AN EVALUATION OF THE ELEVATED TEMPERATURE TENSILE AND CREEP-RUPTURE PROPERTIES OF WROUGHT CARBON STEEL

Prepared for the
METALS PROPERTIES COUNCIL
by G. V. Smith

ASTM Data Series DS 11S1
(Supplement to Publication DS 11, formerly STP 180)

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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List price $6.00

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1916 Race Street, Philadelphia, Pa. 19103

Library of Congress Catalog Card Number: 73-109152
SBN 8031-2004-4

Note

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Printed in Alpha, New Jersey
January 1970

Data Series DS 11S1

The American Society for Testing and Materials

Related

ASTM Publications

Elevated-Temperature Properties of Carbon Steels, DS 11 (1955), $3.75

Elevated-Temperature Properties of Wrought Medium-Carbon Alloy Steels, DS 15 (1957), $4.25

REFERENCE: Smith, G. V., "An Evaluation of the Elevated Temperature Tensile and Creep-Rupture Properties of Wrought Carbon Steel", ASTM Data Series, DS 11 S-1, American Society for Testing and Materials, 1970.

ABSTRACT: This report seeks to offer a best current assessment of the several elevated temperature properties that commonly form the basis for establishing allowable stresses or design stress intensity values. The results are presented in a form readily usable for that purpose. The data that are evaluated are those that have become available since the publication in 1955 of ASTM Data Series Publication DS 11 (formerly STP No. 180), "Elevated Temperature Properties of Carbon Steels," as well as selected data from that earlier publication. The body of the report provides, in text, tables and figures, details concerning the materials, the evaluation procedures that were employed, and the results.

In evaluating rupture strength, extrapolations to 100,000 hours were performed both by direct extension of isothermal plots of stress and rupture-time for the individual lots, and by a time-temperature parameter, scatter-band procedure. Owing to a concern that different populations may be intermixed in a scatter band approach, the rupture strengths shown in the summary Fig. 1 represent the results of the direct individual-lot extrapolations.

A summary of the results of the evaluations is provided in Fig. 1. In this figure, all of the creep and rupture data have been treated as if from a single population, even though there is evidence presented in the body of the report that material produced to specifications that require a minimum tensile strength of 60,000 psi or higher has a greater rupture strength than material produced to specifications that require minimum tensile strengths less than 60,000 psi. Evidence is also offered for a slight superiority in rupture strength at the lower end of the creep range of temperature, of material made to "coarse-grain" practice. The yield and tensile strengths of Fig. 1 represent material that had been tempered after hot working or after normalizing, in practical recognition of the liklihood that material will receive such treatment during fabrication, if not before. The tensile strength curves of Fig. 1 recognize a distinct difference between material made to "coarse-grain" and "fine-grain" practice; however, the differences in yield strength were small, and scatter large, and the curves of Fig. 1 are based on a common trend curve for tempered, coarse- and fine-grain material. Individual trend curves for yield and tensile strength, expressed as strength ratios, are compared in Figs. 2 and 3.

KEY WORDS: elevated temperature, tensile strength, yield strength, creep strength, rupture strength, carbon steel, mechanical properties, data evaluation, elongation, reduction of area.

INTRODUCTION

Since the publication in 1955 of ASTM Data Series Publication DS 11 (formerly STP No. 180), "Elevated Temperature Properties of Carbon Steels," prepared by W. F. Simmons and H. C. Cross for the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals, additional data have been generated for this material. These additional data have been gathered by the Metal Properties Council, and together with the previously published data are evaluated in the present report. The report is one of a continuing series, sponsored by the Metal Properties Council, which seek to assess selected elevated temperature properties of metals and to publish the results in a form readily useful by Code groups and other organizations for establishing design stress intensity values.

The data gathered by the Metal Properties Council are appended to the present report, but with the exception of Code Nos. P 20-25 and T 20-T 22, which represent important, comprehensive test programs, data from DS 11 have not been recopied into the tables. However, a coding key to the DS data that have been integrated into the evaluations is provided in Table I of the present report.

The data were obtained from industrial, government, institute and university laboratories in the United States, and generally do not represent systematic or coordinated test programs. The data are identified in Tables I and II, as to product form and size, specification, deoxidation practice, heat treatment, grain size, chemical composition and source of data. Published literature has indicated that the strength of carbon steel may depend sensitively upon such variables as deoxidation practice, chemical composition and processing treatment, and an effort has been made to identify the lots of material as completely as possible. Unfortunately, however, many lots of material are far from adequately identified, and in fact some of the prior data of DS 11 have been excluded from the evaluations owing to inadequacies of identification.

Wherever possible the steels have been differentiated with respect to deoxidation practice as "coarse-grained" (CG) or "fine-grained" (FG), adopting the supplier's designation when furnished. If not furnished, and providing the aluminum analysis had been reported, a differentiation was established by designating steels having less than 0.015 percent aluminum as coarse grained. A few steels, identified in Table I, were made by the basic oxygen process.

Because of the interest in the possible effects of different variables, and for other reasons which will be cited, it has been deemed desirable to consider first the test results for each lot of material individually. However, in a number of instances, lots of data have been treated later in various groupings that seemed appropriate, after initial examination of the individual sets of data.

A distinction has been made amongst different product forms in most of the plots, although in the final analysis, the data are frequently integrated together for lack of ability to distinguish amongst product forms. A number of the data in DS 11 were identified only as wrought, and these have been arbitrarily classed as bar. The ASTM specification designations listed in Table I are those extant when the data were generated.

Properties of Interest

The evaluations of this report have been undertaken with the primary objective of providing Code organizations, industrial firms, governmental bureaus and others with basic information concerning the strength properties of interest for the establishment of design stress intensity values for elevated temperature service. The properties of interest include the short-time elevated-temperature yield and tensile strengths, and creep and rupture strengths. In making tensile or rupture tests, fracture ductility data are commonly reported, as elongation and/or reduction of area, and these are also included herein, even though the results are only indirectly useful to designers. Other strength properties, e.g. fatigue strength, which do not enter directly into the allowable stress determination, are also excluded from the present report. Some of these, such as the low and high-cycle fatigue characteristics, may be exceedingly important, but the relatively few available data are being considered elsewhere.

In this report, creep strength and rupture strength have been evaluated at two levels each: as the stresses to produce a secondary creep rate of 0.1% or 0.01% per 1000 hours, and to cause rupture in 10,000 or in 100,000 hours. For the reason that the reported data are unsuited to the purpose, no effort has been made to assess the creep strength in terms of the stress causing a creep strain of a specific amount in a given time interval, for example, the stress causing a creep strain of 1% in 100,000 hours, as required in a number of European construction codes. The reported yield and tensile strengths are presumed to have been measured in tests conducted at strain rates within the limits permitted by ASTM recommended practice E 21, but this is not known with certainty in all instances. The yield strengths are known in nearly all instances to correspond to 0.2% offset, or to the lower yield point for materials exhibiting a drop in load at the commencement of plastic flow.

For establishing design stress intensity values, the various properties of interest are individually required over the range of temperature in which they may govern, and are conveniently developed in terms of "trend" curves (or equivalent tabulations) of strength versus temperature.

The yield and tensile strength data of the present evaluation extended above the range in which their levels could be expected to govern, but were evaluated to the limits of the available data.

The original tensile test and creep rupture data are tabulated in Tables III and IV, respectively.

Yield Strength and Tensile Strength

In the previous report in this series (DS 5 S2 on wrought austenitic stainless steels), an evaluation procedure was employed that involves expressing the elevated temperature strength of a particular lot as a ratio to the room temperature strength of that particular lot. This procedure, based on the premise that the short-time, elevated-temperature strength of a specific lot of material reflects its relative strength at room temperature, seemed to have certain merits. An important advantage in analyzing the generally unsystematic type of data that are gathered in the Metal Properties Council solicitations, is that it becomes possible, in principle, to utilize all of the data for which there are corresponding test results at room temperature; when evaluated in terms of real values, results of strong or weak lots of material, available only at scattered temperatures, may distort the true trend of variation of strength with temperature. Another advantage of the strength ratio procedure that will be brought out in the present evaluation is that it can better preserve in the scatter band the individual characteristics that might otherwise be masked in a scatter band.

With the particular objective of determining whether it is possible to establish classes of carbon steels corresponding with different manufacturing practices, individual strength ratio plots were prepared for heats made to the same specification. In these plots, too numerous to include here, distinctions were preserved as to deoxidation practice, whether the material had been tested in the as-rolled or as-normalized condition, and whether the material had been stress-relieved or tempered. Study and comparison of the individual ratio plots with one another revealed considerable and seemingly continuous spread in behavior. The scatter is presumed to reflect both the effects of variations in the important variables and also problems of test reproducibility.

Detailed comparison of the ratio plots did reveal the importance to the tensile strength variations of two factors, first, deoxidation practice, and second, whether or not the material had, as a final treatment, been reheated to the temperature range below the lower critical temperature. Such treatment is commonly termed stress-relief annealing when applied to as-rolled material, and tempering when applied to normalized material; for convenience, the term tempering will be used in this report as an inclusive term for any reheating to the temperature range below the critical. The effect of deoxidation practice and heat treatment upon the tensile strength was evident for the range of temperature between about 200 and 600°F, within which dynamic strain aging manifests itself in susceptible steels as an increase in tensile strength.

Largely to reflect common terminology, but also because a finer classification did not seem warranted, in view of the incomplete character of the reported information, two categories of deoxidation practice, "coarse-grained" and "fine-grained" have been established. In a number of instances, this characterization was made by the original investigator, and when reported was adopted for this report. The basis for assessment was not always evident, but in some instances was based upon the results of the McQuaid-Elm grain size test. When an assessment was not furnished with the data, and providing the aluminum analysis had been reported, a separation was made by classing steels containing less than 0.015 aluminum as coarse grained. The very few data for semi-killed steel were put in the coarse-grained category, inasmuch as the behavior seemed to be similar.

With respect to the separation into coarse- or fine-grained steels according to deoxidation practice, it should be pointed out that the actual grain size (observable under the microscope) of an as-rolled steel depends primarily on the finishing temperature of rolling, a variable that is generally not reported. Thus, a fine-grained steel (as defined by the deoxidation practice), finished at relatively high temperature, may exhibit a coarser ferrite grain size than a steel made to coarse grained practice, but finished at a relatively low temperature. For example, hot-finished steel T 22, made to coarse-grained practice, had an actual grain size of ASTM 7-8.

Examination of the individual strength ratio plots further revealed that tempering may effect a significantly lessened tendency for strain aging of as-rolled or as-normalized steels that had been produced to fine-grained practice. No other correlations were evident from inspection of the data and accordingly four categories of carbon steel were established:

(1) coarse-grained, not tempered
(2) coarse-grained, tempered
(3) fine-grained, not tempered
(4) fine-grained, tempered.

Figures 4 through 7 provide plots of the data according to this classification. No distinction is made in the classification as to whether the material was in the hot finished or normalized conditions, since this seemed unimportant, except possibly for category 3. Only one lot (P 27a) of those falling in this category had been normalized, and it behaved similarly to as-rolled lots; however, this lot had a relatively high nitrogen content of 0.02

percent. It is possible that a better and more representative sample might reveal the need to distinguish in category 3 between hot-finished and normalized lots, for reasons that will be brought out later.

The scheme of classification adopted has some support on technical grounds. The most prominent feature of the temperature dependence of yield and tensile strength of carbon steel is the occurrence of dynamic strain aging, which manifests itself in susceptible steels as a reversal, or levelling off, in the trend of tensile strength with increasing temperature. Strain aging is associated with the interstitially-dissolving elements carbon and nitrogen, but with C exceeding the solubility limit in these steels, the differences in behavior are to be associated with differences in the amount of "available" nitrogen. Nitrogen tends to react with elements such as aluminum and silicon, especially the former, that are added for deoxidation. The extent of the reaction in a given steel depends upon temperature and time, and to the degree that the reaction occurs, nitrogen becomes unavailable to cause strain aging. In steels that have been air-cooled after hot working, nitrogen tends to be available, whether produced to fine- or coarse-grained practice, and hence susceptible to strain aging; this will be evident in the plots. On the other hand, it is commonly accepted that normalizing is conducive to the formation of aluminum nitride, during heating or holding at temperatures, in fine-grained steels. It is, in fact, the presence of aluminum nitride that causes aluminum-deoxidized steels to be fine-grained in the normalized condition. However, the behavior of lot P 27a, previously mentioned, indicates that in this steel, there must be sufficient nitrogen "available" after normalizing to permit strain aging.

Reheating for stress-relief or tempering provides a very favorable opportunity for immobilization of nitrogen provided aluminum is available, the reaction proceeding at a rate which increases with increase of this temperature. The data suggest that after conventional tempering or stress relief treatment, no distinction need be made between fine-grained steels as to prior treatment. In a purely practical vein, it is appropriate to recognize the probability that material not initially tempered will be tempered during fabrication.

