209939.

Test Temperature, F	Stress, psi	Time to Rupture, hr	Elongation in 1.5 in., per cent	Reduction of Area, per cent	Minimum Creep Rate, per cent per hr
		BETHLEHEM STEEL CO. DATA			
800	60 000	0.5	26	64	...
	50 000	19	16	33	...
	48 000	251	23	46	...
	45 000	295	22	58	...
	44 000	318	21	50	...
	40 000	799	23	57	...
	35 000	1782	15	53	...
		AMERICAN OIL CO. DATA			
800	30 000	2878.8	56[a]	62	0.0005
	20 000	(6000)	test in progress		0.000064
	16 000	(6000)	test in progress		0.000038
		BETHLEHEM STEEL CO. DATA			
900	45 000	2.4	27	40	...
	45 000	4.9	13	34	...
	40 000	26	17	45	...
	35 000	40	19	57	...
	28 000	126	19	63	...
	25 000	208	15	38	...
	23 000	621	20	57	...
		AMERICAN OIL CO. DATA			
900	25 000	234.6	62[a]	70	0.011
	20 000	876	61[a]	68	0.0028
	13 000	(6000)	test in progress		0.0005
		BETHLEHEM STEEL CO. DATA			
1000	23 000	13	34	78	...
	20 000	36	34	74	...
	15 000	214	36	79	...
	10 000	2105	41	69	...
		AMERICAN OIL CO. DATA			
1000	10 000	1354.5	86[a]	89	0.002
	4 500	(6000)	test in process		0.00012

[a] Elongation in 2 in.

NOTE—The American Oil Co. tests were conducted on 0.505-in.-diameter specimens, and the Bethlehem Steel Co. tests were conducted on 0.357-in.-diameter specimens.

TABLE 10—CREEP AND CREEP-RUPTURE TEST DATA REPORTED BY THE BETHLEHEM STEEL CO. FOR NORMALIZED AND TEMPERED BASIC-OXYGEN ASTM A 212 STEEL, HEAT 209939.

Test Temperature, F	Stress, psi	Time to Rupture, hr	Elongation in 1.5 in., per cent	Reduction of Area, per cent	Minimum Creep Rate, per cent per hr
800	55 000	4	27	64	...
	55 000	31	29	55	...
	50 000	92	27	48	...
	45 000	486	29	60	...
	43 000	577	31	62	...
	25 000	(2000)[a]	...	...	0.00009
	25 000	(2000)[a]	...	...	(0.00024)[b]
	20 000	(2500)[a]	...	...	(0.00004)[b]
900	45 000	1	30	69	...
	35 000	39	23	65	...
	30 000	195	43	76	...
	28 000	340	41	77	...
	13 000	(2000)	...	...	0.00060
	13 000	(2000)	...	...	(0.00050)[c]
	10 000	(2500)	...	...	(0.00010)[c]
1000	30 000	1.7	32	76	...
	20 000	42	31	83	...
	20 000	51	30	79	...
	15 000	242	37	79	...
	12 500	476	47	62	...
	12 000	601	38	81	...
	4 500	(2000)	...	...	0.00017
	4 500	(4500)	...	...	0.00019

[a] These creep tests were discontinued after test times between 2000 and 4500 hr.

[b] The creep results were obtained by conducting the creep tests at a stress of 20,000 psi for 2500 hr and then increasing the stress to 25,000 psi for 2000 hr.

[c] The creep results were obtained by conducting the creep tests at a stress of 10,000 psi for 2500 hr and then increasing the stress to 13,000 psi for 2000 hr.

NOTE—1. The time in parenthesis indicates the approximate duration of the creep tests.

2. The steel was normalized at 1625 F for 1 hr and then tempered at 1150 F for 1 hr.

3. The creep tests were conducted on 0.505-in.-diameter specimens, and the creep-rupture tests were conducted on 0.357-in.-diameter specimens.

TABLE 11—A SUMMARY OF THE CREEP- AND CREEP-RUPTURE PROPERTIES OF ASTM A 201 AND A 212 STEELS MADE BY THE BASIC-OXYGEN PROCESS.

Steel	Condition	Test Temperature, F	Stress for Rupture, psi			Stress for Minimum Creep Rate, psi	
			1000 hr	10,000 hr[a]	100,000 hr[a]	0.0001% hr	0.00001% hr[a]
A 201...........	hot-rolled	800	29 000	23 000	8 000	23 000	19 500
		900	16 000	11 500	8 200	6 600	4 400
		1000	9 200	6 200	4 100	3 700	2 500
		800	30 000	23 000	18 000	23 000	19 500
	normalized and tempered	900	16 000	11 000	7 000	8 500	6 000
		1000	9 000	6 400	4 500	4 600	3 200
A 212...........	hot-rolled	800	37 000	25 000	17 000	25 000[c]	...[b]
		900	20 000	13 500	9 200	10 000[c]	...[b]
		1000	11 000	7 400	5 000	4 300[c]	...[b]
	normalized and tempered	800	41 000	35 000	...[b]	25 000[c]	...[b]
		900	25 000	19 000	...[b]	10 000[c]	...[b]
		1000	11 000	7 500	...[b]	4 300[c]	...[b]

[a] Extrapolated values.
[b] Insufficient data.
[c] Based on combined data of hot-rolled and normalized product.

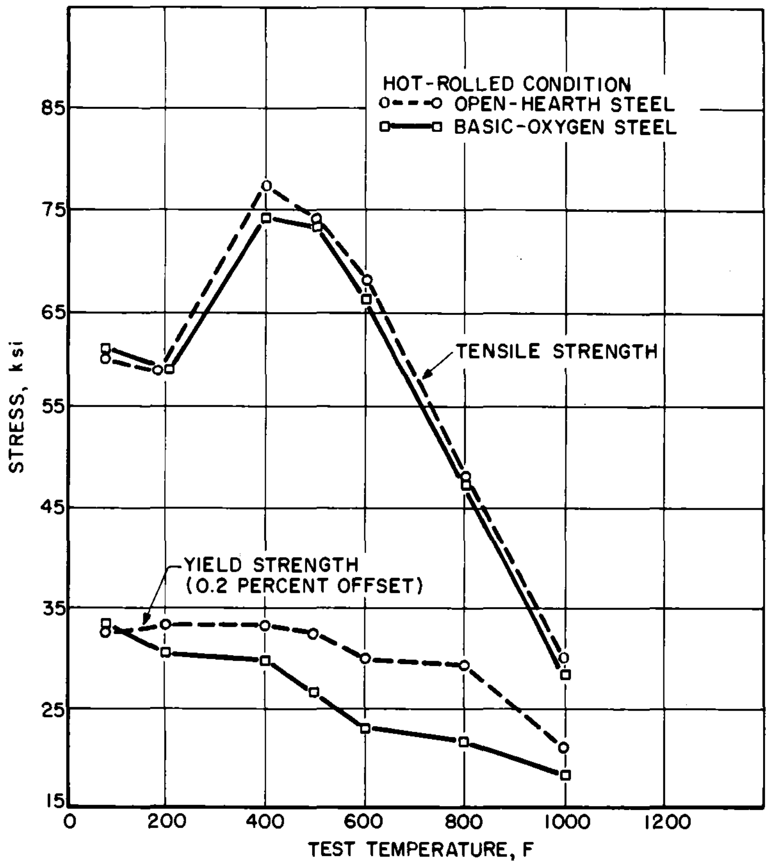


FIG. 1—Effect of testing temperature on the longitudinal yield and tensile strengths of hot-rolled ASTM A 201 steel produced by the basic-oxygen and open-hearth processes.

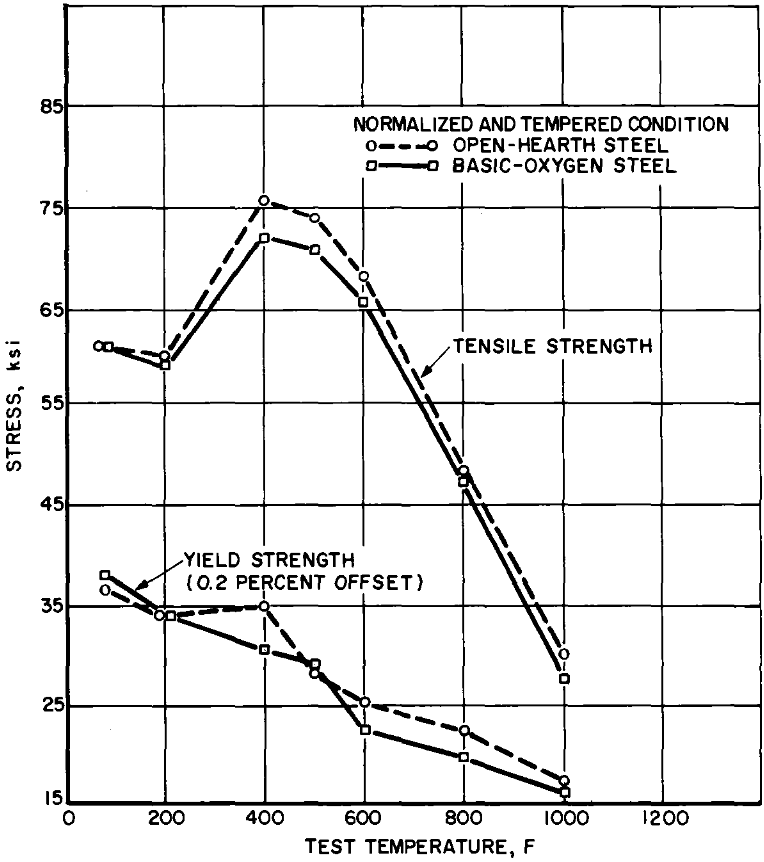


FIG. 2—Effect of testing temperature on the longitudinal yield and tensile strengths of normalized and tempered ASTM A 201 steel produced by the basic-oxygen and open-hearth processes.

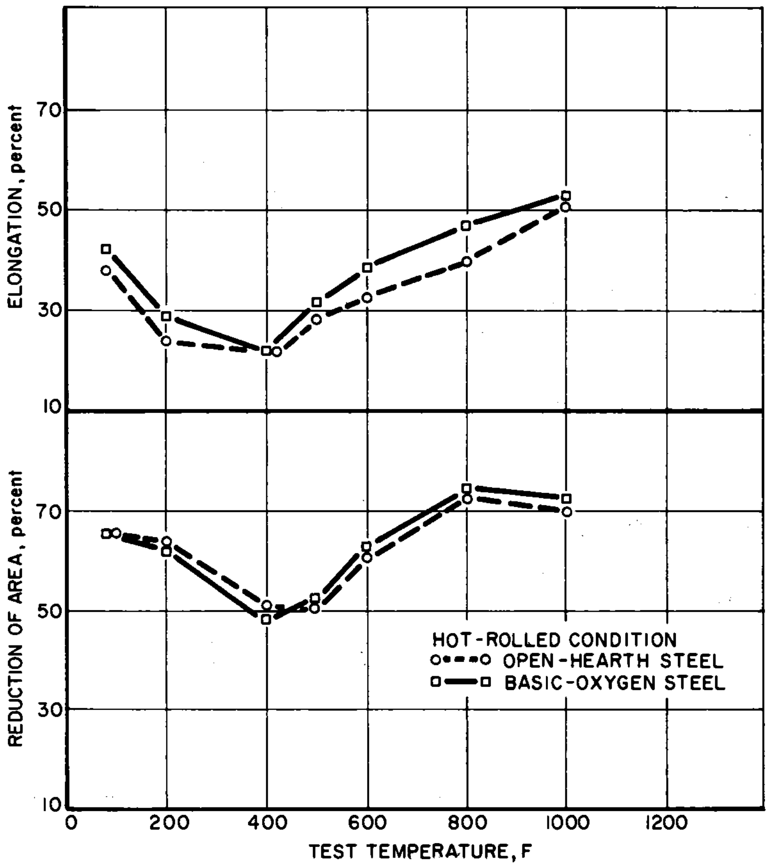


FIG. 3—Effect of testing temperature on the longitudinal elongation and reduction of area of hot-rolled A 201 steel made by the basic-oxygen and open-hearth processes.