Silicon, commonly used as a deoxidant for coarse-grained steels, can also effect immobilization of nitrogen, but the reaction does not proceed as rapidly nor to as complete an extent, so that as the tensile strength ratio plots reveal, tempered material exhibits only slightly lesser strain-aging susceptibility, and so far as can be seen, independent of the prior condition.

It might be mentioned here that the nitrogen-immobilizing reactions may tend to occur in either the silicon- or aluminum-deoxidized steels during relatively long creep and rupture tests.

The cold plastic deformation that is required to set the stage for strain-aging is introduced during the tensile test, and for that reason, strain aging should, in principle, not be evident in the yield strength. Yet, some of the steels did show an increase of yield strength at intermediate temperatures, and it may be inferred that they had had some measure of prior plastic deformation (perhaps from cold-straightening).

Except for a few data which could not be encompassed into the four categories cited above and which will be discussed later, all of the yield strength and tensile strength data were plotted in scatter bands in Figs. 4 a, b, c, and d through Figs. 7 a, b, c, and d, both in terms of strengths and also as strength ratios. The elongation and reduction of area data were also plotted, Figs. 4 e - 7 e. In all of the plots, data representing plate have been differentiated from data representing piping or tubing. (The only data available for bar product could not be encompassed within the classification scheme and are discussed later).

The strength plots exhibit scatter, a portion of which has its origin in the grouping together of materials from different specifications, which individually require different minimum tensile strengths; these ranged between 55,000 and 75,000 psi, with corresponding variation in specified minimum yield strength. The ratioing procedure proved to be reasonably effective in "normalizing" the tensile strength data, except within the temperature range of dynamic strain aging, where the scatter may be presumed to reflect the gradation in the degree to which nitrogen is available to cause strain-aging. The ratio procedure was less effective for the yield strengths, probably reflecting in part a greater degree of testing error inherent in the yield strength determinations. It is of interest that for tensile strength the ratio plots give a truer picture than the strength plots of the variation in strain-aging susceptibility of individual steels. Comparisons such as Fig. 4 b with Fig. 4 d show that individual characteristics can be masked in the scatter band of strength. The scatter plots were studied to determine whether the trend of variation of strength with temperature might exhibit a dependence upon strength level, but no evidence of such a dependency could be detected, within the limits of the data nor, in the case of plate was there any evident dependence upon section thickness.

The variations of strength with temperature were developed from the strength ratio data by polynomial regression; the data were treated without distinction as to product form in view of the scatter and overlapping of data. These trend curves have been drawn on the ratio plots and are also tabulated in Table V. A comparison amongst the different categories is afforded in Fig. 2 and 3. The most important distinction that is evident is the difference between the tensile strength trend curve for fine-grained, tempered, steel and the other three trend curves, arising from the lessened tendency for dynamic strain aging in the former. Based upon the small, and possibly unrepresentative available data, a steel produced to fine-grained practice may, if not tempered, be as susceptible to strain aging as a steel made to coarse-grained practice, for which tempering exerts relatively little influence in this same respect. The four tensile strength trend curves all exhibit the same general form. At temperatures both below and above the strain-aging range, the strength ratios for the different categories differ only slightly. The significance of the differences seems questionable.

The individual yield strength trend curves exhibit slight perturbations, but, in view of the scatter, it is difficult to argue for their significance; yet, there are similarities from one to another, and some resemblance to trend curves developed for carbon steel by the British from extensive, and systematically generated, data.[1] It is also difficult to argue that the differences among the yield strength trend curves for the four categories are real, and further more systematic tests would be required to elucidate this question. The differences are on the order of ± 10 percent from an average for the 4 categories.

As noted earlier, the liklihood that carbon steel will be reheated to below the critical temperature either before or during fabrication should be recognized, and the trend curve categories reduced to only two, namely coarse-grained and tempered and fine-grained and tempered. Further, if the differences in the yield strength trend curves are of questionable significance, it would not be inappropriate to establish a common trend curve for the two tempered conditions; such a trend curve is also tabulated in Table V.

The plots of percent elongation and percent reduction of area exhibit generally similar trends. With increasing temperature, ductility first decreases then passes through a minimum and finally generally increases. The minimum is related to the maximum in the tensile strength, previously noted, and is least pronounced in fine-grained and tempered material, as expected. Some scatter at higher temperature, particularly evident in coarse-grained, not-tempered material, may have its origin in an increased tendency to an intergranular mode of fracture of some lots.

All of the remaining tensile test data, representing heats that could not be put in one of the foregoing categories are plotted (as strength ratios and ductility) in Fig. 8 or 9. These data represent heats that were unconventional or inadequately documented with respect to deoxidation practice and/or processing. Codes P 29 and P 30, plotted in Fig. 8, represent material produced to specifications A 516 and A 515 respectively, except that the silicon content was deliberately reduced to below that required by specification; the aluminum contents were 0.020 and 0.015 respectively. Although A 516 material is intended for "moderate and lower temperature service" and, by specification, should be produced to fine-grained practice, it is evident in Fig. 8 that this material, in the tempered condition, behaves instead as if coarse-grained, perhaps reflecting its borderline aluminum content and low silicon content. On the other hand, the A 515 material, intended for intermediate and higher temperature service, and thus required to be of coarse-grained practice, exhibits pronounced strain-aging susceptibility in the as-rolled condition, but, interestingly, not in the normalized condition. This steel, incidentally had been vacuum degassed; its reported nitrogen content is slightly greater than for other plate steels.

A number of miscellaneous data, all from ASTM DS 11 are plotted in Fig. 9. The limits of behavior do not exceed those exhibited in Figs. 4-8.

Creep and Rupture Properties

The criteria for establishing allowable stresses or design stress intensity values in the "creep" range of temperatures commonly include the stress for rupture in 100,000 hours, further reduced by appropriate fractional factors aimed at providing a reasonably long safe period of usefulness. Since it is seldom possible to conduct tests lasting 100,000 hours (11.5 years), it becomes necessary to extrapolate the results of shorter time tests. In the ASME Code, the allowable stress is also limited by the average stress to cause a secondary creep rate of 0.01% per 1000 hours and extrapolation may or may not be required. In European codes generally, as well as in the draft ISO Codes, creep strength is expressed in terms of the stress required for a creep strain of 1 percent in 100,000 hours, and except as 100,000 hour tests might be conducted, an extrapolation is necessary. (This extrapolation appears to be particularly difficult to perform, with few reported results; the data available to the Metal Properties Council are inadequate to permit an assessment of creep strength defined in this way.)

There are two broad types of procedures for extrapolating time-for-rupture data, commonly plotted on log-log coordinates of stress and time-for-rupture. The second procedure, in which great interest has developed in recent years, involves the concept of a time-temperature parameter expressed as a function of the stress. Both procedures have been considered in the present evaluation.

Direct Extrapolation

In extending the time-for-rupture data at a specific temperature, the extrapolation may be performed either by treating different lots individually, or alternatively by treating all of the data together in a scatter band. The latter procedure assumes that all of the data are from a single population, independent of such factors as chemical composition, manufacturing practice and product form. As will be shown in this evaluation, there is evidence that all of the data are not from the same population. For this reason, and because of an inherent concern that a scatter band approach can mask individual characteristics, even within a given population, as illustrated earlier in this report for tensile strength, principal emphasis in the present evaluation is placed on individual lot evaluations. However, the scatter bands have also been evaluated to permit comparisons.

Individual lot extrapolations were performed on individual plots, too numerous to include in this report. However, to show both the volume of data and their scatter, all of the available data are shown in isothermal scatter band plots of log stress versus log time-for-rupture or log secondary creep rate, Figs. 10 a, b, and c, and Figs. 11 a, b, and c. The elongation and reduction of area results are also shown in isothermal scatter band plots, Figs. 12 a, b, c, d, e, and f without distinction as to product form. With few exceptions, the individual rupture-time plots were not extrapolated unless data were available for three levels of stress, with at least one rupture time exceeding 1000 hours. The creep rate data, also with few exceptions, were not extrapolated by more than 1 log cycle.

Based on an examination of the individual plots, and upon the scatter band plots as well (see later), the individual lot extrapolations of the time-for-rupture data were performed, assuming a linear dependence of log time upon log stress. However, for the variation of log secondary creep rate with log stress, a degree of curvilinearity was exhibited by some lots, and this was recognized in the creep strength evaluations. The best fit lines or curves were developed visually, giving weight to the longer-time or slower-rate data.

The results of the individual isothermal extrapolations or interpolations are tabulated in Tables VI - IX and also plotted as dependent upon temperature in Figs. 13 a and b. The rupture and creep strengths are evaluated at two levels each -- as the stress for rupture in 10,000 or in 100,000 hours and as the stress for a secondary creep rate of 0.1 or of 0.01 percent per 1000 hours. Semilogarithmic coordinates were chosen for the plots of Fig. 13 because they tend to linearize the dependence of log strength upon temperature.

Although bar, pipe-tube, and plate data, as well as data from ASTM DS 11 (probably mostly bar), are differentiated in Fig. 13 a and b, casual examination does not reveal a clearly evident distinction amongst the separate categories. The data were therefore analyzed by the method of least squares, with temperature as the independent variable. The variances of the data were only negligibly, or not at all, improved by assuming a quadratic rather than a linear dependence of the variables, and the average trend curves superimposed on the plots therefore represent a linear dependence. On the assumption that log strength is normally distributed, a minimum trend curve has been derived from the variance of the data and is also drawn on each grouping. This minimum has been arbitrarily taken at the 90% confidence level, or the level above which 95 percent of the data should lie. In drawing the minimum trend curves parallel to the average trend curves, it is assumed that the average slope has been defined without error, and that the variances of the data are independent of temperature. The average and minimum trend curves delineated in Figs. 13 a and b are tabulated in Table X (10,000 hours rupture strength), Table XI (100,000 hour rupture strength) and Table XII (0.1 and 0.01 percent per 1000 hours creep strength).

The wide scatter in the creep and rupture strengths of carbon steel no doubt reflects the uncontrolled variation of one or more influential factors, and it would appear possible in principle (if perhaps not in practice) to reduce the degree of scatter by more restrictive specifications. British studies[1] have shown, for example, that the manganese content and the quantity of molybdenum present as a residual impurity are especially important variables in commercial carbon steel.

For many years, based on published literature, it has been held that steel made to coarse-grained practice has greater creep and rupture strength than steel made to fine-grained practice. It is therefore of interest to inquire whether such a distinction is evident in the data here being evaluated. With reference to creep strength, there were unfortunately too few data to warrant such an attempt; thus, all of the useful data for plate fall in the coarse grained category, and there are no useful 0.01% per 1000 hours creep strength data for pipe-tube, which is commonly made to fine-grained practice. However, if possible differences arising from other factors such as product form, processing history and microstructure, including actual grain size, are ignored, it is possible to look for a difference in rupture strength. Figure 14 a (10,000 hours rupture) and Fig. 14 b (100,000 hours rupture) plot separately data corresponding to fine-grained and coarse-grained practices. (not all of the data of Tables VI and VIII could be categorized in this respect.) The data of the plots were analyzed by the method of least squares with average and minimum (90% confidence) trend curves drawn on the plots and tabulated in Tables X and XI. Each of the regression lines seemed suitably defined by a linear dependence except for the fine-grained, 100,000 hour rupture data which required a second order dependence.

At the lowest test temperature, 800°F, the results reveal a slight inferiority (approximately 10 percent) in 100,000 hour rupture strength for material of fine-grained practice. This difference tends to wash out with increasing temperature. The difference at 800°F also seems slightly more pronounced at 10,000 hour (approximately 25 percent) than at 100,000 hours. Although these differences would seem to be of borderline significance for 100,000 hour rupture strength, in view of the small sample, and the uncontrolled simultaneous variation of other factors, it is of interest that the observed trend with increasing temperature corroborates observations recently reported by Glen and associates[1] for British test results. The tendency for the difference in strength to wane with increasing test time and temperature can be attributed to the occurrence of nitrogen-immobilizing precipitation reactions during creep and rupture tests, as mentioned earlier in this report.

Inspection of the plot of 100,000 hour rupture strength data in Fig. 13b reveals that a large fraction of the points lying near the bottom of the scatter band represent material manufactured to specifications requiring relatively low levels of specified minimum tensile strength; conversely data lying near the top of the scatter band tends to represent material produced to somewhat higher specified minimum tensile strengths. Since a separation based on differences in specified minimum tensile strength is of possible interest to Code groups in establishing design stress intensity values, the 100,000 hour rupture strengths have been evaluated separately for material conforming to specified minimum tensile strength of 60,000 psi or higher and for material produced to specifications requiring less than 60,000 psi minimum specified tensile strength. Separation at the level of 60,000 psi is arbitrary but convenient.

Fig. 15 plots separately data falling into the two foregoing categories* and the regression lines do reveal significantly different levels of rupture strength. In establishing the regression line for the data in the lower portion of the plot, the outlying value of 11,000 psi at 900°F (and its companion value at 1100°F) has been excluded; although produced to specification A 201 A, its tensile strength was 64,000 psi in comparison with a minimum requirement of only 55,000 psi. The average and minimum values of Fig. 15 have been incorporated into Table XI. It is of interest that the differences depending upon the specified minimum room temperature tensile strength level are greater than those associated with differences in deoxidation practice, and the difference does not diminish with increasing test temperature.

The isothermal scatter bands were evaluated by the method of least squares, and average and minimum curves extended to 100,000 hours. The longer-time test results were weighted in the evaluations by excluding rupture-times less than 100 hours. The variances were either not improved significantly, or in some instances were actually worsened, in proceeding from the assumption of a linear relation between log stress and log rupture time to the assumption of a second order relation. As pointed out in the earlier report in this series, covering austenitic stainless steels, significant differences in the extrapolated 100,000 hour values are found depending upon the assignment of dependent and independent variable in the analysis, and the proper choice has been the subject of controversy. The earlier observation that a choice of time as independent variable conforms better with a visual assessment of the data has been confirmed in the present evaluation, and for this reason and others which will be discussed in a separate report,[5] time has been chosen as the independent variable for the least squares evaluations which are summarized in Fig. 16.

The positions of the individual isothermal regression lines in Fig. 16 relative to one another are inconsistent with what would be expected of a real material, and it can only be concluded that different populations are being intermixed. In this connection, study of Figs. 10 a, b, and c will suggest the possibility of different populations related to different product forms. Comparison of the 100,000 hour rupture strengths defined in Fig. 16 with those defined by the trend curve evaluation, Table XI, reveals the latter to be the more conservative. To the extent that different populations may be encompassed within the scatter bands, it seems necessary to question the appropriateness of the scatter band procedure of evaluation.

The elongation and reduction of area at rupture, Figs. 12 a-f, exhibited very wide scatter. At none of the test temperatures was there evident in the scatter bands a well defined trend with increasing time for rupture. The scatter bands were studied in the interests of determining whether ductility could be correlated with deoxidation practice. At both 800 and 900°F, the elongation values

*Data for materials not identified as to specification (principally bar) are not included in Fig. 15

for fine grain material lay at the top of the overall scatter band and conversely elongation for coarse grain material lay at the bottom of the scatter band; at 1000°F the values for fine-grained material fell near the bottom of the scatter band, but with no distinct separation to the high side of values for coarse-grain material. It was not possible to draw any clear distinctions for temperatures of 850, 950 and 1050°F, owing to the character of the samples.

Only six of the elongations at rupture were less than 10%. Five of these represented A 106 C hollow-forged pipe (Code T7) and one represented A 212 B plate (Code P 1a). Inspection of the processing practices and chemical composition did not suggest any explanation for the low values. The scatter bands, Figs. 12 a-f, do not provide any basis for expecting generally reduced ductility for rupture in 100,000 hours.

Parameter Extrapolation

In recent years, a great deal of interest has developed in the possible use of time-temperature parameters for correlating creep and rupture strengths. In brief, the parameter techniques make possible an estimate of the stress for rupture (or stress for a particular creep rate or creep strain) in a relatively long time at some temperature of practical interest from tests of relatively short duration at higher temperature. A number of different parameters have been proposed, and their relative merits have been argued frequently in published literature. Typical of these and sufficient for present purposes is the parameter suggested by Larson and Miller(2):

$$P = T\ (C + \log t) = F(\sigma)$$

where T is the temperature in degrees Rankine, t is the time for rupture in hours and C is a material constant.

The possible usefulness of parameters for evaluating data of the type being considered in the present report is being explored by the Metal Properties Council in a separate program to be reported separately. However, it has seemed appropriate to give some consideration in the present evaluation to the use of parameters. Accordingly a view point has been adopted for the present evaluation, based upon considerations which can only be briefly summarized in this report. Firstly, the constant C has been reported to vary with such factors as chemical composition, microstructure, fracture mode, environment and even temperature or stress range; therefore, it must be evaluated from the test results. This suggests that each lot of material must be evaluated individually for extrapolation by any specific parameter procedure. Furthermore, in order to evaluate the constant, and to assess properly the ranges of variables within which it holds true, it is generally agreed that tests at three or more temperatures are necessary. Such a quantity of test data is only infrequently available in the data gathered in the Metal Properties Council solicitations. In the present instance, for example, for only four lots of carbon steel were test results available for a minimum of three test temperatures. Consequently, an individual parametric evaluation could only be performed on a minimal fraction of the available data, and has not seemed worthwhile.

A parametric extrapolation procedure involving the isothermal scatter bands has been developed and employed by the British Steelmakers' Creep Committee,(3) and in spite of inherent reservations concerning scatter band procedures, it has been deemed desirable to perform a similar analysis of the present carbon steel data to provide an opportunity for comparisons. Following the general form of the British evaluation procedure, the isothermal regression lines of Fig. 16 have been employed in a graphical crossplot of log time versus reciprocal temperature for several constant stresses. In satisfying the Larson-Miller parameter, these isostress lines should converge at -C for reciprocal temperature equal to zero. In fact, the isostress lines intersected the ordinate axis over a range of values, the average of which approximated 20 (a value suggested by Larson and Miller(2) as the best single value approximately suitable for a variety of materials). The isostress data were also evaluated mathematically using a least squares, computer procedure suggested by Manson and Mendelson;(4) by this procedure, the Larson-Miller constant had a value of 19.6.

A value of 20 for the constant was therefore adopted and individual values of the parameter computed for every test for which the rupture time exceeded 5 hours. It then became possible to examine by polynomial regression analysis the variation of parameter with stress. This was done for all the data grouped together, as if from a single population, and also in various subgroupings to explore for possible differences arising from differences in product form or deoxidation practice. For illustration, Figs. 17 a, b, and c show plots of stress versus parameter for bar, pipe-tube, and plate respectively. Shown on the plots are the best-fit, least squares results along with the 90% confidence-level minimum. Plots for the combined data and for different deoxidation practices were not made, owing to the large volume of data that would have had to be plotted. However, the results of the least squares analysis for these groupings are tabulated, for comparison with one another and with the direct log-log extrapolations, in Table X (rupture in 10,000 hours) and Table XI (rupture in 100,000 hours). Fig. 18 provides a graphical comparison of the regression lines for coarse-grained and fine-grained material in relation to the combined data, and also compares the regression lines for the different product forms. Study of Tables X and XI reveal that the trends evident in the parameter extrapolations closely resemble those evident in the direct extrapolations both insofar as the temperature dependence of strength, and also with respect to the difference between coarse-grained and fine-grained materials. The differences amongst the different product forms, revealed by the parameter evaluations are of interest. It is possible that these differences relate to basic differences in composition and practice. For example, the superiority of plate relative to pipe-tube at the lower temperatures (lower values of parameter) may reflect, principally, the widespread use of coarse-grained deoxidation pracitce for plate and of fine-grained practice for pipe-tube.

Whether the results of the direct extrapolations or of the parameter extrapolations offer the better assessment of the strength of carbon steel is probably not capable of convincing resolution, except as 100,000 hour test results become available. However, the differences for all data are not large, amounting to only 1-2 percent at 800°F and increasing progressively to about 11% at 1000°F, with the direct extrapolation always the more conservative. It is of interest that the disparity between the two types of extrapolation is of about the same percentage magnitude at 10,000 hours as at 100,000 hours. Yet, the error in the extrapolated value is expected to increase with increasing time for rupture.

Acknowledgments

The evaluations of this report were made for the Metal Properties Council under the general guidance of a subcommittee of which Dr. M. Semchyshen is chairman. Particular appreciation is expressed to members of a task force of that subcommittee, chaired by Mr. C. E. Spaeder, Jr. Recognition is also given to the Boiler and Pressure Vessel Committee of the American Society of Mechanical Engineers for making available the results of prior data evaluations that facilitated the preparation of the present report.

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TABLE I-P

Identification of Carbon Steels - Plate

Code No.	Specification Number	Deoxid. Pract.	Heat Treatment[1]	ASTM[2] Grain Size	Product Size	Data Source
P-1 a	A 212-B	C.G.; Si	HR; T 1150°F	1-4 ME	1"	Babcock and Wilcox Co.
P-1 b	"	"	N 1625°F; T 1150°F	"	"	"
P-2	A 212-B	C.G.; Si	N 1625°F; T 1150°F	1-5 ME	3"	"
P-3 a	A 212-B	C.G.; Si	HR; T 1150°F	1-5 ME	1"	"
P-3 b	"	"	N 1625°F; T 1150°F	"	1"	"
P-4	A 212-B	C.G.; Si	N 1625°F; T 1150°F	1-4 ME	2-3/4"	"
P-5	C-1026 Mod	Not Given	Hot Finished	-	2" x .375"	"
P-6	A 201-B	C.G.; Si	Hot Rolled	-	1"	U.S. Steel Corp.
P-7	A 36	C.G.	Hot Rolled	-	1"	"
P-8 a+	A 201 A Firebox	C.G.; Si	Hot Rolled	4-5	1"	ASTM DS 40
P-8 b+	"	"	N 1625°F; T 1150°F	5-6	1"	"
P-9 a	"	"	Hot Rolled	4-5	1"	"
P-9 b	"	"	N 1625°F; T 1150°F	6-7	1"	"
P-10 a+	A212 B Firebox	"	Hot Rolled	5-6	1"	"
P-10 b+	"	"	N 1625°F; T 1150°F	7-8	1"	"
P-11 a	"	"	Hot Rolled	5-6	1"	"
P-11 b	"	"	N 1625°F; T 1150°F	7-8	1"	"
P-12 +	A 285 C Firebox	Semi-Kill	Hot Rolled	-	3/4"	ASTM STP 364
P-13	"	"	"	-	3/4"	"
P-14 a+	A 442-55 Flange	F.G.; Si-Al	Hot Rolled	7	1"	"
P-14 b+	"	"	N 1675°F; T 1150°F	-	1"	"
P-15 a	A 442-55 Flange	"	Hot Rolled	6	1"	"
P-15 b	"	"	N 1675°F; T 1150°F	-	1"	"

(1) HR - Hot Rolled; T - Tempered; N - Normalized; CD - Cold Drawn; A - Annealed
(2) Actual grain size except for lots with superscript, ME for McQuaid Ehn

\+ Produced by basic oxygen process

Table I-P, continued

Code No.	Specification Number	Deoxid. Pract.	Heat Treatment[1]	ASTM[2] Grain Size	Product Size	Data Source
P-16 a+	A 442-70	Si-Al Killed, F.G.	Hot Rolled	7	1"	ASTM STP 364
P-16 b+	"	"	N 1675°F; T 1150°F	-	1"	"
P-17 a	A 212-B	C.G.; Si	HR; T 1150°F	1-4 ME	1"	J.S. Worth ASME 1959
P-17 b	A 212-B	C.G.; Si	N 1625°F; T 1150°F	1-4 ME	1"	"
P-18 a	A 212-B	C.G.; Si	HR: T 1150°F	1-5 ME	1"	"
P-18 b	A 212-B	C.G.; Si	N 1625°F; T 1150°F	1-5 ME	1"	"
P-19	A 212-B	C.G.; Si	N 1625°F; T 1150°F	1-5 ME	3"	"
P-20	A 201-B	C.G.; Si, Ti	HR; T 1150°F	6	1"	R.F. Miller ASTM 1954
P-21	"	C.G.; Si	" "	5-6	"	"
P-22	"	C.G.; Si	" "	6	"	"
P-23 a	"	F.G.; Si-Al-Ti	" "	6-7	"	"
P-23 b	"	F.G.; Si-Al-Ti	Hot Rolled	6-7	"	"
P-24 a	"	F.G.; Si-Al	HR; T 1150°F	5-6	"	"
P-24 b	"	" "	Hot Rolled	5-6	"	"
P-25	"	F.G.; Si-Al	HR; T 1150°F	6-7	"	"
P-26 a	A 201-A	C.G.; Si-Al	N 1625°F	-	"	Amer. Oil Company
P-26 b	A 201-A	C.G.; Si-Al	N 1625°F; T 1100°F (24 hr)	-	"	"
P-26 c	"	" "	N 1625°F; T 1200°F (65 hr)	-	"	"
P-26 d	"	" "	N 1625°F; T 1200°F (24 hr)	-	"	"
P-26 e	"	" "	N 1625°F; T 1300°F (1 hr)	-	"	"
P-27 a	A 201 B	F.G.; Si-Al	N 1625°F	-	"	"
P-27 b	A 201 B	" "	N 1625°F; T 1200°F (65 hrs)	-	"	"
P-27 c	A 201 B	" "	As Rolled	-	"	"

Table I-P, continued

Code No.	Specification Number	Deoxid. Pract.	Heat Treatment[1]	ASTM[2] Grain Size	Product Size	Data Source
P-28	A 299	Si-Al	N 1650°F; T1175°F	-	6"	Lukens Steel Corp.
P-29 a	A 516-65 Low Silicon	Si-Al	As Rolled	-	3/4"	"
P-29 b	"	"	N 1650°F; T 1150°F	-	3/4"	"
P-29 c	"	"	As Rolled		1"	"
P-30 a (Bot.)	A 515-55 Low Si	Si-Al+	As Rolled (bottom of plate)	-	1-1/4"	"
P-30 a (top)	"	"	As Rolled (top of plate)	-	"	"
P-30 b (Bot.)	"	"	N 1650°F (bottom of plate)	-	"	"
P-30 b (Top)	"	"	N 1650°F (Top of plate)	-	"	"
P-31	A 299	F.G., Si-Al	N 1650°F; T 1100°F	-	5"	"
P-32 a	A 515-70	C.G.; Si	N 1650°F	-	4-3/8"	"
P-32 b	A 515-70	C.G.; Si	N 1650°F; T 1125°F	-	"	"
P-33*	A 516-70	F.G.; Si-Al	N 1650°F	-	1-1/8"	"
P-34 a**	"	"	"	-	1-1/8"	"
P-34 b*	"	"	"	-	"	"
P-35**	"	"	"	-	2-3/8"	"
P-36*	"	"	"	-	6-1/8"	"
P-37	A 515-70	C.G.; Si	N 1575°F; T 1125°F	-	7-3/8"	Babcock & Wilcox Co.