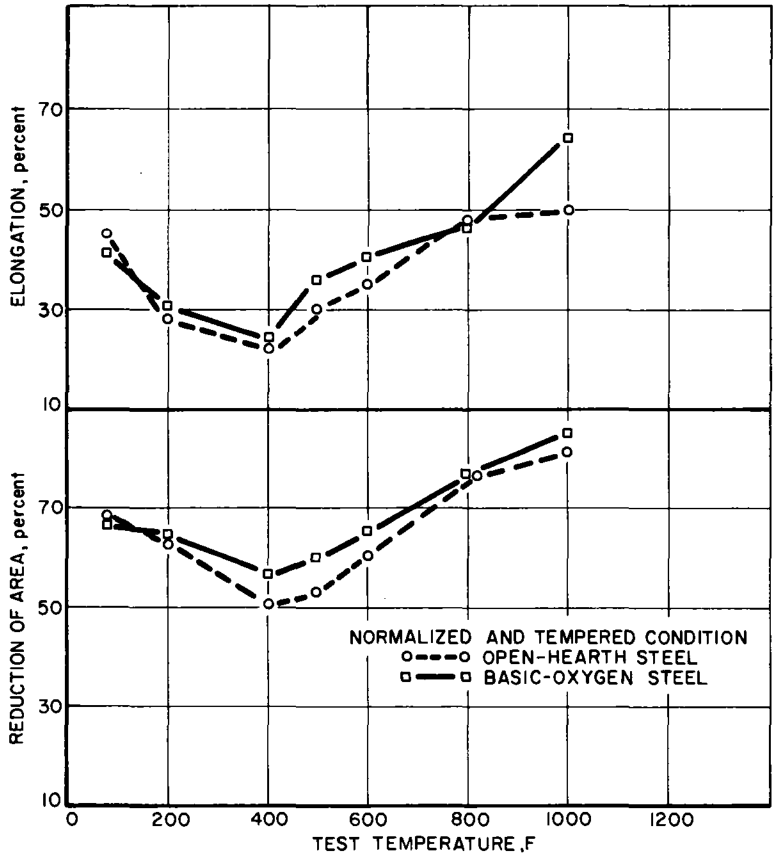


FIG. 4—Effect of testing temperature on the longitudinal elongation and reduction of area of normalized and tempered A 201 steel produced by the basic-oxygen and open-hearth processes.

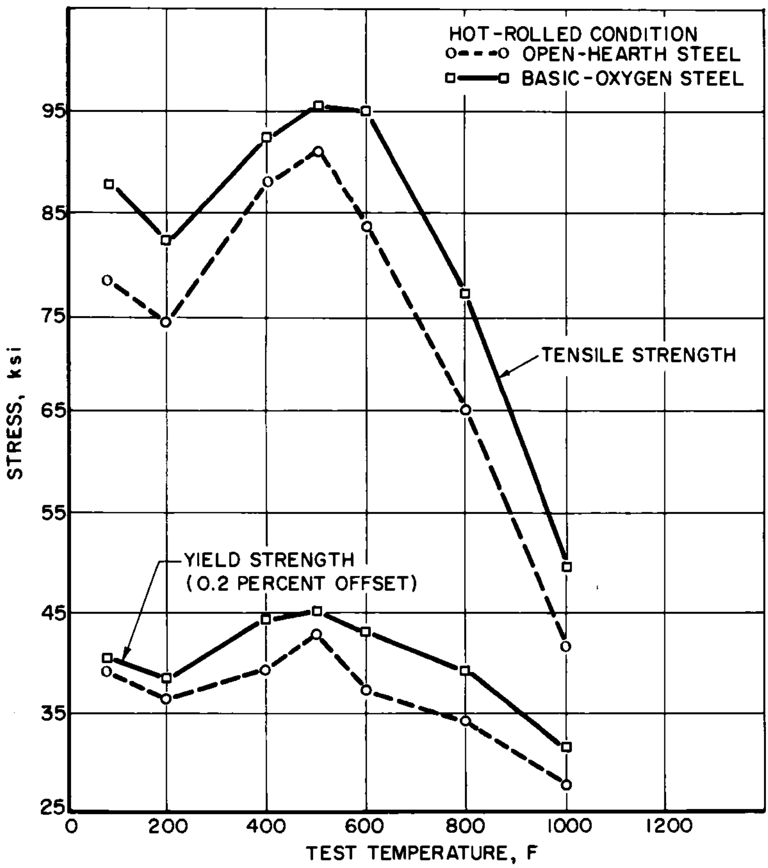


FIG. 5—Effect of testing temperature on the longitudinal yield and tensile strengths of hot-rolled ASTM A 212 steel produced by the basic-oxygen and open-hearth processes.

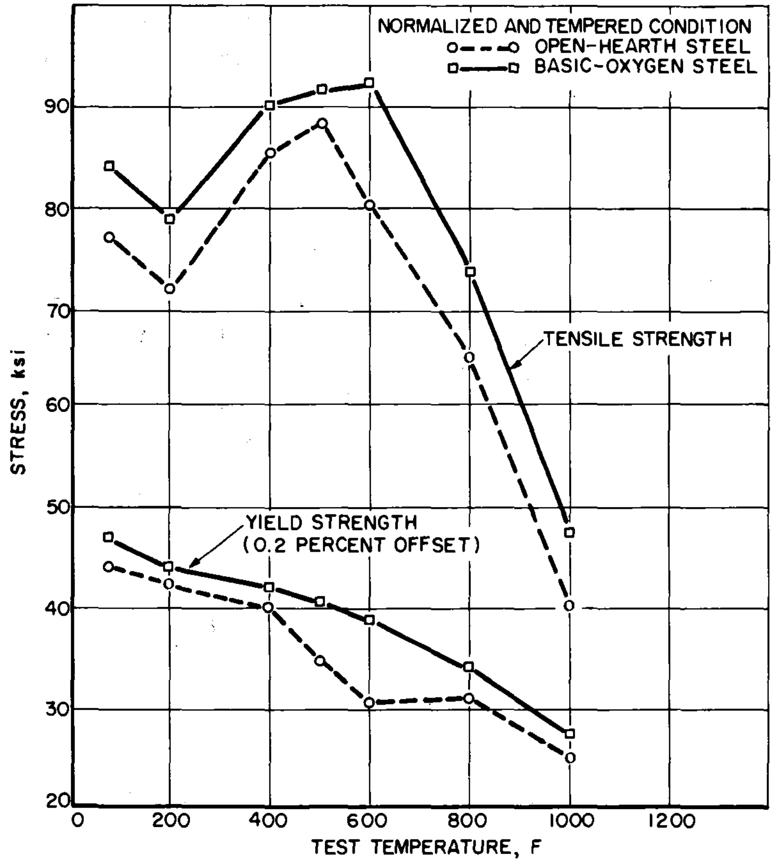


FIG. 6—Effect of testing temperature on the longitudinal yield and tensile strengths of normalized and tempered ASTM A 212 steel produced by the basic-oxygen and open-hearth processes.

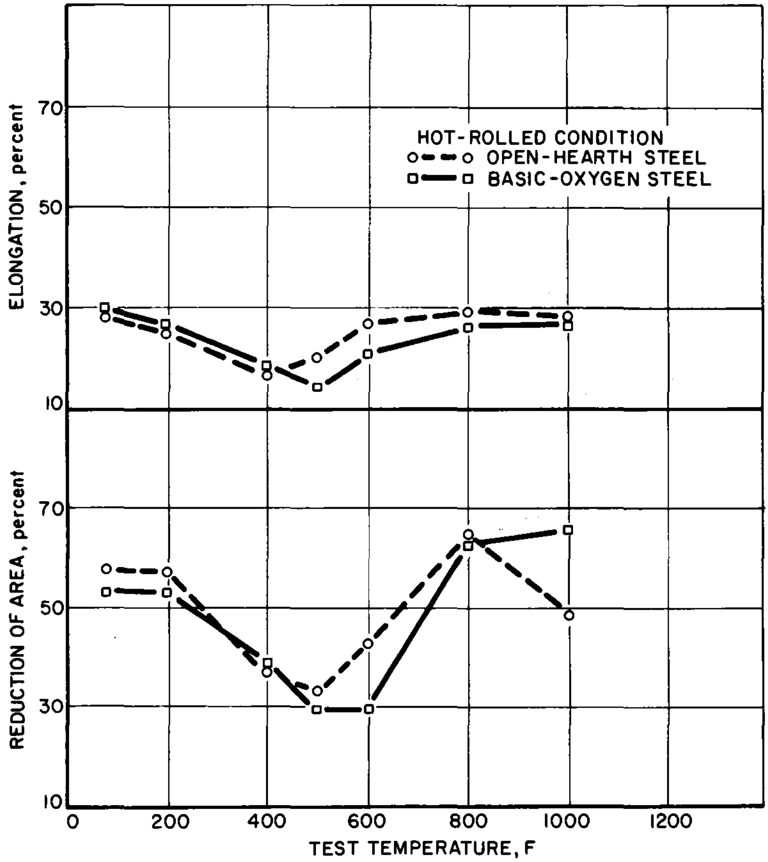


FIG. 7—Effect of testing temperature on the longitudinal elongation and reduction of area of hot-rolled A 212 steel made by the basic-oxygen and open-hearth processes.

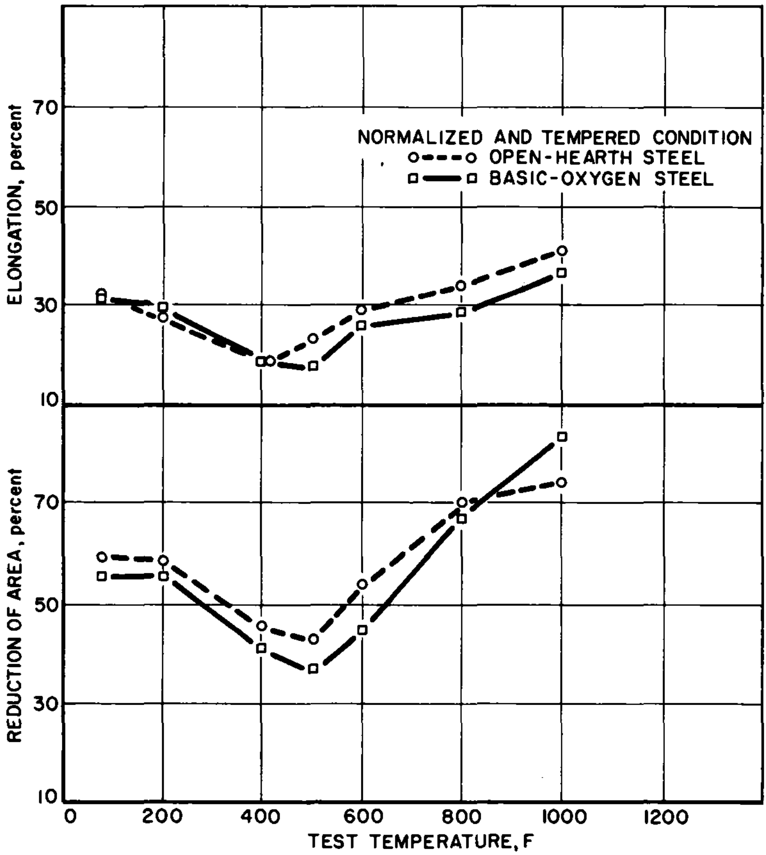


FIG. 8—Effect of testing temperature on the longitudinal elongation and reduction of area of normalized and tempered A 212 steel made by the basic-oxygen and open-hearth processes.

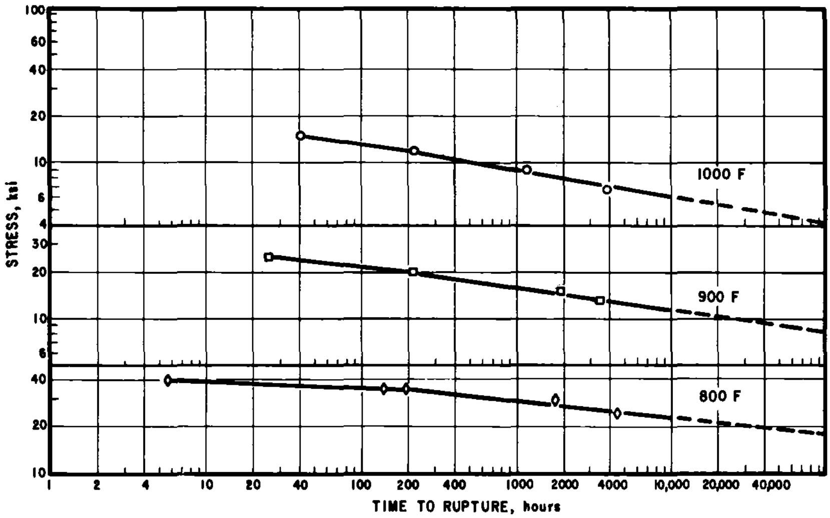


FIG. 9—Stress versus time to rupture for hot-rolled ASTM A 201 steel made by the basic-oxygen process.

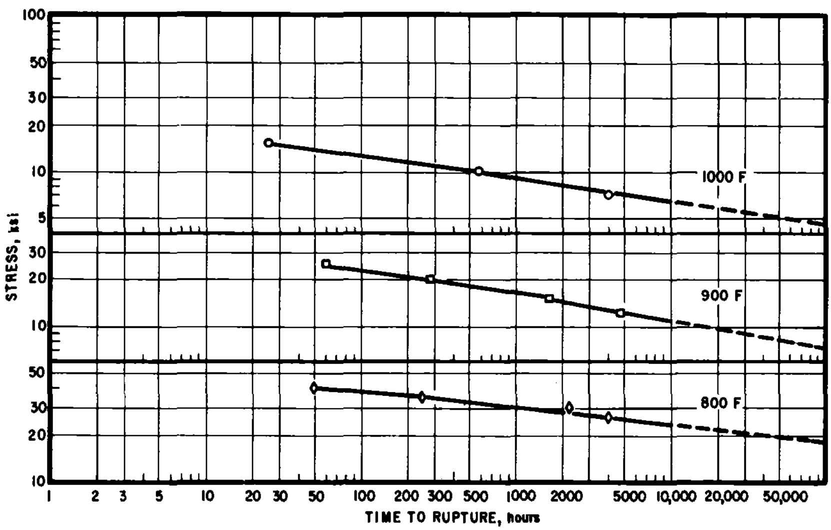


FIG. 10—Stress versus time to rupture for normalized and tempered ASTM A 201 steel made by the basic oxygen process.

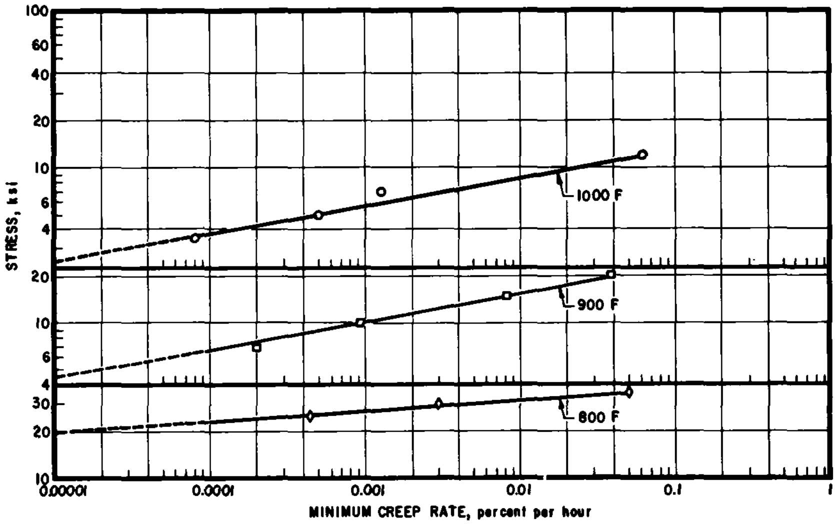


FIG. 11—Stress versus minimum creep rate for hot-rolled ASTM A 201 steel made by the basic-oxygen process.

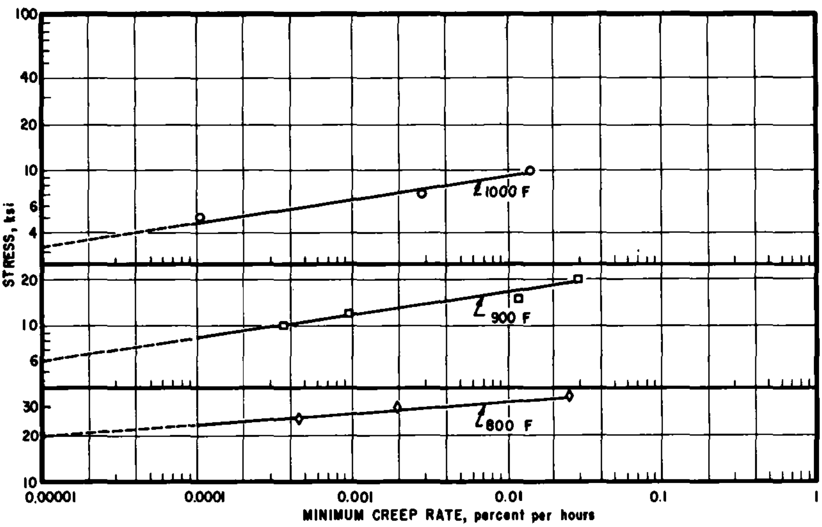


FIG. 12—Stress versus minimum creep rate for normalized and tempered ASTM A 201 steel made by the basic-oxygen process.

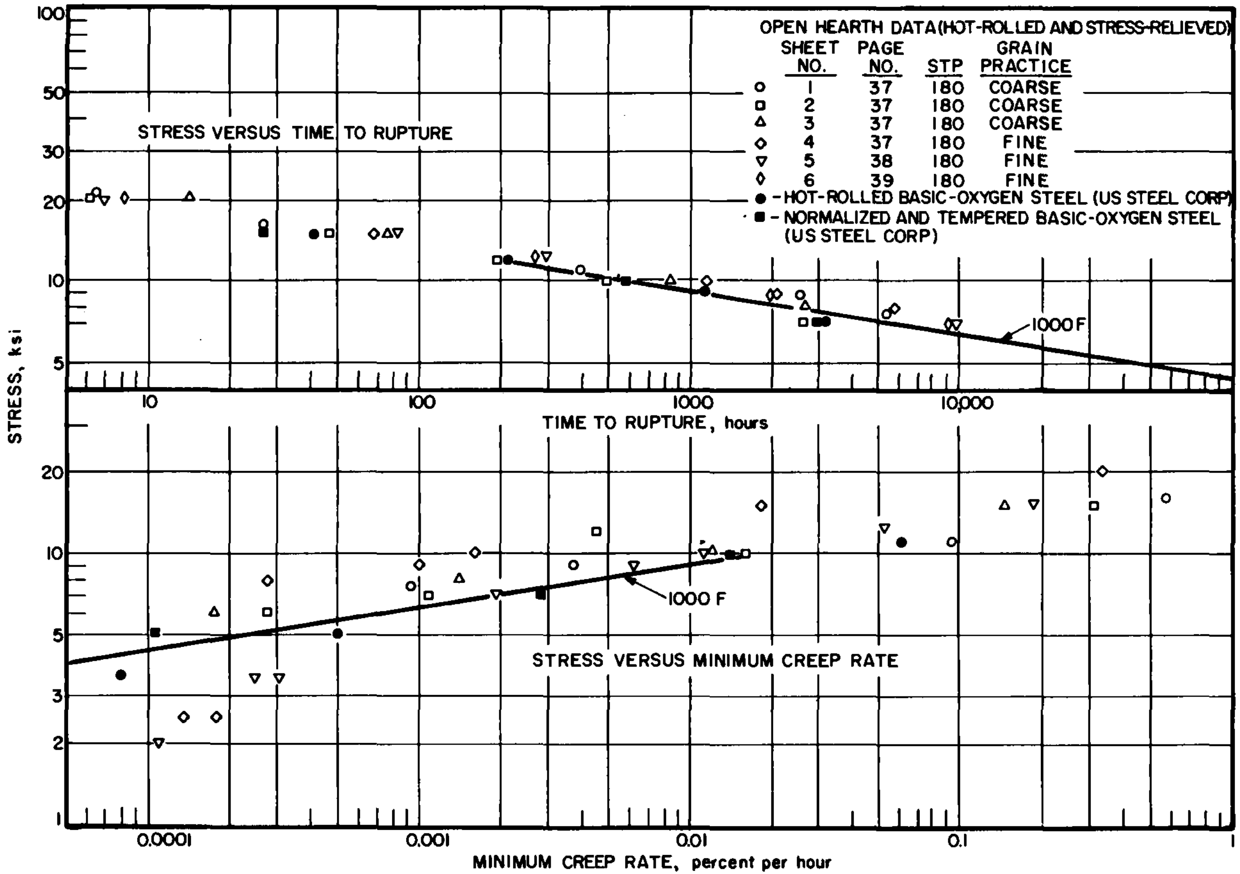


FIG. 13—Comparison of creep and creep-rupture test data for ASTM A 201 steel made by the open-hearth and basic-oxygen processes.

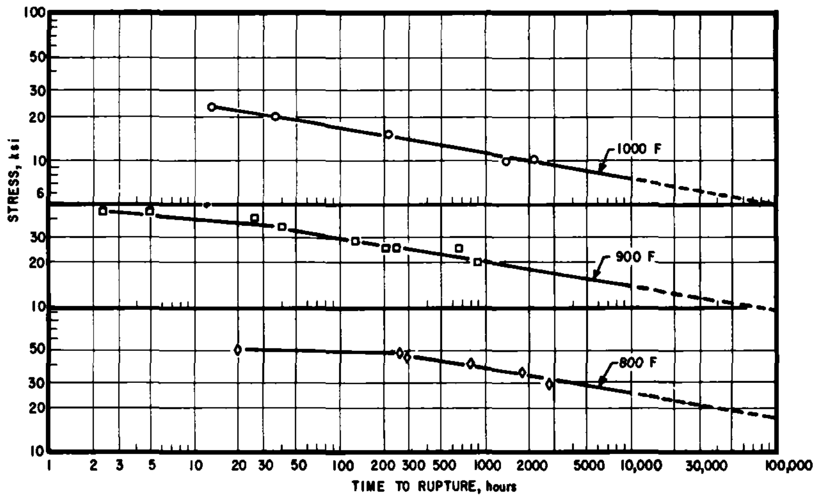


FIG. 14—Stress versus time to rupture for hot-rolled ASTM A 212 steel made by the basic-oxygen process.

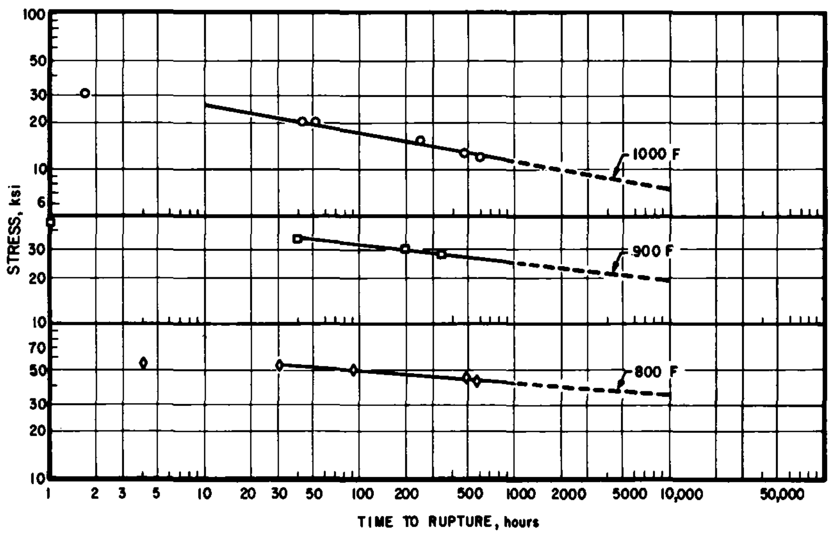


FIG. 15—Stress versus time to rupture for normalized and tempered ASTM A 212 steel made by the basic-oxygen process.

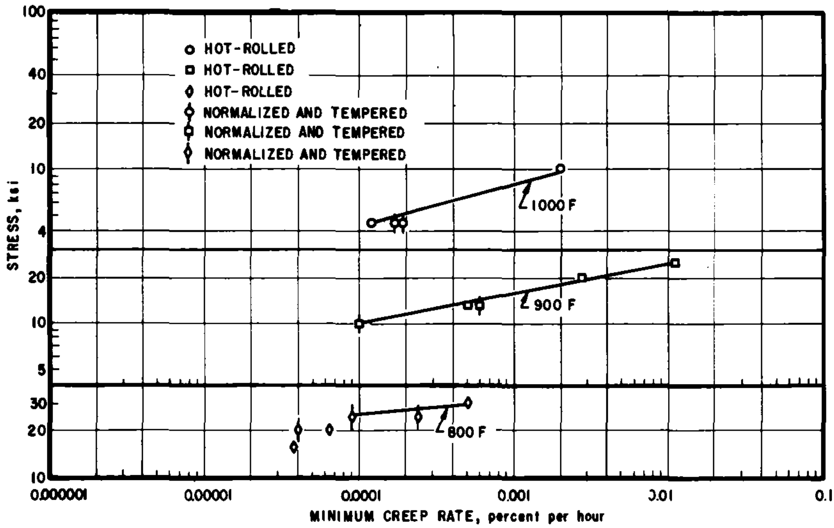


FIG. 16—Stress versus minimum creep rate for normalized and tempered and for hot-rolled ASTM A 212 steel made by the basic-oxygen process.