Data from ASTM DS 11

Note: Plate steel data on pages 33-39 of ASTM DS 11 are identical with Code Nos. P 20-P 25 of this report.

\+ Vacuum degassed; * Transverse; ** Longitudinal

TABLE I-T

Identification of Carbon Steels - Pipe and Tube*

Code No.	Specification	Deoxid. Pract.	Heat Treatment	ASTM Grain Size	Product Size	Data Source
T-1	A-210	F.G.; Si-Al	T 1300°F	6-8 ME	3/4" Bar	Babcock and Wilcox Co.
T-2 a	A-210	Not given	N 1600°F	-	5" OD x .500"	"
T-2 b	"	Not given	N 1600°F	-	2-1/2" x .280"	"
T-3	A-210	Not given	N 1650°F; T 1300°F	-	2" OD x .500"	"
T-4	A-192-A	Si-Al	N 1700°F	-	3/4" Bar	"
T-5	A 106-B	F.G.; Si-Al	As Rolled	6-8 ME	10-5/8" x .843"	"
T-6	A 106-B	C.G.; Si-Al-Ti	As Rolled	7-8	8-5/8" OD x .906"	"
T-7	A 106-C	Not given	N 1600°F; SR 1150°F	-	Hollow Forged Pipe	"
T-8	A 83-A	Al	N 1700°F	-	3/4" Bar	Babcock and Wilcox
T-9	A 178-C (Max.)	Not given	N 1700°F	-	Transv. Skelp Strip	"
T-10	A 210-A-1	F.G.; Si-Al	C.D.; A 1300°F	-	1.5" OD x .260"	U.S. Steel Corp.
T-11	A 210 A-1	"	C.D.; A 1275°F	-	2.0" OD x .340"	"
T-12	A 210 A-1	"	C.D.; A 1300°F	-	1.75" OD x .240"	"
T-13	A 210 A-1	"	C.D.; A 1300°F	-	3.0" OD x .500"	"
T-14	A 210 A-1	"	C.D.; A 1300°F	-	2.0" OD x .220"	"
T-15	A 106-C	F.G.; Si-Al	HR	-	8.64" OD x 2.14	Timken Co.
T-16	A 106-C	F.G.; Si-Al	HR	-	6.64" OD x 1.99"	"
T-17	A 106-C	F.G.; Si-Al	HR	-	6.64" OD x 1.99"	"

Table I-T, continued

Code No.	Specification	Deoxid. Pract.	Heat Treatment	ASTM Grain Size	Product Size	Data Source
T-18	A 106-C	F.G.; Si-Al	HR	-	8.64"OD x 2.14"	Timken Co.
T-19	A 106-C	F.G.; Si-Al	HR	-	8.64"OD x 1.86"	"
T-20 a	A 106-B	F.G.; Si-Al	As Rolled	6-8 ME	10-5/8"OD x .843"	R.F. Miller ASTM 1954
T-20 b	"	"	SR 1150°F	-	"	"
T-21 a	A 106-B	F.G.; Si-Al	As Rolled	4-6	8-5/8"OD x .906	"
T-21 b	"	"	SR 1150°F	"	"	"
T-22 a	A 106-B	C.G. Si-Al-Ti	As Rolled	7-8	"	"
T-22 b	"	"	SR 1150°F	"	"	"
T-23	A 192	F.G.; Al	CD; A 1275°F	-	2.50"OD x .150"	U.S. Steel Corp.
T-24	"	"	"	-	"	"
T-25	"	"	"	-	"	"
T-26	"	"	"	-	"	"
T-27	"	"	"	-	"	"

* Some lots although made to pipe or tube specification were tested as forged bar.

Data from ASTM DS 11

						DS Identification
ST-1	A 192-A	Si-Al	N 1700°F	-	3/4" Bar	Pg. 18, No.1
ST-2	1020		"Prob. Annealed"		2.4" OD x 1/4"	Pg. 32, No.5
ST-3	A-210	F.G.; Si-Al	T 1300°F	6-8 ME	3/4" Bar	Pg. 32, No.6
	Note: Pipe steel data on pages 41-46 of ASTM DS 11 are identical with Code Nos. T 20- T 22					
ST-4	A 83-A	Al	N 1700°F	-	3/4" Bar	Pg. 56, No.2

TABLE I-B

Identification of Carbon Steels - Bar

Code No.	Specification (if furnished)	Deoxid. Pract. (if furnished)	Heat Treatment	ASTM Grain Size	Product Size	Data Source
B-1	Not given	Al(.8 lb)-Ti(.3 lb)	N 1650°F	1-3 5-7	1"	U.S. Steel Corp.
B-2	"	F.G.; Si-Al (1.4 lb)	N 1650°F	6-8	1"	"
B-3	"	F.G.; Al (1.8 lb)	N 1650°F	6-8	1"	"
B-4	"	C.G.; Si	N 1650°F	1-3	1"	"
B-5	"	C.G.; Si-Al (.4 lb)	N 1650°F	1-3	1"	"
B-6	"	F.G.; Al (1.4 lb)	N 1650°F	6-8	1"	"
B-7	"	F.G.; Si-Al (1.4 lb)	N 1650°F	6-8	1"	"
B-8	"	F.G.; Al (1.2 lb)-Ti (.3 lb)	N 1650°F	6-8	1"	"
		Data from ASTM	DS 11			DS Ident.
SB-1	Not given	"Killed"	N 1650°F, T 1200°F (1 wk)		1"	Pg. 18, No. 2
SB-2	"	Si-Al	N 1650°F	7-8	-	Pg. 18, No. 3
SB-3	"	Si-Al	N 1650°F	7-8	-	Pg. 18, No. 4
SB-4*	1015	Si-Al	A 1550°F	3-5 ME	1"	Pg. 19, No. 6
SB-5	1015	"Killed"	"Annealed"	-	-	Pg. 10, No. 7
SB-6	1015	Si-Al	A 1550°F	305 ME	1"	Pg. 19, No. 8
SB-7 a	Not given	Si-Al	A 1550°F	5-6 ME	1"	Pg. 20, No. 9

* See also SB-6 which appears to be same data

SB-7 b	Not given	Si-Al	Hot Rolled	5-6 ME	1"	Pg. 20, No. 10
SB-7 c	"	"	N 1725°F; T 1200°F (1 hr)	"	"	Pg. 20, No. 11
SB-7 d	"	"	N 1725°F; T 1200°F (1 wk)	"	"	Pg. 21, No. 12
SB-8 a	"	Si-Al	Hot Rolled	4-5 ME	"	Pg. 21, No. 13
SB-8 b	"	"	N 1725°F; T 1200°F (1 hr)	"	"	Pg. 21, No. 14
SB-8 c	Not Given	Si-Al	A 1550°F	4-5 ME	1"	Pg. 21, No. 15
SB-8 d	"	"	N 1725°F; T 1200°F (1 wk)	"	"	Pg. 22, No. 16
SB-9 a	"	"Killed"	N 1650°F; T 1200°F (100 hrs)	-	1"	Pg. 22, No. 17
SB-9 b	"	"	N 1650°F	-	"	Pg. 22, No. 18
SB-9 c	"	"	T 1300°F (100 hrs)	-	"	Pg. 22, No. 19
SB-10	"	Si-Al	N 1650°F	6-8	-	Pg. 22, No. 20
SB-11	"	Si-Al (2.5 lbs)	N 1650°F	7-8	-	Pg. 23, No. 21
SB-12	"	Si-Al (2 lbs)	N 1650°F	7-8	-	Pg. 23, No. 23
SB-13	"	Si-Al-Ti	N 1650°F	7-8	-	Pg. 23, No. 24
SB-14	"	Si	A 1625	1-4 ME	7/8"	Pg. 31, No. 2
SB-15	"	Si-Ti	N 1650°F	6-8		Pg. 31, No. 3
SB-16	"	Si	A 1550°F	-	3/4"	Pg. 31, No. 4
SB-17	"	Si-Al (1.8 lbs)	N 1650°F	8.9	-	Pg. 32, No. 7
SB-18	"	Si	N 1650°F	4-8	-	Pg. 50, No. 1
SB-19 a	"	Si-Al (1.2 lb)	A 1550°F	8	-	Pg. 51, No. 7

SB-19 b	"	Si-Al (1.2 lb)	N 1550°F	8	-	Pg. 51, No. 7
SB-19 c	"	"	N 1900°F	0-3	-	Pg. 51, No. 7
SB-20 a	"	Si-Al (2.0 lb)	N 1550°F	6-8	-	Pg. 51, No. 8
SB-20 b	"	"	N 1850°F	2-4	-	Pg. 51, No. 8
SB-21 a	"	Si-Al (1.0 lb)	N 1500°F	6-7	-	Pg. 52, No. 9
SB-21 b	"	"	N 1900°F	2-4	-	Pg. 52, No. 9
SB-22	"	Al (3.4 lb)	N 1650°F	7-9	-	Pg. 56, No. 3
SB-23	"	Rimmed	A 1625°F	1 ME	7/8"	Pg. 59, No. 1
SB-24	"	Capped	N 1650°F	5-7	-	Pg. 60, No. 6
SB-25	"	Capped	N 1650°F	4-8	-	Pg. 60, No. 7
SB-26	"	Rimmed	Spheroid-ized	-	1"	Pg. 60, No. 8
SB-27 a	"	Not given	N 1725°F	-	1-1/8"	Pg. 62, No. 2
SB-27 b	"	Not given	Annealed	-	"	Pg. 62, No. 2

TABLE II

Chemical Composition of Carbon Steels - Weight Per Cent

Code No.	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	N	V	Co	Sn
<u>Plate</u>														
P-1 a,b	.28	.74	.012	.023	.27	.02	.02		.04	.007				
P-2	.28	.71	.012	.022	.19				.07	.007				
P-3 a,b	.27	.65	.017	.021	.22				.15	.006				
P-4	.28	.70	-	-	.25	.02	Nil	.03	.07					
P-5	.23	.73	.018	.011	.18	.05	.01	.01	.05					
P-6	.15	.51	.008	.022	.19	.01		.005						
P-7	.24	.96	.011	.027	.043				.058	.002	.006			
P-8 a,b	.15	.51	.008	.022	.19	.01	.01	.005	.13	.005	.004	.005		
P-9 a,b	.15	.50	.011	.031	.19	.028	.01	.005	.07	.005	.007	.005		
P-10 a,b	.29	.80	.009	.016	.25	.011	.01	.005	.12	.005	.006			
P-11 a,b	.29	.78	.018	.027	.23	.027	.02	.005	.07	.005	.007	.005		
P-12	.20	.40	.007	.016	.03	.010	.009	.002	.10	.005	.003	.005	.021	
P-13	.21	.40	.007	.018	.06	.014	.015	.002	.06	.005	.005	.005	.022	
P-14	.12	.76	.011	.017	.23	.05	.08	.01	.11	.05	.0076			.01
P-15	.12	.76	.012	.024	.17	.10	.07	.01	.12	.047	.0065			.01
P-16	.23	1.01	.010	.019	.17	.06	.08	.01	.07	.032	.0062			.01
P-17 a,b	.28	.74	.012	.023	.27	.02	.02		.04	.007				
P-18 a,b	.27	.65	.017	.021	.22				.15	.006				
P-19	.28	.71	.012	.022	.19				.07	.007				
P-20	.16	.55	.013	.032	.24					.005	.004			
P-21	.19	.57	.023	.034	.19					.006	.005			
P-22	.20	.66	.028	.034	.27					.015	.005			