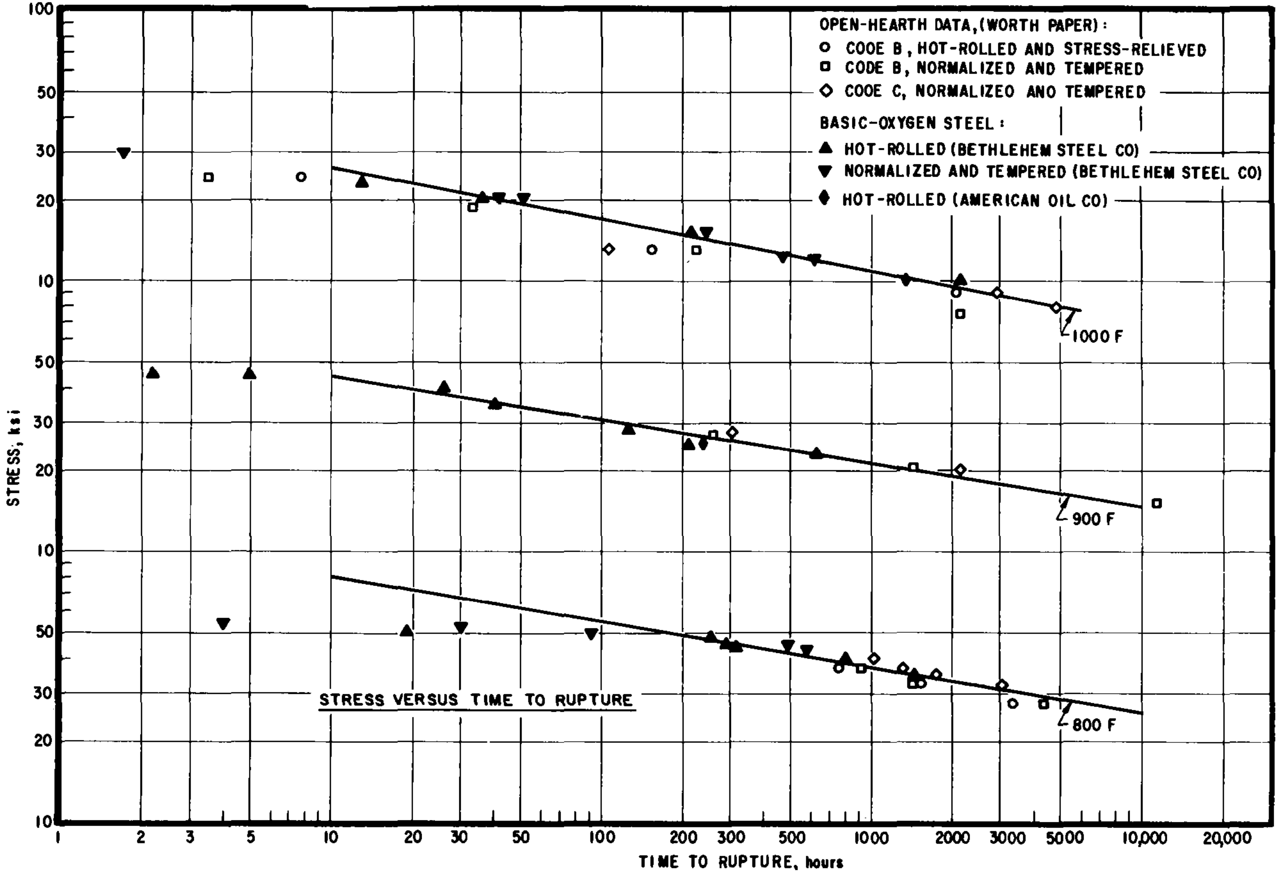


FIG. 17—Comparison of creep-rupture test data for ASTM A 212 steel made by the open-hearth and basic-oxygen processes.

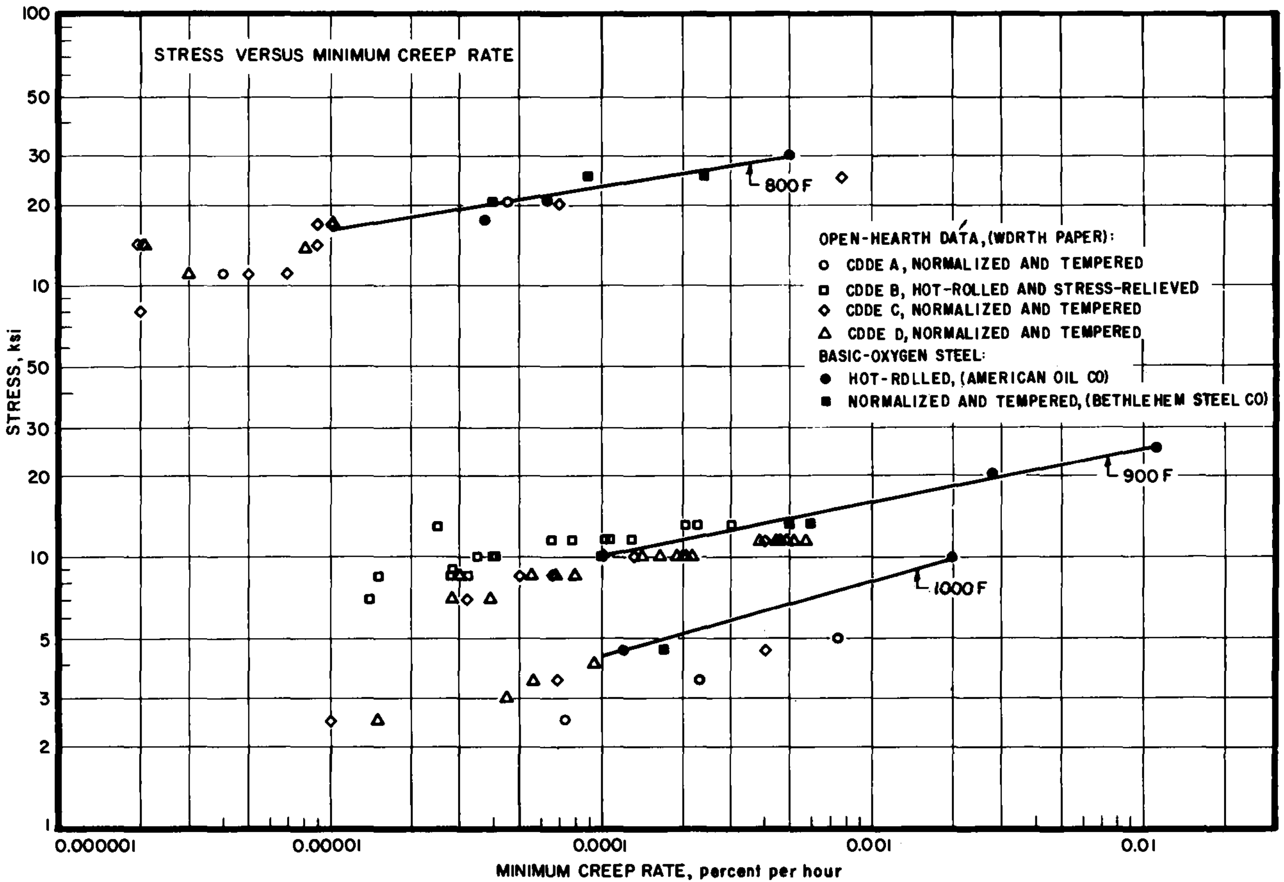
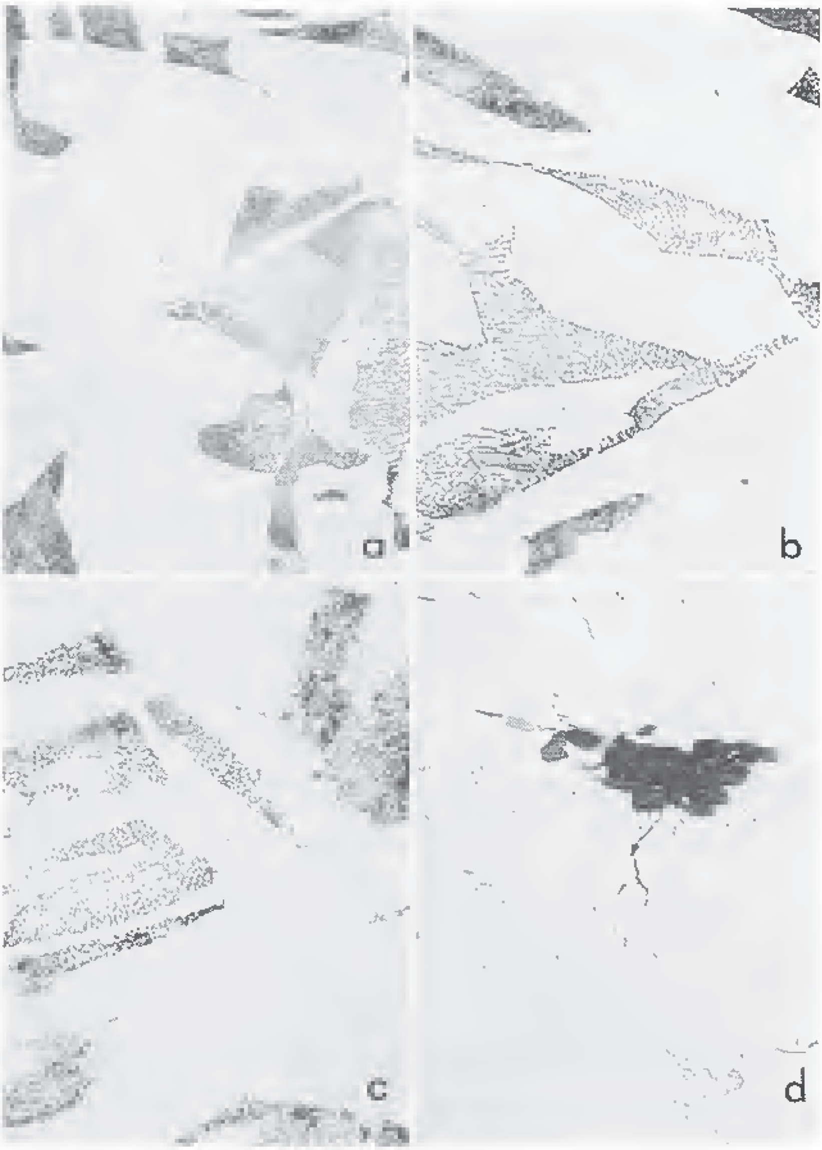
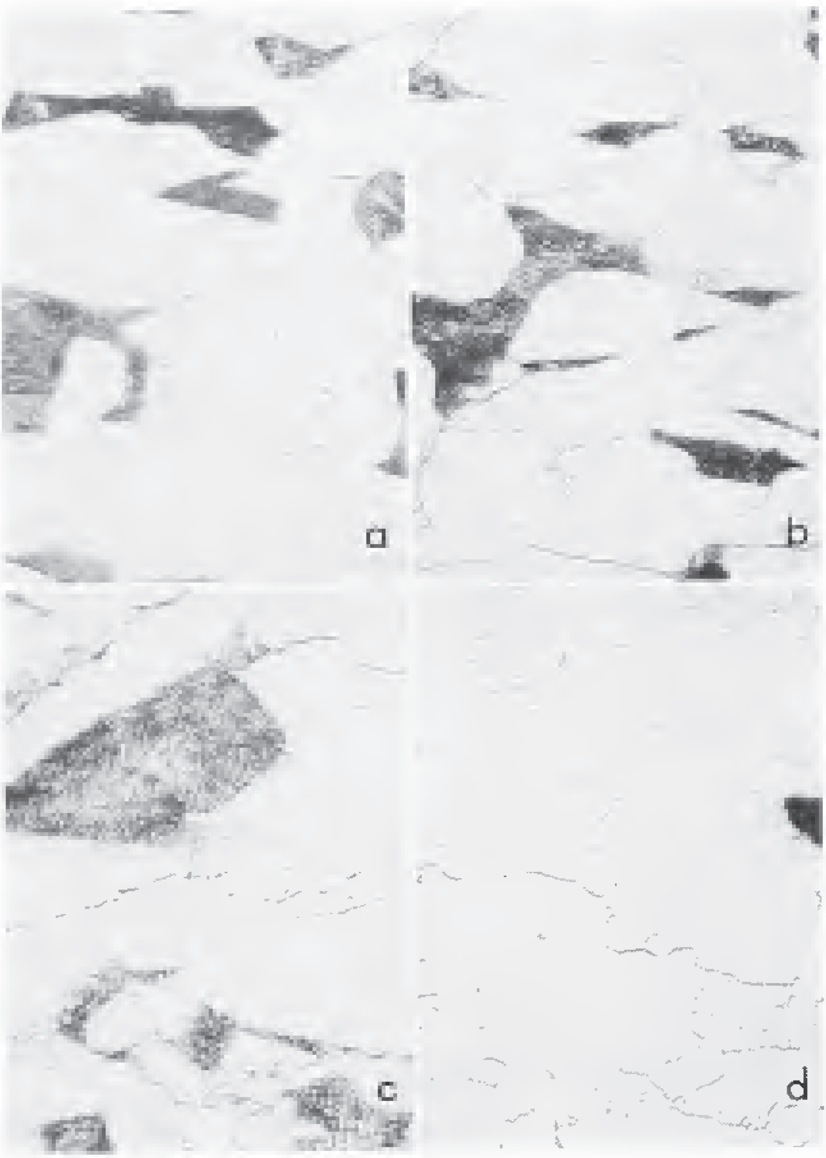


FIG. 18—Comparison of creep-test data for ASTM A 212 steel made by the open-hearth and basic-oxygen processes.



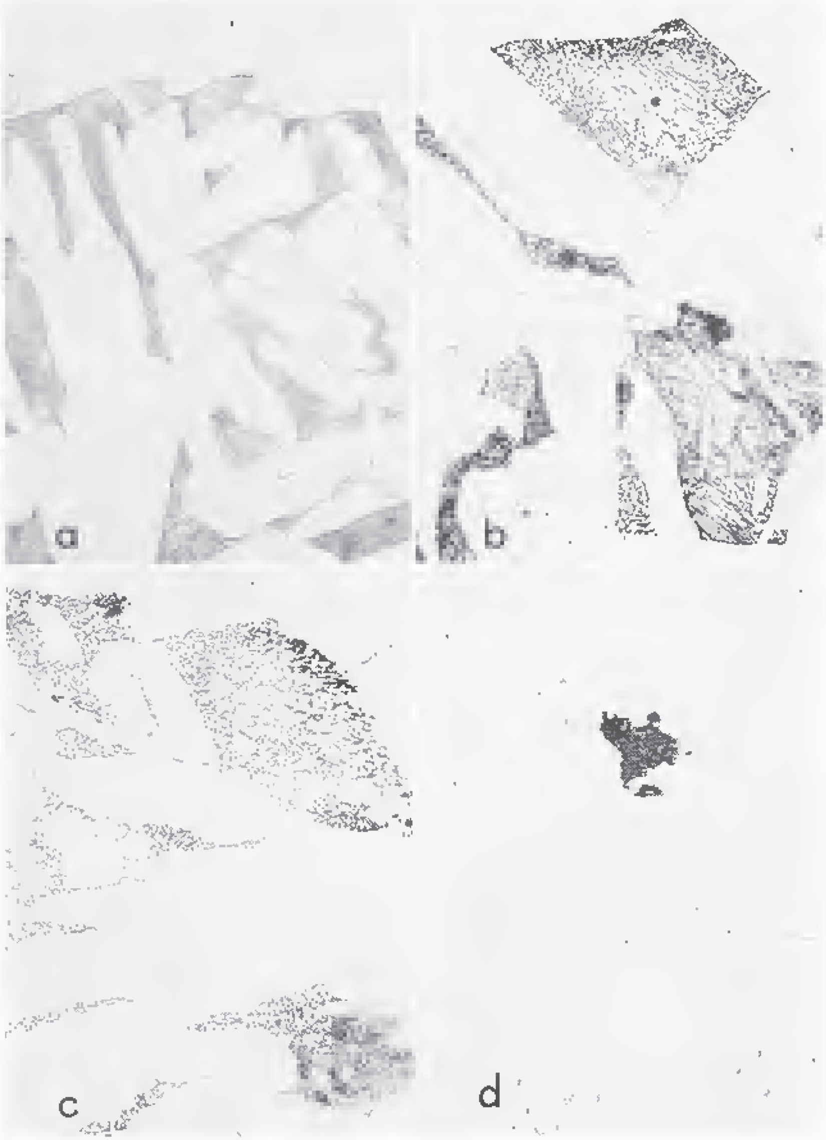
(*a*) Prior to testing, hot-rolled condition.
(*b*) After rupturing in 4478.1 hr at 800 F, stress—25,000 psi.
(*c*) After rupturing in 3663.1 hr at 900 F, stress—13,000 psi.
(*d*) After rupturing in 3816 hr at 1000 F, stress—7000 psi.

FIG. 19—Microstructure of hot-rolled basic-oxygen A 201 steel before and after long-time creep-rupture testing at 800, 900, and 1000 F (X500), picral reagent.



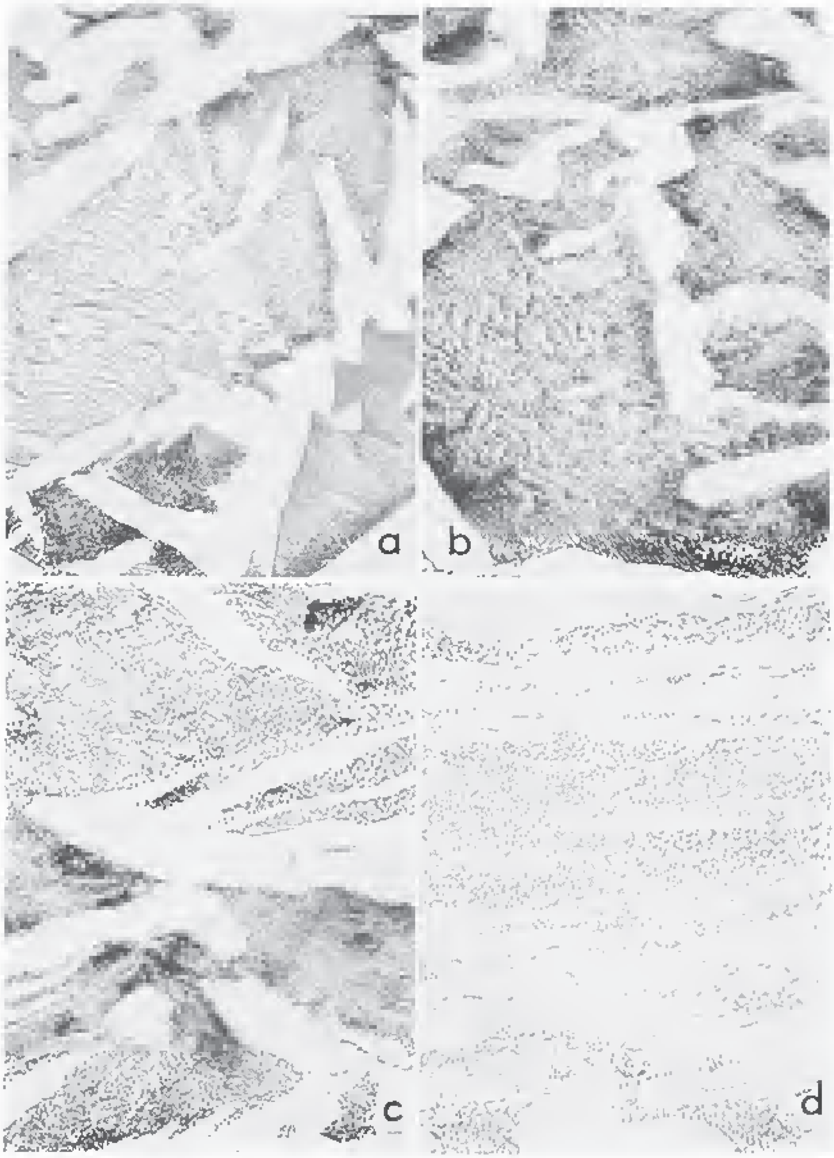
(*a*) Prior to testing, hot-rolled condition.
(*b*) After rupturing in 4478.1 hr at 800 F, stress—25,000 psi.
(*c*) After rupturing in 3663.1 hr at 900 F, stress—13,000 psi.
(*d*) After rupturing in 3816 hr at 1000 F, stress—7000 psi.

FIG. 20—Microstructure of hot-rolled basic oxygen A 201 steel before and after long-time creep-rupture testing at 800, 900, and 1000 F (X500), nital reagent.



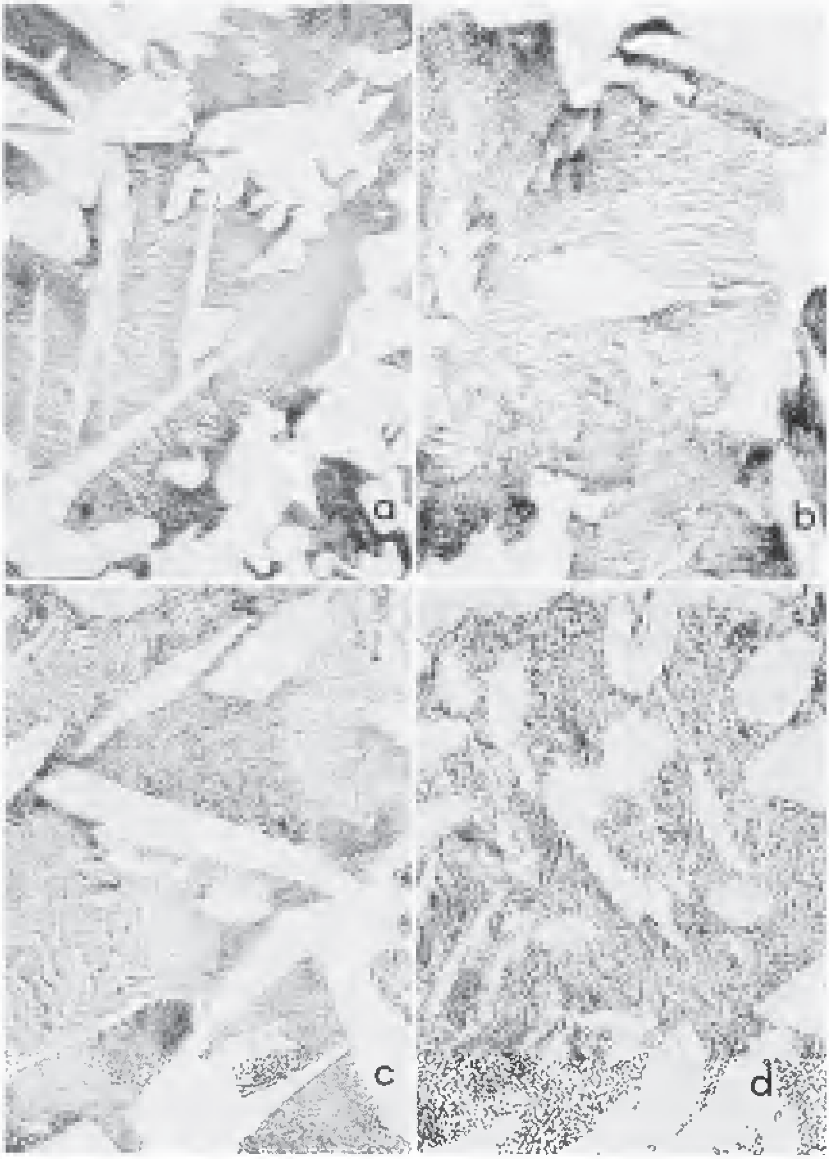
(*a*) Prior to testing, normalized and tempered condition.
(*b*) After rupturing in 3900 hr at 800 F, stress—25,000 psi.
(*c*) After rupturing in 4740.7 hr at 900 F, stress—12,000 psi.
(*d*) After rupturing in 3989.6 hr at 1000 F, stress—7000 psi.

FIG. 21—Microstructure of normalized and tempered basic-oxygen A 201 steel before and after long-time creep-rupture testing at 800, 900, and 1000 F (X500), picral reagent.



(*a*) Prior to testing, hot-rolled condition.
(*b*) After rupturing in 2878.8 hr at 800 F, stress—30,000 psi.
(*c*) After rupturing in 876 hr at 900 F, stress—20,000 psi.
(*d*) After rupturing in 1354.5 hr at 1000 F, stress—10,000 psi.

FIG. 22—Microstructure of hot-rolled basic-oxygen A 212 steel before and after creep-rupture testing at 800, 900, and 1000 F (X500), picral reagent.



(*a*) Prior to testing, normalized and tempered condition.
(*b*) After 800 F creep testing for 2500 hr with a stress of 20,000 psi plus 2000 hr with a stress of 25,000 psi.
(*c*) After 900 F creep testing for 2500 hr with a stress of 10,000 psi plus 2000 hr with a stress of 13,000 psi.
(*d*) After 1000 F creep testing for 4500 hr with a stress of 4500 psi.

FIG. 23—Microstructure of normalized and tempered basic-oxygen A 212 steel before and after creep testing at 800, 900, and 1000 F (X500), picral reagent.

APPENDIX[1]

[1] Data reported by Kaiser Steel Corp.

TABLE 12—ROOM-TEMPERATURE TENSILE PROPERTIES REPORTED BY KAISER STEEL CORP. FOR ASTM A 201 STEEL MADE BY THE BASIC-OXYGEN AND OPEN HEARTH PROCESSES.