Table II, continued

Code No.	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	N	V	Co	Sn
P-23 a,b	.20	.70	.015	.029	.18					.044	.005			
P-24 a,b	.19	.68	.026	.036	.24					.053	.004			
P-25	.18	.66	.031	.032	.26					.051	.004			
P-26 a-e	.17	.65	.009	.022	.26	.08	.12	.06	.22	.006	.003			
P-27 a,b	.23	.48	.008	.041	.26	.02	.002	.005		.02	.02			
P-28	.28	1.19	.013	.025	.26	.10	.11	.03	.18	.014				
P-29 a-c	.12	1.20	.013	.023	.11	.06	.07	.02	.09	.020	.010			
P-30 a,b	.14/ .17	.52	.010	.024	.06	.11	.17	.05	.24	.015	.009			
P-31	.31	1.16	.012	.028	.27					.050				
P-32 a,b	.27	.82	.009	.027	.21	.12	.15	.04	.22	.008				
P-33	.26	1.02	.010	.021	.25	.12	.13	.03	.12	.043				
P-34 a,b	.21	.95	.011	.019	.21	.06	.10	.02	.13	.039				
P-35	.29	1.03	.008	.023	.19	.07	.10	.02	.12	.036				
P-36	.21	1.06	.008	.015	.23	.09	.10	.03	.22	.039				
P-37	.24	.75	.019	.017	.23									
<u>Pipe and Tube</u>														
T-1	.22	.44	.015	.027	.14									
T-2 a	.25	.53	.024	.013	.14									
T-2 b	.22	.50	.023	.015	.13									
T-3	.23	.46	.013	.01	.33									
T-4	.12	.54	.018	.027	.13									
T-5	.29	.64	.014	.025	.13									
T-6	.26	.77	.011	.022	.20									
T-7	.29	.76	.018	.017	.23	.09	.05	Nil	.08					

Table II, continued

Code No.	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	N	V	Co	Sn
T-8	.11	.40	.016	.017	.04									
T-9	.16	.76	.013	.021	.16									
T-10	.26	.79	.009	.012	.19	.032	.003	.021		.023	.005			
T-11	.23	.81	.010	.012	.21	.037	.018	.005		.029	.007			
T-12	.26	.80	.013	.017	.19	.049	.003	.025		.031	.006			
T-13	.22	.75	.010	.014	.22	.036	.003	.005		.030	.006			
T-14	.26	.77	.020	.017	.17	.045	.023	.024		.044	.005			
T-15	.31	.92	.010	.014	.25	.09	.19	.02	.11	.035				
T-16	.29	.91	.010	.013	.25	.06	.07	.03	.09	.030				
T-17	.28	1.00	.008	.014	.26	.10	.15	.04	.08	.026				
T-18	.26	.86	.008	.020	.20	.05	.09	.03	.10	.025				
T-19	.29	.93	.001	.023	.24	.08	.06	.03	.10	.025				
T-20 a,b	.29	.64	.014	.025	.13					.031	.006			
T-21 a,b	.27	.43	.012	.026	.16					.029	.005			
T-22 a,b	.26	.77	.011	.022	.20					.007	.003			
T-23	.15	.49	.011	.022	.022	.06	.002	.005	.012	.094	.008			
T-24	.13	.46	.010	.018	.022	.007	.002	.005	.012	.10	.007			
T-25	.15	.48	.009	.017	.021	.025	.002	.005	.008	.11	.007			
T-26	.12	.54	.011	.019	.020	.026	.002	.005	.016	.11	.007			
T-27	.18	.42	.009	.016	.020	.034	.002	.005	.007	.09	.005			
<u>Bar</u>												Ti		
B-1	.26	.54	.007	.032	.048	.026	.009	.006		.008	.005	.006		
B-2	.20	.37	.010	.038	.26	.022	.006	.004	.01	.024	.005			
B-3	.17	.46	.009	.029	.028	.092	.007	.004	.01	.025	.005			
B-4	.20	.57	.011	.032	.22	.023	.005	.004		.006	.005			
B-5	.19	.45	.016	.023	.25	.043	.007	.005	.01	.003	.006			

Table II, continued

Code No.	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	N	Ti	Sn
B-6	.27	.54	.008	.028	.054	.038	.009	.004		.032	.005		
B-7	.26	.48	.007	.025	.27	.026	.011	.06		.029	.006		
B-8	.18	.40	.007	.021	.032	.022	.007	.003		.016	.004	.006	

Table III - P

Short-Time Tensile Properties of Carbon Steel - Plate

		(1000 psi)		Percent	
Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
P-5	75	49.5	71.2	55.0	-
P-6	80	36.0	64.4	34.0	65.0
	200	31.0	58.6	33.0	66.0
	400	32.2	70.8	22.0	52.0
	600	24.4	72.4	26.0	53.0
	800	22.8	57.8	40.0	74.0
	1000	18.8	37.0	50.0	78.0
	1200	11.2	21.8	67.0	89.0
	1400	6.0	12.2	82.0	97.0
	1600	4.4	12.8	73.0	99.0
	1900	1.8	6.6	95.0	99.0
P-7	80	36.0	72.2	36.0	30.0
	200	33.1	67.3	33.0	29.0
	400	34.6	80.1	35.0	18.0
	600	31.4	78.8	31.0	27.0
	800	31.7	60.5	32.0	30.0
	1000	26.2	38.9	26.0	32.0
	1200	13.0	16.2	13.0	38.0
	1400	7.3	11.8	7.3	74.0
	1600	5.3	8.6	5.3	74.0
	1900	1.6	4.2	1.6	66.0
P-8 a	75	33.1	60.7	42.0	65.0
	200	30.5	58.7	29.0	62.0
	400	29.9	74.2	22.0	48.0
	500	26.7	73.8	32.0	52.0
	600	23.0	66.0	38.0	63.0
	800	21.7	47.8	47.0	74.0
	1000	17.8	28.6	52.0	72.0
P-8 b	75	38.0	61.2	42.0	67.0
	200	34.0	59.0	31.0	64.0
	400	30.4	72.1	24.0	56.0
	500	29.0	71.0	36.0	60.0
	600	22.4	65.6	40.0	65.0
	800	19.8	47.4	46.0	77.0
	1000	16.3	27.9	64.0	85.0

Table III-P, continued

Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
P-9 a	75	32.6	60.1	38.0	65.0
	200	33.3	58.9	24.0	64.0
	400	33.3	77.4	22.0	51.0
	500	32.8	74.0	28.0	51.0
	600	29.8	68.1	33.0	61.0
	800	29.5	48.5	40.0	73.0
	1000	21.1	30.3	51.0	70.0
P-9 b	75	36.5	61.1	45.0	68.0
	200	34.0	59.9	28.0	63.0
	400	35.0	75.9	22.0	50.0
	500	28.3	74.1	30.0	53.0
	600	25.3	68.3	35.0	61.0
	800	22.4	48.6	47.0	76.0
	1000	17.2	30.6	50.0	81.0
P-10 al	75	42.2	87.1	30.0	53.0
	200	40.0	81.7	27.0	53.0
	400	44.2	91.6	18.0	38.0
	500	44.8	94.2	14.0	30.0
	600	43.3	94.3	21.0	30.0
	800	40.0	76.6	27.0	63.0
	1000	31.9	49.3	28.0	66.0
P-10 bl	75	44.5	83.6	32.0	56.0
	200	43.1	78.4	30.0	56.0
	400	41.9	89.7	19.0	41.0
	500	41.4	92.0	18.0	37.0
	600	39.2	92.1	26.0	44.0
	800	37.1	72.8	29.0	67.0
	1000	28.5	47.0	37.0	84.0
P-10 aT	75	43.9	86.8	29.0	50.0
	200	41.8	81.7	26.0	51.0
	400	44.1	90.8	17.0	36.0
	500	44.0	92.8	13.0	32.0
	600	43.5	93.8	22.0	30.0
	800	40.6	76.4	25.0	60.0
	1000	32.3	48.7	27.0	61.0
P-10 bT	75	42.2	83.1	33.0	53.0
	200	42.4	78.2	29.0	54.0
	400	41.9	89.3	18.0	37.0
	500	42.2	92.1	18.0	35.0
	600	39.7	91.6	25.0	42.0
	800	40.2	72.0	28.0	63.0
	1000	30.0	46.7	36.0	81.0

Table III-P, continued

Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
P-11 a	75	39.1	78.0	29.0	58.0
	200	36.3	74.2	26.0	57.0
	400	39.2	88.1	17.0	37.0
	500	42.9	91.0	20.0	33.0
	600	37.4	83.6	27.0	43.0
	800	34.3	65.1	29.0	64.0
	1000	27.8	41.6	28.0	49.0
P-11 b	75	43.9	76.8	32.0	59.0
	200	42.3	71.6	28.0	59.0
	400	40.1	85.6	19.0	45.0
	500	34.3	88.5	23.0	43.0
	600	30.3	80.2	29.0	54.0
	800	30.9	64.9	34.0	70.0
	1000	24.6	39.9	41.0	74.0
P-12	75	30.4	55.5	37.5	65.0
	200	28.7	56.4	27.0	58.5
	400	26.1	64.7	23.0	56.5
	500	25.0	66.9	25.0	53.2
	600	24.3	60.3	35.0	62.0
	800	21.8	41.4	50.0	79.0
	1000	15.4	25.8	56.0	85.0
P-13	75	32.3	58.6	38.0	63.5
	200	30.5	59.3	25.0	59.0
	400	29.5	77.8	20.0	45.2
	500	25.6	74.1	27.0	48.7
	600	25.3	65.5	37.0	62.0
	800	23.4	44.2	44.0	76.4
	1000	15.8	26.9	53.5	77.5
P-14 a	75	40.9	63.0	37.0	69.3
	200	36.7	60.1	31.0	68.6
	400	37.4	76.8	22.0	53.3
	500	33.6	76.0	24.0	51.0
	600	29.9	73.2	28.0	62.0
	800	25.6	56.8	27.0	62.0
	1000	23.5	37.9	30.0	68.0
P-14 b	Room	43.4	61.6	40.0	74.0
	200	38.3	57.8	38.0	74.0
	400	32.7	59.4	31.0	72.0
	500	31.2	60.0	33.0	71.0
	600	25.2	60.5	32.0	73.0
	800	22.5	47.7	41.0	82.0
	1000	18.0	30.7	37.0	84.0

Table III-P, continued

Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
P-15 a	Room	34.2	62.8	40.0	68.0
	200	30.3	58.3	30.0	66.0
	400	32.3	73.9	22.0	51.0
	500	30.8	74.0	23.0	53.0
	600	27.1	68.9	25.0	58.0
	800	26.0	55.2	27.0	61.0
	1000	21.2	34.2	22.0	58.0
P-15 b	Room	43.3	62.4	40.0	72.0
	200	38.0	62.6	33.0	69.0
	400	30.4	68.4	25.0	64.0
	500	26.8	61.2	30.0	70.0
	600	23.4	59.3	32.0	69.8
	800	25.6	48.8	30.0	79.0
	1000	17.0	30.4	32.0	84.0
P-16 a	Room	44.4	80.7	30.0	62.0
	200	42.2	74.9	25.0	60.0
	400	41.4	88.7	19.0	42.0
	500	35.8	87.2	20.0	42.0
	600	34.0	84.0	26.0	47.0
	800	33.2	67.2	33.0	63.0
	1000	27.9	45.9	31.0	65.0
P-16 b	Room	47.8	78.7	32.0	65.0
	200	49.7	72.9	32.0	66.0
	400	35.8	70.9	28.0	63.0
	500	29.7	74.2	28.0	62.0
	600	27.5	71.1	30.0	65.0
	800	26.8	61.9	37.0	78.0
	1000	22.6	40.0	46.0	80.0
P-17 a	75	44.5	77.5	30.0	57.0
	200	37.5	71.7	32.0	57.0
	400	36.2	77.2	23.8	49.0
	500	33.7	82.0	20.2	41.0
	600	31.7	81.0	32.0	52.0
	700	33.5	74.2	32.5	64.0
	800	29.7	65.1	35.0	72.0
	900	28.0	54.5	42.5	79.0
	1000	25.5	45.7	50.0	80.0
P-17 b	75	43.7	77.0	30.0	56.0
	200	36.9	70.0	33.7	61.0
	400	36.7	78.7	22.5	47.0
	500	31.6	82.5	21.2	43.0
	600	36.6	84.5	27.8	44.0
	700	30.2	76.5	36.0	63.0
	800	31.1	67.5	39.0	72.0
	900	29.7	56.0	42.0	79.0
	1000	23.5	41.0	50.0	78.0