Heat	Steelmaking Process	Orientation	Yield Strength,[a] psi	Tensile Strength, psi	Elongation in 2 in., per cent
		SPECIFIED[b] TENSILE PROPERTIES			
		longitudinal	30 000 min	55 000 to 67 000[c]	29 min
		HOT-ROLLED CONDITION			
310453......	basic oxygen	longitudinal	30 800	61 700	34
		transverse	30 500	61 300	32
42835.......	open hearth	longitudinal	31 000	61 800	34
		transverse	30 500	61 800	34
		NORMALIZED AND TEMPERED CONDITION			
310453......	basic oxygen	longitudinal	31 500	58 500	38
		transverse	37 200	60 500	38
42835.......	open hearth	longitudinal	38 500	61 900	37
		transverse	38 500	61 600	32

[a] Determined at 0.5 per cent total strain.
[b] ASTM specification A 201 for Grade A of firebox quality.
[c] The 67,000 psi max applies only to firebox quality steel.
NOTE—The tests were conducted on 0.505-in.-diameter specimens.

TABLE 13—ROOM-TEMPERATURE TENSILE PROPERTIES REPORTED BY KAISER STEEL CORP. FOR ASTM A 212 STEEL MADE BY THE BASIC-OXYGEN AND OPEN-HEARTH PROCESSES.

Heat	Steelmaking Process	Orientation	Yield Strength,[a] psi	Tensile Strength, psi	Elongation in 2 in., per cent
		SPECIFIED[b] TENSILE PROPERTIES			
		longitudinal	38 000 min	70 000 to 87 000[c]	22 min
		HOT-ROLLED CONDITION			
209939......	basic oxygen	longitudinal	42 300	83 800	28
		transverse	42 500	87 600	26
88244.......	open hearth	longitudinal	44 800	83 800	27
		transverse	41 400	87 300	27
		NORMALIZED AND TEMPERED CONDITION			
209939......	basic oxygen	longitudinal	45 500	85 500	32
		transverse	46 400	83 000	31
88244.......	open hearth	longitudinal	46 400	78 000	31
		transverse	45 000	78 000	29

[a] Determined at 0.5 per cent total strain.
[b] ASTM specification A 212-61T for Grade B of firebox quality.
[c] The 87,000 psi max applies only to firebox quality steel.
NOTE—The tests were conducted on 0.505-in.-diameter specimens.

TABLE 14—THE TRANSITION TEMPERATURES REPORTED BY KAISER STEEL CORP. FOR ASTM A 201 STEEL MADE BY THE BASIC-OXYGEN AND OPEN-HEARTH PROCESSES.

Heat	Steelmaking Process	Orientation	Transition Temperature, F	
			15 ft-lb	50 Per Cent Shear
	HOT-ROLLED CONDITION			
310453..........	basic oxygen	longitudinal	35	90
		transverse	40	...[a]
42835...........	open hearth	longitudinal	35	80
		transverse	40	...[a]
	NORMALIZED AND TEMPERED CONDITION			
310453..........	basic oxygen	longitudinal	5	40
		transverse	5	70
42835...........	open hearth	longitudinal	0	40
		transverse	10	65

[a] Insufficient data.

NOTE—1. These results are based on impact tests on Charpy V-notch specimens.
2. The steels were normalized at 1625 F for 1 hr and then tempered at 1150 F for 1 hr.

TABLE 15—THE TRANSITION TEMPERATURES REPORTED BY KAISER STEEL CORP. FOR ASTM A 212 STEEL MADE BY THE BASIC-OXYGEN AND OPEN-HEARTH PROCESSES.

Heat	Steelmaking Process	Orientation	Transition Temperature, F	
			15 ft-lb	50 Per Cent Shear
	HOT-ROLLED CONDITION			
209939..........	basic oxygen	longitudinal	80	...[a]
		transverse	70	...[a]
88244...........	open hearth	longitudinal	55	...[a]
		transverse	60	...[a]
	NORMALIZED AND TEMPERED CONDITION			
209939..........	basic oxygen	longitudinal	15	...[a]
		transverse	25	...[a]
88244...........	open hearth	longitudinal	10	...[a]
		transverse	20	...[a]

[a] Insufficient data.

NOTE—1. These results are based on impact tests on Charpy-V-notch specimens.
2. The steels were normalized at 1625 F for 1 hr and then tempered at 1150 F for 1 hr.

TABLE 16—THE RESULTS OF GRAIN-SIZE DETERMINATIONS REPORTED BY KAISER STEEL CORP. FOR ASTM A 201 AND A 212 STEELS PRODUCED BY THE BASIC-OXYGEN AND OPEN-HEARTH PROCESSES.

Heat	Grade	Steelmaking Process	ASTM Ferrite-Grain Size	ASTM Austenite-[a] Grain Size
		HOT-ROLLED CONDITION		
310453..........	A 201	basic oxygen	4 to 5	3 to 5
42835...........	A 201	open hearth	4 to 5	3 to 5
209939..........	A 212	basic oxygen	5 to 6	2 to 5
88244...........	A 212	open hearth	5 to 6	3 to 5
		NORMALIZED AND TEMPERED CONDITION		
310453..........	A 201	basic oxygen	5 to 6	...
42835...........	A 201	open hearth	6 to 7	...
209939..........	A 212	basic oxygen	7 to 8	...
88244...........	A 212	open hearth	7 to 8	...

[a] Determined by the McQuaid-Ehn test (1700 F for 8 hr).

TABLE 17—THE LONGITUDINAL ROOM-TEMPERATURE TENSILE AND IMPACT PROPERTIES REPORTED BY KAISER STEEL CORP. FOR STRAIN-AGED ASTM A 201 AND A 212 STEELS MADE BY THE BASIC-OXYGEN PROCESS.

Heat	Steelmaking Process	Yield Strength, psi	Tensile Strength, psi	Elongation in 2 in., per cent	Charpy V-Notch Impact Tests	
					Energy Absorbed, ft-lb	Shear Fracture, per cent
			ASTM A 201 STEEL			
310453.....	basic oxygen	71 000	75 100	19	7, 7, 8	10, 10, 10
42835......	open hearth	72 500	76 400	18	8, 8, 7	10, 10, 10
			ASTM A 212 STEEL			
209939.....	basic oxygen	101 000	102 200	12	7, 8, 8	10, 10, 10
88244......	open hearth	94 900	98 700	14	5, 7, 8	10, 10, 10

NOTE—These tests were conducted on hot-rolled steel that was strained 10 per cent and then aged at 450 F for 2 hr.

TABLE 18—RESULTS OF WELDING QUALIFICATION TESTS REPORTED BY KAISER STEEL CORP. FOR ASTM A 201 AND A 212 STEELS PRODUCED BY THE BASIC-OXYGEN PROCESS AND WELDED BY THE MANUAL SHIELDED-METAL ARC PROCESS.

Heat	Steel	Tension Test		Bend Test	
		Tensile Strength, psi	Location of Failure	Type of Bend	Bend-Test Results
310453.......	A 201	62 100	base metal	side	sound weld
				tee	sound weld
209939.......	A 212	79 700	weld metal	side	sound weld
				tee	sound weld

NOTE—1. The plates were welded in the flat position by manual shielded-metal arc process with vertical $\frac{3}{16}$-in.-diameter AWS E7018 electrodes.

2. The weld joint designs are shown in Figs. Q23-(a) and Q9-(a) of the "ASME Boiler and Pressure Vessel Code, Section IX, Welding Qualifications."

3. The macroetch tests indicated that fusion was complete.

4. The steels were welded in the hot-rolled condition.

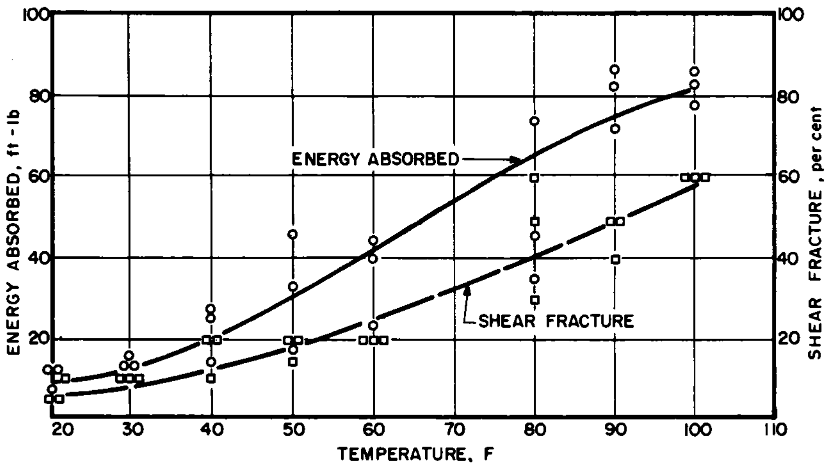


FIG. 24—Effect of test temperature on the longitudinal Charpy V-notch impact properties of hot-rolled basic-oxygen A 201 steel.

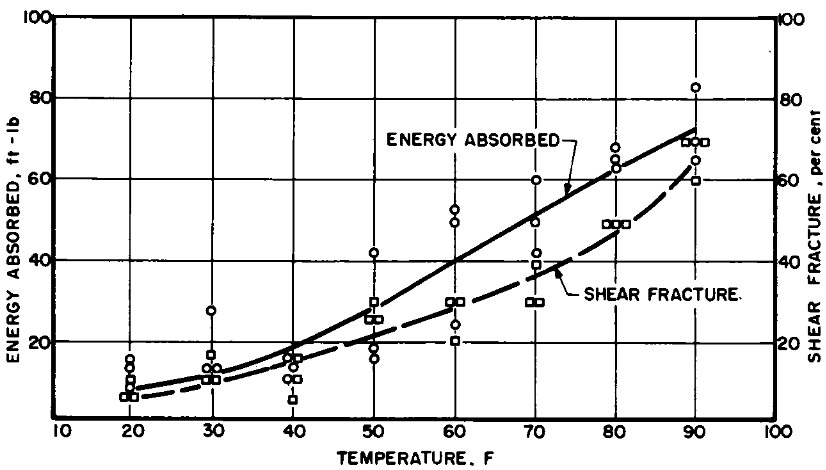


FIG. 25—Effect of test temperature on the longitudinal Charpy V-notch impact properties of hot-rolled open-hearth A 201 steel.

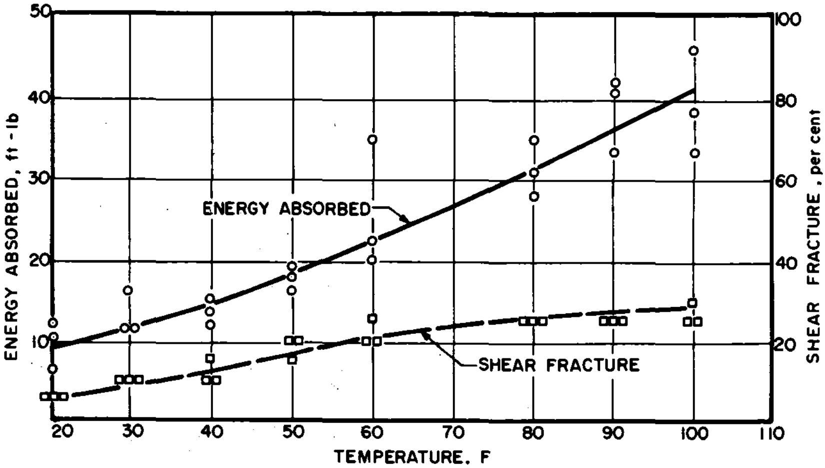


FIG. 26—Effect of test temperature on the transverse Charpy V-notch impact properties of hot-rolled basic-oxygen A 201 steel.

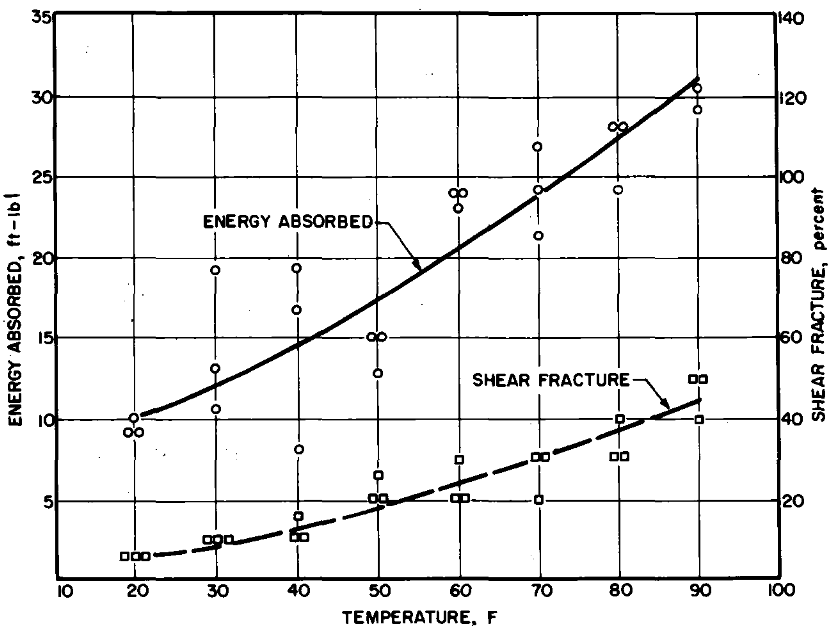


FIG. 27—Effect of test temperature on the transverse Charpy V-notch impact properties of hot-rolled open-hearth A 201 steel.

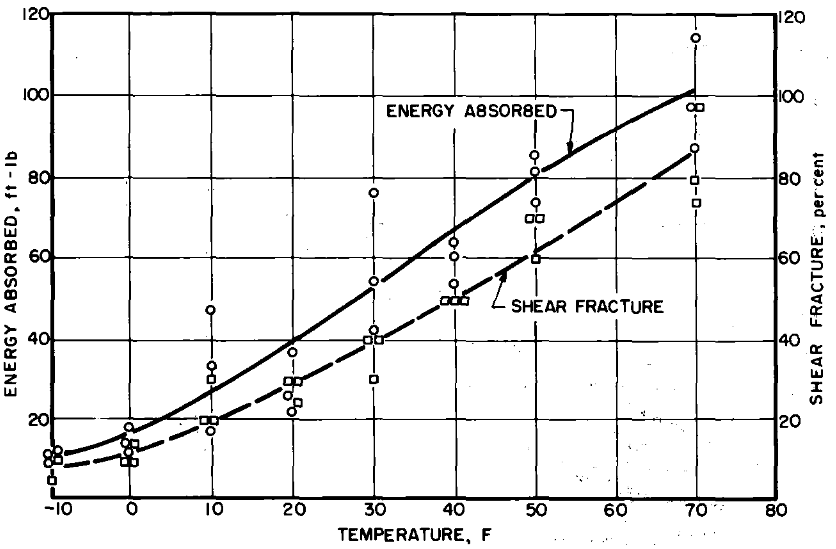


FIG. 28—Effect of test temperature on the longitudinal Charpy V-notch impact properties of normalized and tempered basic-oxygen A 201 steel.

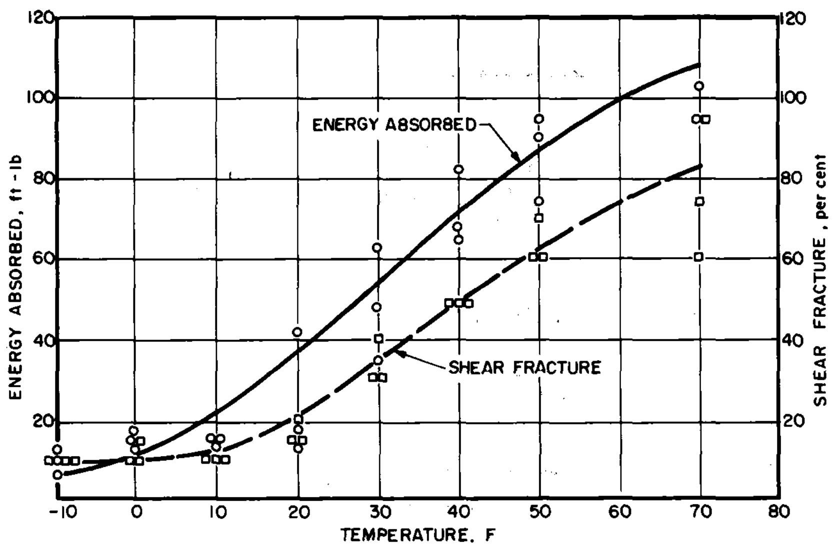


FIG. 29—Effect of test temperature on the longitudinal Charpy V-notch impact properties of normalized and tempered open-hearth A 201 steel.

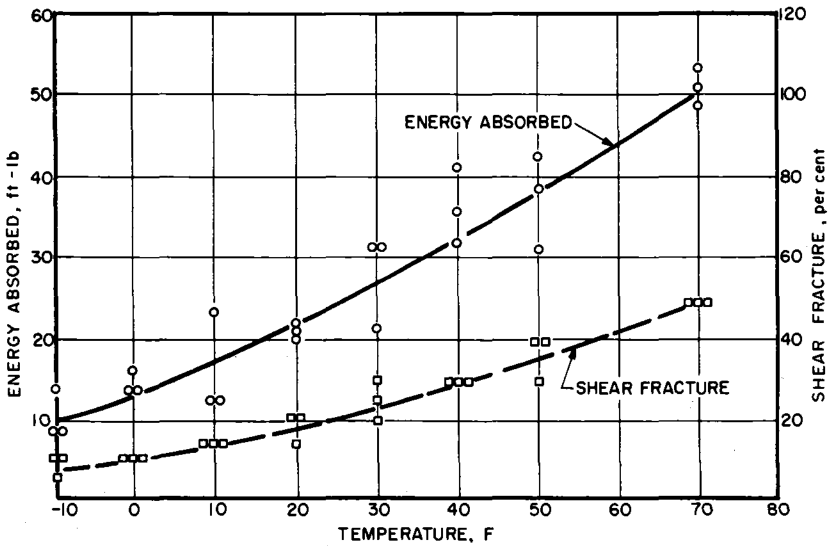


FIG. 30—Effect of test temperature on the transverse Charpy V-notch impact properties of normalized and tempered basic-oxygen A 201 steel.

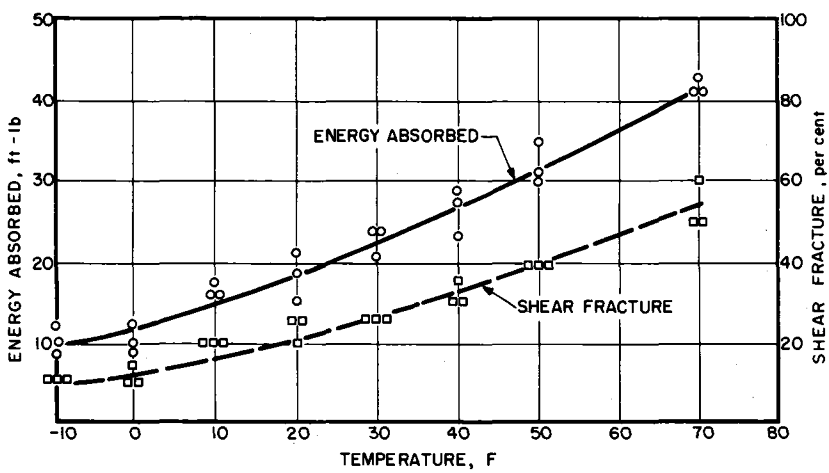


FIG. 31—Effect of test temperature on the transverse Charpy V-notch impact properties of normalized and tempered open-hearth A 201 steel.

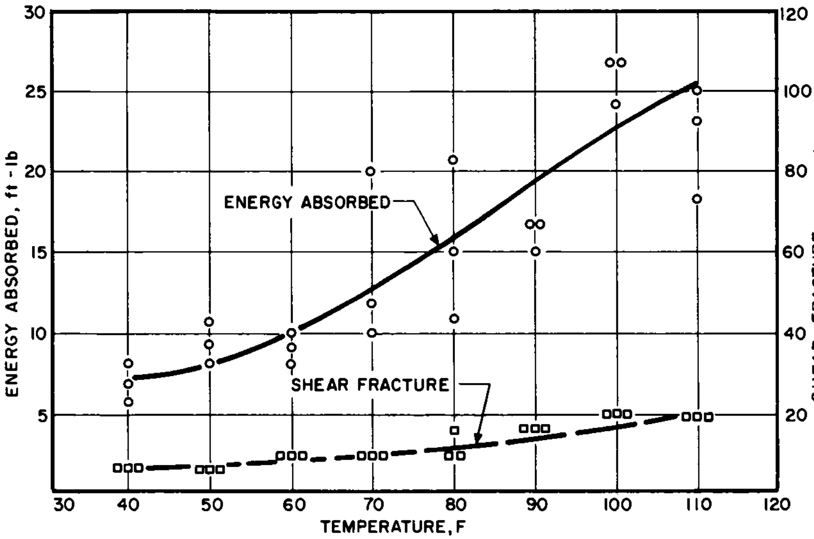


FIG. 32—Effect of test temperature on the longitudinal Charpy V-notch impact properties of hot-rolled basic-oxygen A 212 steel.

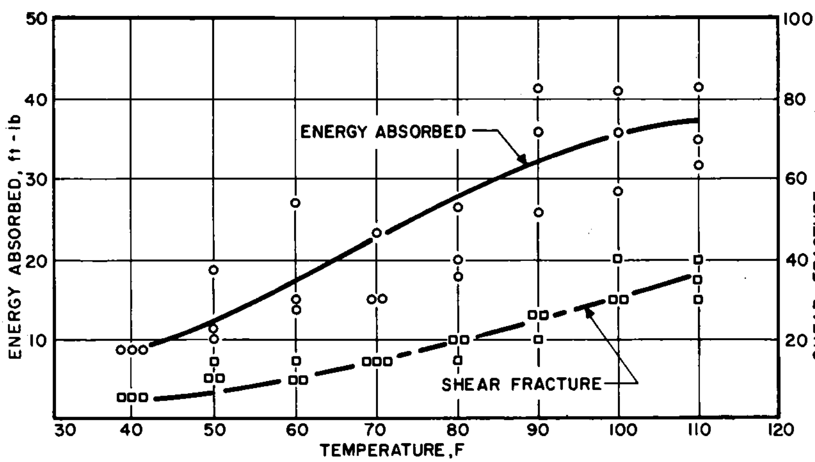


FIG. 33—Effect of test temperature on the longitudinal Charpy V-notch impact properties of hot-rolled open-hearth A 212 steel.

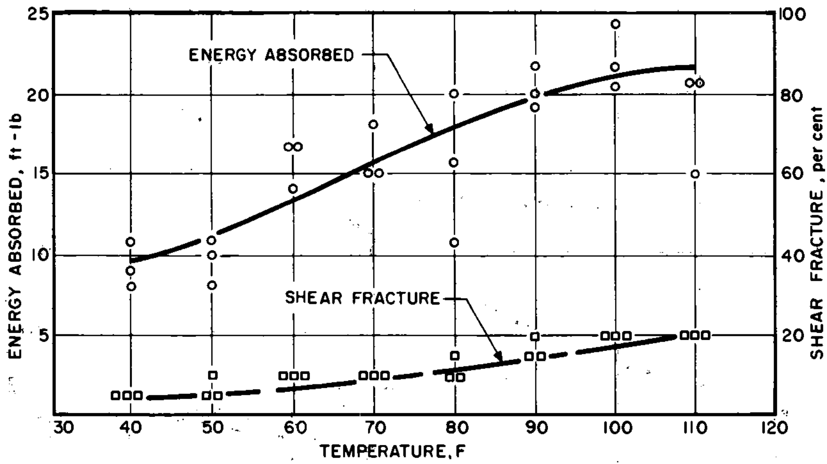


FIG. 34—Effect of test temperature on the transverse Charpy V-notch impact properties of hot-rolled basic-oxygen A 212 steel.

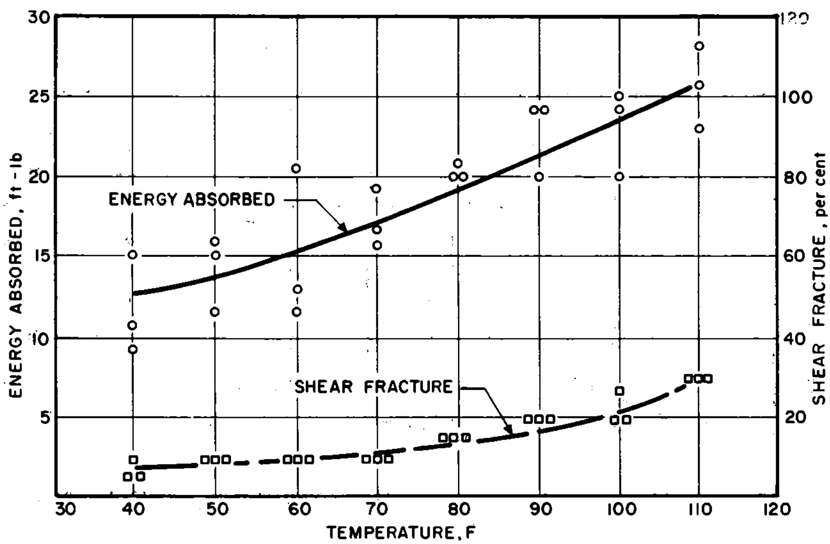


FIG. 35—Effect of test temperature on the transverse Charpy V-notch impact properties of hot-rolled open-hearth A 212 steel.