Table III-P, continued

Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
P-18 a	RT	42.4	72.5	30.7	62.0
	200	38.1	66.2	33.5	62.0
	400	37.5	71.7	24.5	54.0
	500	38.6	76.0	22.2	51.0
	600	31.9	75.5	29.2	56.0
	700	31.2	70.7	34.7	63.0
	800	30.4	60.6	38.5	69.0
	900	29.5	51.7	39.5	71.0
	1000	25.4	40.5	45.0	70.0
P-18 b	RT	43.2	70.5	32.7	63.0
	200	38.2	64.7	35.0	64.0
	400	36.7	70.0	25.5	56.0
	500	33.0	71.7	22.7	55.0
	600	28.5	72.5	31.5	58.0
	700	27.0	69.2	36.2	65.0
	800	25.5	59.6	42.0	70.0
	900	25.0	49.0	42.5	75.0
	1000	21.9	40.0	52.0	78.0
P-19	RT	41.5	74.9	29.3	53.0
	200	37.7	70.5	30.3	54.0
	400	37.0	84.8	21.0	41.0
	500	34.0	87.5	22.5	36.0
	600	28.2	83.5	29.8	46.0
	700	27.7	74.7	35.2	58.0
	800	27.0	65.0	38.2	65.0
	900	25.6	51.5	40.2	72.0
	1000	23.4	42.0	49.0	82.0
P-20	75	37.0	65.5	34.0	62.0
	200	32.5	60.0	35.5	63.0
	400	34.3	72.8	24.3	49.0
	600	28.1	75.5	25.3	49.0
	800	26.6	57.5	39.5	71.0
	1000	21.4	37.3	54.8	79.0
P-21	75	34.5	61.5	35.5	64.0
	200	31.2	58.9	29.0	61.0
	400	29.3	74.3	21.0	50.0
	600	23.3	67.6	31.5	59.0
	800	22.7	51.2	39.5	73.0
	1000	18.0	31.8	54.0	83.0
P-22	75	36.7	64.3	34.5	63.0
	200	33.2	62.1	27.5	61.0
	400	31.4	74.8	20.0	49.0
	600	25.0	71.3	30.0	58.0
	800	24.9	54.7	36.5	68.0
	1000	20.4	34.5	50.0	80.0

Table III-P, continued

Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
P-23 a	75	38.0	64.5	40.0	66.0
	200	36.5	60.5	33.5	65.0
	400	32.0	61.0	32.0	56.0
	600	28.5	61.5	33.0	60.0
	800	26.8	42.0	21.5	65.0
	1000	23.5	29.8	39.5	60.0
P-23 b	Room	37.6	65.6	34.0	65.0
	200	35.4	60.9	31.0	63.0
	400	34.0	66.2	23.0	53.0
	600	28.8	69.0	30.0	59.0
	800	26.8	55.1	35.5	70.0
	1000	21.1	35.7	44.0	69.0
P-24 a	Room	35.0	64.6	34.0	58.0
	200	35.0	60.0	33.5	57.0
	400	28.8	59.4	28.5	59.0
	600	26.5	59.0	30.0	59.0
	800	23.9	52.4	40.0	70.0
	1000	20.3	34.7	40.0	58.0
P-24 b	Room	33.0	66.2	35.0	60.0
	200	30.2	61.3	32.0	55.0
	400	30.0	68.5	23.0	54.0
	600	29.2	68.7	27.0	51.0
	800	26.8	55.9	35.0	65.0
	1000	22.5	35.7	40.0	70.0
P-25	Room	36.8	65.6	32.5	61.0
	200	34.4	61.1	33.0	63.0
	400	31.7	60.5	28.5	60.0
	600	26.3	60.3	29.0	61.0
	800	25.8	54.0	40.0	69.0
	1000	20.6	37.1	37.0	56.0
P-26 a	75	42.8	64.0	41.0	66.0
	200	38.5	61.5	32.0	63.0
	300	37.6	71.8	24.0	54.0
	350	38.4	75.8	24.0	53.0
	400	34.5	74.2	24.0	52.0
	450	36.5	77.2	22.0	50.0
	500	36.0	77.8	28.0	52.0
	550	32.6	75.0	31.0	56.0
	600	26.2	72.0	34.0	56.0
	650	25.5	68.5	36.0	62.0
	700	24.4	66.0	36.0	64.0
	800	23.5	57.2	34.0	66.0
	900	22.5	45.8	40.0	68.0
	1000	20.0	36.6	41.0	68.0
	1100	15.8	26.8	48.0	77.0
	1200	9.2	16.9	78.0	90.0
	1300	7.6	12.5	82.0	96.0
	1350	6.8	10.6	92.0	92.0

Table III-P, continued

Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
	1400	6.0	9.3	106.0	84.0
	1450	5.5	9.0	114.0	76.0
	1500	5.3	10.0	74.0	70.0
	1550	4.7	10.5	68.0	86.0
	1600	4.1	9.2	74.0	82.0
	1700	3.6	7.1	68.0	86.0
	1800	2.5	5.7	71.0	95.0
P-26 b	75	35.5	57.6	44.0	68.0
	200	34.2	55.3	38.0	68.0
	400	31.2	58.6	26.0	60.0
	500	27.8	59.2	31.0	61.0
	600	22.0	58.2	32.0	60.0
	900	19.0	38.7	50.0	75.0
P-26 c	75	38.0	57.1	42.0	70.0
	200	33.2	52.8	36.0	69.0
	500	29.2	58.1	30.0	65.0
P-26 d	75	37.5	58.4	41.0	70.0
	500	29.8	59.3	30.0	62.0
P-26 e	75	40.9	62.4	38.0	69.0
	500	33.0	75.3	28.0	56.0
P-27 a	75	41.2	69.3	36.0	60.0
	200	39.0	68.0	28.0	57.0
	300	37.1	75.0	23.0	53.0
	350	38.2	78.2	22.0	51.0
	400	38.0	86.8	20.0	45.0
	450	37.5	81.0	25.0	50.0
	500	35.5	85.5	30.0	48.0
	600	25.8	76.2	35.0	60.0
	700	24.8	69.4	41.0	66.0
	800	22.9	55.5	41.0	74.0
	900	23.5	46.5	42.0	74.0
	1200	9.8	17.2	72.0	91.0
P-27 b	75	37.0	61.0	42.0	68.0
	200	33.2	56.1	38.0	68.0
	400	29.9	56.8	31.0	66.0
	500	24.4	58.0	32.0	66.0
	600	20.6	59.6	34.0	64.0
	700	20.2	57.0	46.0	72.0
	900	17.4	36.6	54.0	83.0
	1200	8.7	15.0	76.0	95.0

Table III-P, continued

Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
P-28	75	45.2	80.5	31.5	57.0
	200	42.9	74.1	28.0	63.0
	400	38.9	70.5 ?	27.0	55.0
	600	33.3	74.9	25.0	50.0
	650	31.3	74.4	27.0	55.0
	700	34.0	72.6	30.0	60.0
	750	31.6	71.8	30.0	67.0
	800	34.1	64.0	34.0	69.0
	900	31.0	54.4	35.0	74.0
P-29 a	75	40.2	65.8	37.5	73.0
	200	37.3	61.3	35.5	71.0
	400	35.35	79.4	23.0	57.0
	600	32.0	79.0	28.5	58.0
	650	30.7	74.3	31.0	60.0
	700	30.4	71.5	31.5	64.0
	750	31.1	67.25	31.0	64.0
	800	28.5	62.55	30.0	66.0
	900	30.05	54.5	29.0	65.0
P-29 b	75	43.4	67.5	32.0	68.0
	200	39.5	63.6	32.0	72.0
	400	37.5	80.2	24.0	51.0
	600	35.3	77.4	28.0	54.0
	650	32.8	74.0	32.0	61.0
	700	34.3	71.5	32.0	64.0
	750	32.7	68.7	32.0	66.0
	800	31.6	63.8	32.0	69.0
	900	31.7	54.3	28.0	69.0
P-29 c	75	41.9	67.9	32.0	75.0
	200	37.7	63.3	34.5	71.0
	400	38.4	83.7	24.5	53.0
	600	34.9	81.4	29.5	55.0
	650	33.9	77.5	30.0	59.0
	700	33.2	73.8	31.5	64.0
	750	34.2	69.7	30.5	65.0
	800	34.0	64.6	30.5	67.0
	900	31.5	55.2	30.0	67.0
P-30 a (Top)	70	31.9	60.9	33.0	58.0
	200	25.2	61.1	23.0	51.0
	300	29.6	75.4	18.0	38.0
	400	32.8	78.0	13.0	33.0
	500	26.6	74.4	21.0	38.0
	600	25.0	72.0	21.0	34.0
	650	23.8	66.8	26.0	46.0
	700	23.0	63.5	27.0	45.0
	750	22.3	58.4	25.0	37.0
	800	22.0	55.0	33.0	58.0
	850	23.1	52.3	26.0	47.0
	900	22.9	48.0	29.0	55.0

Table III-P, continued

Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
P-30 a (Bottom)	70	33.0	62.5	33.0	57.0
	200	31.3	59.0	24.0	58.0
	300	31.5	75.6	22.0	46.0
	400	31.5	75.0	21.0	46.0
	500	23.3	65.5	25.0	58.0
	600	23.4	69.5	28.0	53.0
	650	24.3	64.5	29.0	56.0
	700	21.4	61.8	28.0	57.0
	750	22.9	55.8	40.0	60.0
	800	22.7	58.9	34.0	60.0
	850	22.2	48.2	32.0	60.0
	900	21.8	44.1	30.0	56.0
P-30 b (Top)	70	42.3	65.5	32.0	59.0
	200	37.8	60.0	32.0	60.0
	300	36.9	59.8	27.0	58.0
	400	34.8	62.9	23.0	49.0
	500	28.6	61.6	24.0	51.0
	600	24.5	61.9	25.0	51.0
	650	19.4	62.1	27.0	55.0
	700	22.5	58.5	38.0	61.0
	750	21.3	56.8	35.0	61.0
	800	20.5	52.5	26.0	63.0
	850	22.2	49.5	38.0	67.0
	900	20.5	42.0	25.0	68.0
P-30 b (Bottom)	70	35.1	58.2	38.0	63.0
	200	33.6	53.5	33.0	66.0
	300	34.0	54.5	27.0	64.0
	400	31.3	53.5	28.0	62.0
	500	29.7	56.9	26.0	60.0
	600	20.9	54.5	27.0	61.0
	650	21.6	57.0	29.0	63.0
	700	22.7	54.3	37.0	66.0
	750	20.6	52.0	31.0	68.0
	800	20.6	48.5	41.0	61.0
	850	19.5	44.5	39.0	76.0
	900	17.9	42.5	46.0	72.0
P-31	70	50.1	84.4	30.0	64.0
	200	47.3	77.8	31.0	66.0
	400	39.2	75.8	29.0	81.0
	500	36.3	79.4	24.0	57.0
	600	35.5	81.1	32.0	54.0
	700	35.6	79.0	32.0	64.0
	800	32.0	68.5	32.0	70.0

Table III-P, continued

Code No.	Test Temp. °F	Yd. St.	Tensile St.	Elong.	Red. Area
P-32 a	75	43.9	79.2	29.0	44.0
	600	40.3	88.2	20.0	37.0
	700	35.7	81.3	26.0	44.0
	800	38.1	69.4	29.0	56.0
P-32 b	75	42.7	75.5	31.0	54.0
	600	34.6	72.8	23.0	42.0
	700	33.1	70.7	26.0	48.0
	800	29.8	62.2	30.0	53.0
P-33	75	44.5	81.1	30.0	62.0
	600	40.4	89.2	24.0	44.0
	700	41.8	81.8	26.0	54.0
	800	41.1	69.8	22.0	49.0
P-34 a	75	43.2	70.2	36.0	71.0
	600	26.8	67.7	37.0	71.0
	700	30.7	67.0	40.0	77.0
	800	26.6	56.9	40.0	81.0
P-34 b	75	44.0	69.4	34.0	64.0
	600	30.1	67.9	31.0	60.0
	700	29.8	61.4	36.0	70.0
	800	27.5	54.9	38.0	74.0
P-35	75	39.2	75.6	30.0	61.0
	600	36.6	83.5	22.0	45.0
	700	38.3	73.1	30.0	60.0
	800	35.6	65.2	27.0	53.0
P-36	75	42.8	73.0	34.0	59.0
	600	35.1	69.9	29.0	55.0
	700	27.3	66.2	35.0	58.0
	800	27.7	58.4	37.0	74.0
P-37	75	39.5	72.2	33.0	60.0
	200	37.2	66.4	29.0	58.0
	300	35.7	69.1	23.0	53.0
	400	34.7	76.3	19.0	45.0
	600	30.7	76.6	24.0	47.0
	700	27.0	71.5	26.0	53.0
	800	26.7	66.4	29.0	59.0

Table III - T

Short-Time Tensile Properties of Carbon Steel - Tube and Pipe

Code No.	Test Temp. °F	1000 psi Yd. St.	1000 psi Tensile St.	% Elong.	% Red. Area
T-10	70	46.3	70.1	31.0	71.0
	200	40.7	64.3	29.0	70.0
	400	40.8	65.5	27.0	69.0
	600	38.8	62.3	30.0	67.0
	800	32.9	50.6	44.0	82.0
	950	24.1	35.3	48.0	81.0
T-11	70	38.3	67.9	36.0	72.0
	200	33.4	62.0	33.0	71.0
	400	29.0	61.1	31.0	68.0
	600	26.9	62.4	36.0	70.0
	800	26.8	48.6	46.0	79.0
	950	21.2	35.1	51.0	81.0
T-12	70	41.2	71.5	30.0	69.0
	200	40.3	66.2	28.0	70.0
	400	38.8	66.7	26.0	67.0
	600	39.2	68.6	30.0	67.0
	800	32.2	52.0	38.0	79.0
	950	24.9	37.2	44.0	80.0
T-13	70	37.0	65.0	36.0	71.0
	200	33.2	60.2	35.0	71.0
	400	30.6	60.1	32.0	70.0
	600	24.8	60.6	36.0	69.0
	800	23.4	48.6	46.0	82.0
	950	20.9	33.9	56.0	84.0
T-14	70	52.2	78.8	30.0	70.0
	200	48.7	68.4	28.0	71.0
	400	43.6	68.8	25.0	68.0
	600	37.6	73.2	30.0	68.0
	800	29.5	54.1	38.0	82.0
	950	21.0	39.5	46.0	84.0
T-15	75	53.5	93.7	24.0	55.0
	300	49.9	87.2	23.0	57.0
	500	49.75	92.0	23.0	34.0
	700	48.0	80.2	24.0	57.0
	800	44.25	67.6	34.0	77.0
	900	40.5	56.8	32.0	70.0
	1000	33.5	45.2	36.0	62.0
	1100	26.5	34.1	41.0	70.0

Table III-T, continued

Code No.	Test Temp. °F	1000 psi Yd. St.	1000 psi Tensile St.	% Elong.	% Red. Area
T-16	Room	53.5	92.0	26.0	53.0
	300	47.5	84.0	25.0	58.0
	500	51.0	91.2	21.0	32.0
	700	45.5	76.5	29.0	65.0
	800	42.2	67.6	35.0	79.0
	900	38.3	53.6	41.0	78.0
	1000	-	46.3	39.0	79.0
	1100	26.7	34.8	48.0	81.0
T-17	Room	50.5	90.8	27.0	61.0
	300	46.0	83.0	25.0	60.0
	500	48.0	90.4	25.0	46.0
	700	44.8	79.5	36.0	69.0
	800	38.3	68.4	34.0	82.0
	900	37.3	57.2	39.0	81.0
	1000	32.3	46.4	36.0	72.0
	1100	26.5	35.2	47.0	80.0
T-18	Room	43.7	80.4	28.0	59.0
	300	43.5	76.9	24.0	57.0
	500	43.75	82.1	24.0	42.0
	700	37.75	67.8	31.0	62.0
	800	38.25	61.6	34.0	71.0
	900	33.25	49.6	36.0	65.0
	1000	30.50	41.5	36.0	57.0
T-19	Room	40.5	78.8	31.0	61.0
	300	-	72.0	25.0	60.0
	500	32.0	76.8	28.0	59.0
	700	31.75	71.2	33.0	68.0
	800	29.0	62.7	36.0	67.0
	900	29.0	51.9	31.0	86.0
	1000	24.9	39.6	34.0	43.0
	1100	19.4	28.4	34.0	40.0
T-20 a	75	35.0	71.4	35.0	58.0
	200	35.4	68.7	24.5	56.0
	400	35.95	81.7	16.5	41.0
	600	30.0	78.2	30.5	50.0
	800	28.25	59.1	35.5	60.0
	1000	24.9	35.0	44.0	55.0
T-20 b	75	36.5	68.8	35.0	58.0
	200	34.0	63.8	31.0	56.0
	400	29.1	65.9	31.0	52.0
	600	27.6	64.6	37.0	61.0

Table III-T, continued

Code No.	Test Temp. °F	1000 psi Yd. St.	Tensile St.	% Elong.	% Red. Area
T-22 a	75	37.5	72.0	38.5	60.0
	200	34.0	67.6	31.5	60.0
	400	34.5	75.05	21.0	48.0
	600	31.0	73.8	36.0	59.0
	800	30.3	57.0	40.0	76.0
	1000	23.3	33.2	59.5	81.0
T-22 b	75	39.5	68.5	36.0	61.0
	200	35.0	64.9	29.0	59.0
	400	32.5	71.9	24.0	54.0
	600	22.0	67.4	38.0	66.0
T-23	80	27.6	52.2	37.	-
	200	25.7	47.1	36.	-
	400	23.8	48.1	30.	-
	600	23.7	53.9	37.	-
	800	18.9	38.8	52.	-
	900	17.9	30.2	57.	-
T-24	80	31.6	50.6	39.	-
	200	28.6	47.1	38.	-
	400	26.0	49.0	28.	-
	600	16.7	47.2	36.	-
	800	16.2	35.7	55.	-
	900	15.2	28.8	58.	-
T-25	80	26.8	52.7	36.	-
	200	26.3	48.0	32.	-
	400	22.8	50.4	28.	-
	600	19.9	47.7	35.	-
	800	18.9	37.5	57.	-
	900	17.5	30.2	57.	-
T-26	80	30.4	51.6	39.	-
	200	27.9	47.6	34.	-
	400	25.4	51.2	28.	-
	600	17.9	48.3	35.	-
	800	15.9	37.5	55.	-
	900	16.9	30.1	60.	-
T-27	80	23.8*	49.6	40.	-
	200	28.1	45.7	34.	-
	400	26.2	48.4	32.	-
	600	17.2	46.9	34.	-
	800	19.2	37.0	42.	-
	900	15.3	28.5	59.	-

* This value is unreasonable and is assumed to be erroneous.

Table III - B

Short-Time Tensile Properties of Carbon Steel - Bar

Code No.	Test Temp. °F	1000 psi Yd. St.	1000 psi Tensile St.	% Elong.	% Red. Area
B-1	80°	46.1	67.0	39.0	62.0
B-2	80°	33.7	51.5	45.0	78.0
B-3	80°	35.3	55.8	40.0	68.0
B-4	80°	37.2	64.0	38.0	63.0
B-5	80°	40.9	63.8	39.0	68.0
B-6	80°	45.9	65.7	39.0	67.0
B-7	80°	46.9	69.5	37.0	65.0
B-8	80°	41.9	56.6	43.0	71.0

Table IV - P

Creep and Rupture Data - Plate

Code No.	Temp. °F	1000 psi Stress	Test[1] Duration Hours	Larsen-[2] Miller Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	At Rupture - % R.A.
P-1 a	800	37.0	745.0	28.80	.0072	34.0	68.0
		35.0	1537.0	29.22	-	30.0	68.0
		32.0	1516.0	29.20	.0023	28.0	67.0
		27.5	3355.0	29.65	-	25.0	71.0
		24.0	8385.0	30.15	.00025	3.0	72.0
	1000	24.0	7.7	30.50	-	50.0	84.0
		13.0	154.0	32.40	-	53.0	84.0
		9.0	2080.0	34.05	.00765	54.0	67.0
		7.0	5964.0	34.70	-	37.0	70.0
		5.0	32118.0	35.80	.00058	27.0	56.0
P-1 b	800	37.0	805.0	28.85	-	37.0	78.0
		35.0	1449.0	29.18	-	34.0	70.0
		27.5	4193.0	29.75	.00055	39.0	80.0
		25.0	7807.0	30.10	.00027	51.0	81.0
		20.0	2245.0 C	-	.000045		
		11.0	3000.0 C	-	.000004		
	1000	24.0	3.5	30.00	-	63.0	88.0
		18.5	33.5	31.45	-	40.0	84.0
		13.0	225.0	32.65	-	89.0	89.0
		7.5	2123.0	34.05	-	48.0	89.0
		6.0	21169.0	35.50	-	55.0	72.0
		5.0	3000.0 C	-	.00075	-	-
		3.5	3024.0 C	-	.000232	-	-
		2.5	3024.0 C	-	.000073	-	-
P-2	800	40.0	1018.0	29.00	-	36.0	65.0
		37.0	1304.0	29.12	.0040	25.0	65.0
		35.0	1775.0	29.30	.0026	30.0	68.0
		32.0	3024.0	29.57	.0009	36.0	66.0
		11.0	2544.0 C	-	.000007	-	-
		8.0	1968.0 C	-	.000002	-	-
	900	27.5	301.0	30.60	.0208	36.0	71.0
		24.0	1472.0	31.50	-	45.0	67.0
		20.0	2182.0	31.75	-	46.0	64.0
		17.0	4106.0	32.10	-	41.0	55.0
		8.5	3000.0 C	-	.000066	-	-
		7.0	2520.0 C	-	.000032	-	-

(1) All tests to rupture except those designated C, which were discontinued before rupture.

(2) P=T(C+log t), where T is degrees Rankine, t is time for rupture in hours, and C is a constant here assumed to have a value of 20.

Table IV-P, continued

Code. No.	Temp. °F	1000 psi Stress	Test[1] Duration Hours	Larsen-[2] Miller Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
	1000	13.0	400.0	33.00	.0219	67.0	73.0
		10.0	1971.0	34.00	.0010	14.5	57.0
		7.0	9750.0	35.00	.00049	17.4	44.0
		2.5	2160.0 C	-	.000010	-	-
P-3 a	900	27.0	137.0	30.10	-	32.0	49.0
		20.0	1641.0	31.60	.00235	46.0	45.0
		17.5	4039.0	32.10	.00066	29.0	45.0
		15.0	14281.0	32.85	-	29.0	34.0
		11.5	3969.0 C	-	.000066	-	-
		10.0	2616.0 C	-	.000042	-	-
		8.5	2616.0 C	-	.000032	-	-
		8.5	3048.0 C	-	.000027	-	-
		7.0	2040.0 C	-	.000014	-	-
	1030	9.75	756.0	34.10	.0058	33.0	46.0
	1080	7.8	920.0	35.35	.0124	35.0	49.0
	1140	3.75	2687.0	37.50	.0032	24.0	41.0
P-3 b	800	14.0	3126.0 C	-	.000008	-	-
		11.0	5856.0 C	-	.000003	-	-
	900	27.5	260.0	30.50	.0428	48.0	61.0
		20.0	1443.0	31.50	.0042	39.0	62.0
		15.0	11388.0	32.70	.00107	32.0	46.0
		11.5	4248.0 C	-	.000495	-	-
		11.5	2544.0 C	-	.000468	-	-
		11.5	3384.0 C	-	.000454	-	-
		10.0	3000.0 C	-	.000219	-	-
		10.0	3000.0 C	-	.000166	-	-
		8.5	2616.0 C	-	.000079	-	-
		8.5	3384.0 C	-	.000055	-	-
		7.0	2304.0 C	-	.000039	-	-
		7.0	2520.0 C		.000028	-	-
	1000	10.0	1779.0	33.95	.00657	38.0	46.0
		8.0	7991.0	34.90	.00117	12.0	38.0
		2.5	5016.0 C	-	.000015	-	-
P-4	1000	13.0	106.0	32.15	-	55.0	81.0
		11.0	793.0	33.45	-	52.0	77.0
		9.0	2941.0	34.25	-	37.0	45.0
		8.0	4875.0	34.60	-	44.0	53.0
		6.5	9966.0	35.05	.0052	19.0	43.0

Table IV-P, continued

Code. No.	Temp. °F	1000 psi Stress	Test Duration Hours (1)	Larsen-Miller Parameter (10^{-3}) (2)	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
P-5	800	43.67	706.0	28.80	.00325	20.0	52.0
		37.0	2765.0	29.53	.00014	19.5	49.0
		32.0	7362.0	30.05	.0000307	22.0	41.0
	900	27.5	671.0	31.05	.00216	29.0	39.0
		24.0	1515.0	31.55	.00065	25.0	36.0
		20.0	3997.0	32.10	.00026	28.0	35.0
		17.0	8242.0	32.50	.00028	28.0	37.0
P-8 a	800	40.0	5.7	26.15	-	34.0	61.0
		35.0	140.0	27.90	-	38.0	69.0
		35.0	194.0	28.10	.049	31.0	58.0
		30.0	1785.0	29.30	.00294	40.0	67.0
		25.0	4478.0	29.80	.00042	40.0	73.0
	900	25.0	25.3	29.10	-	51.0	80.0
		20.0	216.0	30.40	.038	52.0	80.0
		15.0	1942.0	31.65	.0081	56.0	75.0
		13.0	3663.0	32.05	-	50.0	74.0
		10.0	10471.0	32.65	.00094	65.0	76.0
		7.0	13780.0 C	-	.00014	-	-
	1000	15.0	40.5	31.55	-	65.0	87.0
		12.0	219.0	32.60	.061	70.0	82.0
		9.0	1205.0	33.70	-	62.0	75.0
		7.0	3816.0	34.45	.00126	56.0	76.0
		5.0	16150.0 C	-	.00036	-	-
		3.5	4000.0 C	-	.00008	-	-
P-8 b	800	40.0	50.0	27.35	-	30.0	54.0
		35.0	249.0	28.20	.025	30.0	60.0
		30.0	2160.0	29.40	.00194	36.0	70.0
		25.0	3900.0	29.70	.00044	46.0	74.0
	900	25.0	59.3	29.60	-	43.0	73.0
		20.0	279.0	30.55	.0271	48.0	77.0
		15.0	1610.0	31.55	.0118	45.0	73.0
		12.0	4740.0	32.20	.00095	50.0	72.0
		10.0	11090.0	32.70	.00036	55.0	75.0
	1000	15.0	25.0	31.25	-	60.0	83.0
		10.0	595.0	33.25	.014	67.0	77.0
		7.0	3990.0	34.45	.00284	50.0	66.0
		5.0	16150.0 C	-	.000105	-	-
P-10 a	800	60.0	0.5	24.80	-	26.0	64.0
		50.0	19.0	26.80	-	16.0	33.0
		48.0	251.0	28.20	-	23.0	46.0
		45.0	295.0	28.30	-	22.0	58.0
		44.0	318.0	28.35	-	21.0	50.0
		40.0	799.0	28.85	-	23.0	57.0
		35.0	1782.0	29.30	-	15.0	53.0