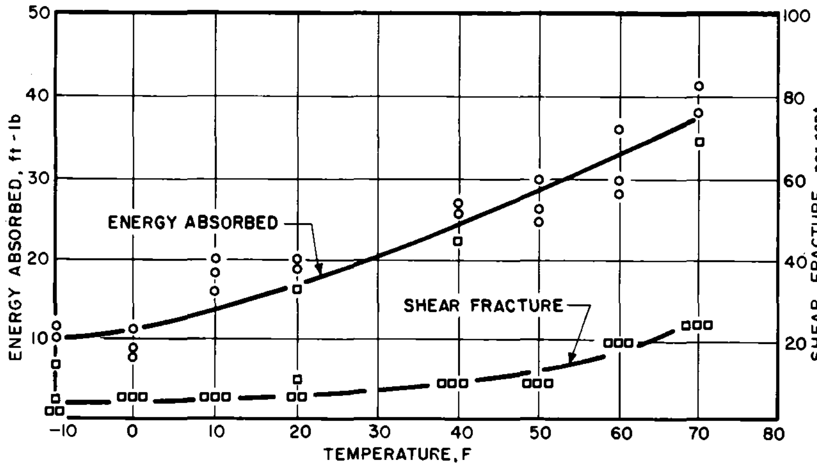


FIG. 36—Effect of test temperature on the longitudinal Charpy V-notch impact properties of normalized and tempered basic-oxygen A 212 steel.

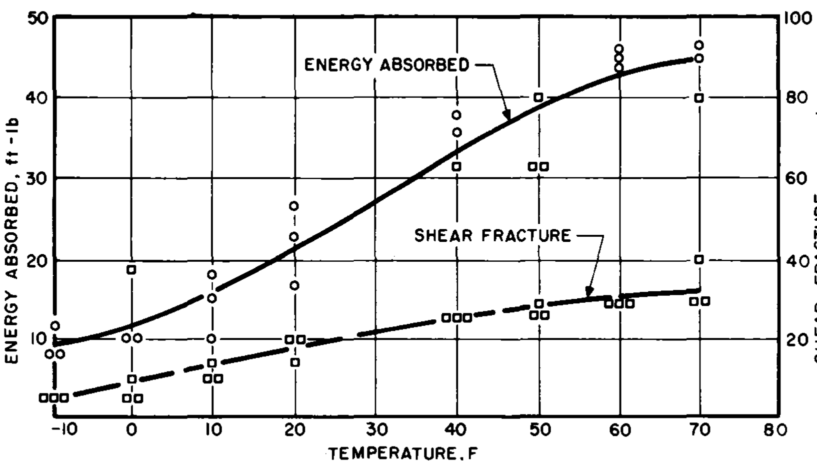


FIG. 37—Effect of test temperature on the longitudinal Charpy V-notch impact properties of normalized and tempered open-hearth A 212 steel.

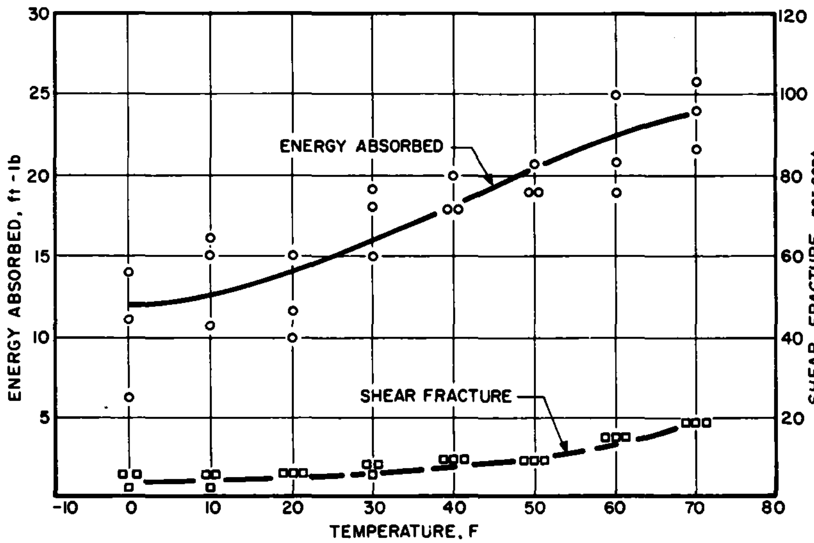


FIG. 38—Effect of test temperature on the transverse Charpy V-notch impact properties of normalized and tempered basic-oxygen A 212 steel.

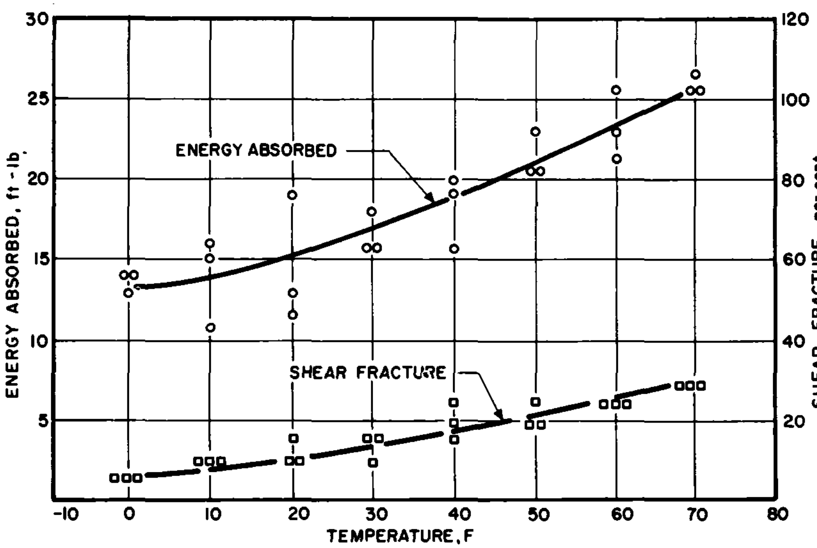
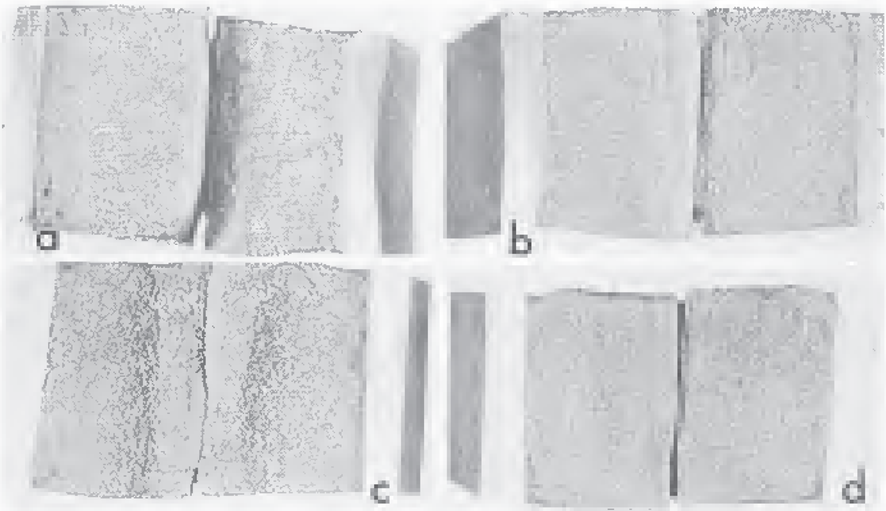
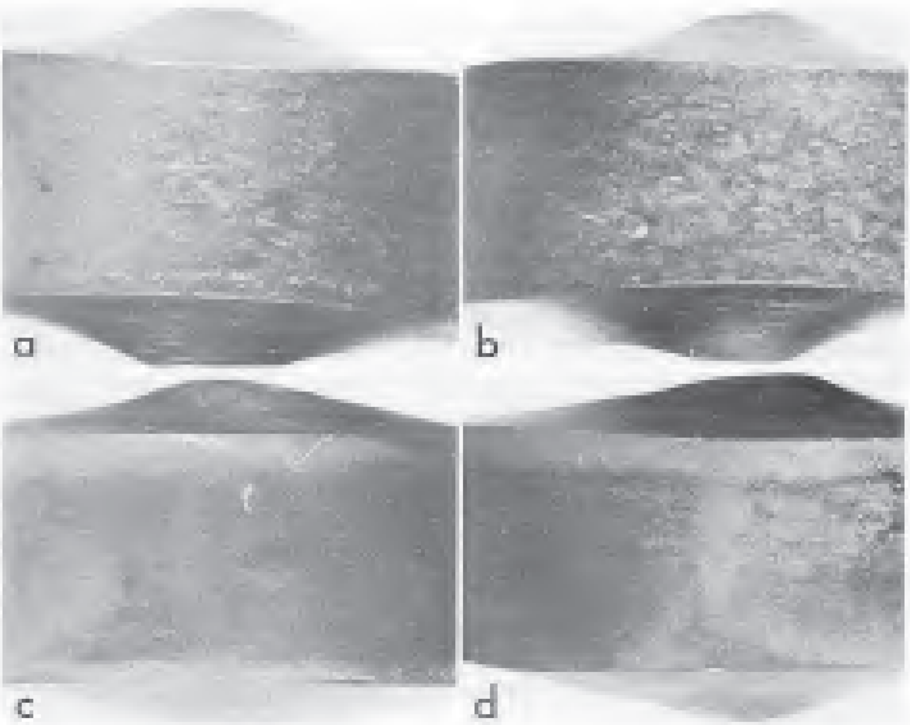


FIG. 39—Effect of test temperature on the transverse Charpy V-notch impact properties of normalized and tempered open-hearth A 212 steel.



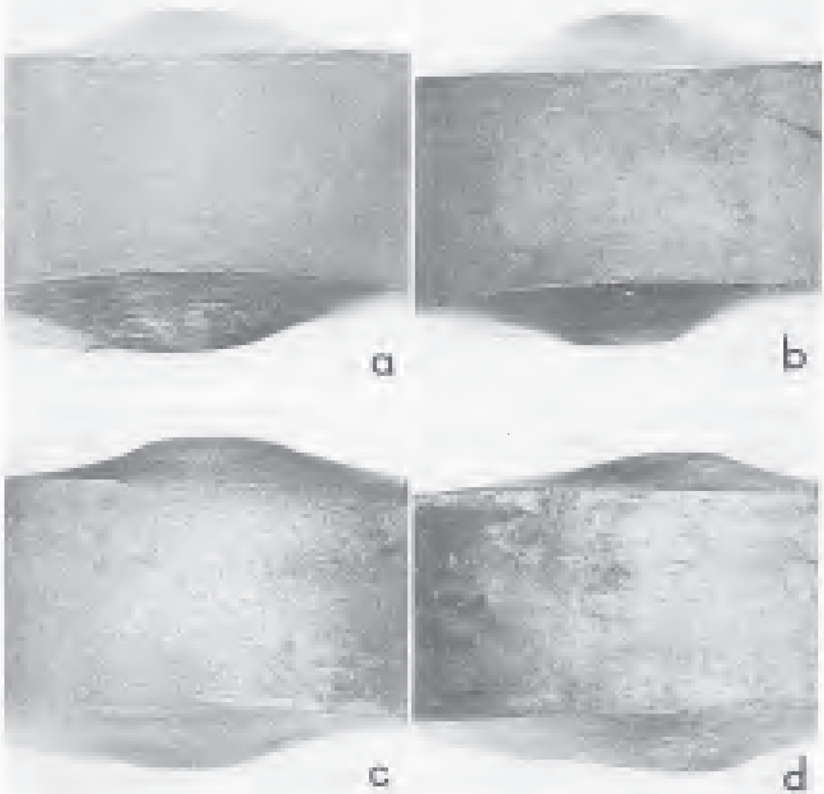
(*a*) Basic-oxygen A 201 steel.
(*b*) Open-hearth A 201 steel.
(*c*) Basic oxygen A 212 steel.
(*d*) Open-hearth A 212 steel.

FIG. 40—Results of homogeneity tests on hot-rolled basic-oxygen and open-hearth ASTM A 201 and A 212 steels.



(*a*) Basic-oxygen hot-rolled condition.
(*b*) Open-hearth hot-rolled condition.
(*c*) Basic-oxygen normalized and tempered condition.
(*d*) Open-hearth normalized and tempered condition.

FIG. 41—Results of bend tests on basic-oxygen and open-hearth ASTM A 201 steels both in the hot-rolled condition and in the normalized and tempered condition.



(*a*) Basic-oxygen hot-rolled condition.
(*b*) Open-hearth hot-rolled condition.
(*c*) Basic-oxygen normalized and tempered condition.
(*d*) Open-hearth normalized and tempered condition.

FIG. 42—Results of bend tests on basic-oxygen and open-hearth ASTM A 212 steels both in the hot-rolled condition and in the normalized and tempered condition.