Table IV-P, continued

Code No.	Temp. °F	1000 psi Stress	Test[1] Duration Hours	Larsen-[2] Miller Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
		30.0	2879.0	29.55	.00053	56.0	62.0
		20.0	30978.0	30.85	.000087	-	-
		16.0	Overheated at 9130 hrs.		.000048	-	-
	900	45.0	2.4	27.70	-	27.0	40.0
		45.0	4.9	28.15	-	13.0	34.0
		40.0	26.0	29.15	-	17.0	45.0
		35.0	40.0	29.35	-	19.0	57.0
		28.0	126.0	30.05	-	19.0	63.0
		25.0	208.0	30.35	-	15.0	38.0
		25.0	235.0	30.45	.0105	62.0	70.0
		23.0	621.0	31.00	-	20.0	57.0
		20.0	876.0	31.20	.0029	61.0	68.0
		13.0	9353 0	32.60	.00053	-	-
	1000	23.0	13.0	30.85	-	34.0	78.0
		20.0	36.0	31.50	-	34.0	74.0
		15.0	214.0	32.60	-	36.0	79.0
		10.0	2105.0	34.05	-	41.0	69.0
		10.0	1355.0	33.80	.0029	86.0	89.0
		4.5	>44210.0		.00024	-	-
P-10 b	800	55.0	4.0	25.95	-	27.0	64.0
		55.0	31.0	27.10	-	29.0	55.0
		50.0	92.0	27.65	-	27.0	48.0
		45.0	486.0	28.60	-	29.0	60.0
		43.0	577.0	28.70	-	31.0	62.0
		25.0	2000.0 C	-	.00009	-	-
		20.0	2500.0 C	-	.00004	-	-
	900	45.0	1.0	27.20	-	30.0	69.0
		35.0	39.0	29.35	-	23.0	65.0
		30.0	195.0	30.30	-	43.0	76.0
		28.0	340.0	30.65	-	41.0	77.0
		13.0	2000.0 C	-	.00060	-	-
		10.0	2500.0 C	-	.00010	-	-
	1000	30.0	1.7	29.55	-	32.0	76.0
		20.0	42.0	31.55	-	31.0	83.0
		20.0	51.0	31.70	-	30.0	79.0
		15.0	242.0	32.70	-	37.0	79.0
		12.5	476.0	33.15	-	47.0	62.0
		12.0	601.0	33.25	-	38.0	81.0
		4.5	2000.0 C	-	.00017	-	-
		4.5	4500.0 C	-	.00019	-	-
P-20	1000	21.0	6.3	30.35	3.0	-	-
		16.0	26.4	31.30	.57	-	-
		11.0	392.0	33.00	.093	-	-
		9.0	2504.0	34.15	.0037	-	-
		7.5	5280.0	34.65	.00093	-	-
		2.5	2100.0 C	-	.000020	-	-

Table IV-P, continued

Code No.	Temp. °F	1000 psi Stress	Test[1] Duration Hours	Larsen-[2] Miller Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
P-21	1000	20.0	6.0	30.35	3.45	73.0	83.0
		15.0	47.0	31.65	.31	78.0	85.0
		12.0	195.0	32.55	.0045	81.0	83.0
		10.0	500.0	33.15	.016	81.0	81.0
		7.0	2650.0	34.20	.0011	-	60.0
		6.0	3000.0 C	-	.000275	-	-
		4.0	3000.0 C	-	.000036	-	-
		3.5	2650.0 C	-	.000021	-	-
P-22	1000	25.0	2.0	29.65	9.42	65.0	78.0
		20.0	14.0	30.90	1.35	69.0	80.0
		15.0	76.0	31.95	.144	78.0	82.0
		10.0	850.0	33.50	.012	77.0	73.0
		8.0	2650.0	34.20	.0014	76.0	69.0
		6.0	3000.0 C	-	.000177	-	-
		4.0	3000.0 C	-	.000031	-	-
		3.5	2650.0 C	-	.000010	-	-
P-23 a	1000	25.0	.33	28.50	40.0	-	-
		20.0	4.7	30.20	.33	38.0	-
		15.0	68.6	31.90	.0188	39.0	-
		10.0	1155.0	33.65	.0016	40.0	-
		9.0	2035.0	34.05	.0010	37.0	-
		8.0	5637.0	34.70	.00028	28.0	-
		2.5	2400.0 C	-	.00024	-	-
		2.5	1700.0 C	-	.00023	-	-
		2.5	1700.0 C	-	.00028	-	-
P-24 a	1000	30.0	.12	27.85	160.0	42.0	58.0
		24.5	.90	29.15	15.7	31.0	46.0
		20.0	6.75	30.40	2.34	38.0	45.0
		15.0	83.0	32.00	.187	46.0	49.0
		12.5	289.0	32.80	.0516	39.0	47.0
		10.0	1150.0	33.70	.0113	39.0	38.0
		9.0	2509.0	34.15	.00620	21.0	31.0
		7.0	9626.0	35.00	.00193	20.0	28.0
		3.5	2300.0 C	-	.00031	-	-
		3.5	2000.0 C	-	.00025	-	-
		2.0	2000.0 C	-	.00011	-	-
P-25	1000	30.0	.13	27.90	154.0	42.0	57.0
		24.5	1.6	29.50	9.6	35.0	44.0
		20.0	8.2	30.55	1.88	38.0	47.0
		15.0	71.0	31.90	.200	43.0	52.0
		12.5	267.0	32.75	.0534	48.0	50.0
		10.0	1171.0	33.70	.00933	31.0	41.0
		9.0	2078.0	34.05	.00439	33.0	35.0
		7.0	9240.0	35.00	.00200	20.0	33.0
		3.5	2500.0 C	-	.00025	-	-

Table IV-P, continued

Code No.	Temp. °F	1000 psi Stress	Test(1) Duration Hours	Larsen-(2) Miller Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
P-26 a	800	30.0	7235.0	30.05	.00036	35.0	56.0
		30.0	5930.0	29.95	.00035	44.0	56.0
	900	30.0	98.0	29.95	-	42.0	60.0
		24.0	541.0	30.90	.0073	43.0	57.0
		20.0	1286.0	31.40	.0014	62.0	59.0
		20.0	1541.0	31.55	.0017	42.0	57.0
		16.0	8094.0	32.50	.00028	51.0	53.0
	1000	10.5	1281.0	33.75	.016	70.0	54.0
		10.5	1088.0	33.65	.011	71.0	51.0
	1100	20.0	.5	-	-	66.0	81.0
		20.0	.45	-	-	61.0	80.0
		10.5	32.0	33.55	.84	70.0	75.0
		10.5	45.0	33.75	.55	70.0	72.0
		7.0	336.0	35.15	.067	71.0	55.0
		7.0	367.0	35.20	.058	75.0	56.0
		5.5	1054.0	35.90	.022	56.0	52.0
		5.5	1130.0	35.95	.019	68.0	55.0
P-26 c	800	30.0	849.0	28.90	.024	52.0	72.0
	900	20.0	492.0	30.85	.052	59.0	68.0
		16.0	3800.0	32.05	.0059	58.0	54.0
	1000	10.5	873.0	33.50	.027	47.0	47.0
P-27 a	800	(1)30.0	2278.0	29.40	.0019	42.0	73.0
		(2)30.0	2430.0 C	-	.00050	-	-
	900	(1)20.0	399.0	30.75	.021	49.0	80.0
		(2)20.0	879.0	31.20	.0055	46.0	76.0
		(3)20.0	826.0	31.15	.0042	58.0	80.0
P-27 b	800	(1)30.0	35.0	27.15	-	59.0	78.0
		(2)30.0	57.0	27.40	-	61.0	78.0
		(3)30.0	50.0	27.35	-	58.0	63.0
	900	(1)20.0	44.0	29.43	-	66.0	82.0
		(2)20.0	57.0	29.60	-	69.0	81.0
		(3)20.0	59.0	29.60	-	74.0	81.0
P-27 c	900	(1)20.0	340.0	30.65	.018	61.0	75.0
		(2)20.0	660.0	31.05	.0047	55.0	73.0
		(3)20.0	627.0	31.00	.0047	56.0	74.0

(1) Edge of 6' wide plate
(2) Quarter point of 6' wide plate
(3) Center of 6' wide plate

Table IV - T

Creep and Rupture Data - Pipe and Tube

Code No.	Temp. °F	1000 psi Stress	Test[1] Duration Hours	Larsen-Miller[2] Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
T-1	850	27.0	145.0	29.00	-	38.0	57.0
		25.0	204.0	29.25	-	41.0	52.0
		23.0	450.0	29.65	-	30.0	39.0
		21.6	794.0	30.00	-	43.0	43.0
		18.0	2567.0	30.65	-	31.0	38.0
		16.5	8931.0	31.35	-	38.0	22.0
		15.0	15192.0	31.70	-	20.0	29.0
		13.5	27224.0	32.00	-	35.0	30.0
	950	20.0	20.4	30.05	-	29.0	43.0
		18.0	87.3	30.95	-	32.0	37.0
		16.76	236.0	31.55	-	27.0	35.0
		12.8	983.0	32.45	-	26.0	32.0
		10.5	2384.0	32.95	-	22.0	27.0
		8.5	8261.0	33.75	-	21.0	22.0
		8.0	5329.0	33.45	-	23.0	33.0
		7.5	27961.0	34.45	-	17.0	9.6
T-2 a	850	25.0	702.0	29.95	-	44.0	79.0
		23.0	3057.0	30.75	.00025	54.0	79.0
		20.0	8007.0	31.30	-	42.0	78.0
	950	15.0	839.0	32.35	.02467	77.0	83.0
		13.5	1790.0	32.80	.011	63.0	82.0
		12.0	3190.0	33.15	.0073	64.0	82.0
		10.0	4406.0	33.35	-	34.0	81.0
T-2 b	850	25.0	177.0	29.15	.050	37.0	81.0
		21.5	1498.0	30.35	.00167	30.0	75.0
		20.0	2223.0	30.60	.0004	105.0	81.0
		18.0	4076.0	30.95	-	49.0	78.0
	950	15.0	312.0	31.70	-	36.0	81.0
		12.5	1200.0	32.55	-	51.0	70.0
		10.5	3822.0	33.25	-	28.0	63.0
		9.4	6050.0	33.55	-	38.0	57.0
T-3	850	28.0	238.0	29.30	.125	62.0	79.0
		23.0	1988.0	30.50	.0145	47.0	70.0
		21.5	4772.0	31.05	.007	78.0	73.0
		20.0	12801.0	31.60	.00295	78.0	80.0

(1) All tests to rupture except those designated C, which were discontinued before rupture.

(2) $P=T(C+\log t)$; C assumed to have value of 20

Table IV-T, continued

Code. No.	Temp. °F	1000 psi Stress	Test(1) Duration Hours	Larsen-(2) Miller Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
T-3	950	17.0	330.0	31.75	.084	54.0	83.0
		15.0	1387	32.65	.0231	85.0	84.0
		13.5	2998.	33.10	.011	82.0	81.0
		12.0	6228.0	33.55	.00525	69.0	76.0
T-4	850	25.0	49.0	28.40	-	59.0	85.0
		20.0	296.0	29.45	-	78.0	87.0
		17.0	837.0	30.05	-	69.0	81.0
		13.5	5805.0	31.15	-	83.0	74.0
		12.5	8605.0	31.35	-	67.0	66.0
	950	14.0	81.0	30.90	-	49.0	84.0
		13.5	104.0	31.10	-	53.0	84.0
		11.0	441.0	31.95	-	68.0	77.0
		9.0	1832.0	32.85	-	76.0	63.0
		7.7	3355.0	33.15	-	45.0	62.0
		7.0	6650.0	33.60	-	51.0	53.0
T-7	850	40.0	378.0	29.60	.0088	2.0	5.7
		35.0	245.0	29.35	.0335	14.5	17.3
		30.0	1641.0	30.40	-	8.5	17.8
		25.0	14875.0	31.65	.00032	7.5	9.0
	950	25.0	137.0	31.25	-	14.0	18.5
		20.0	1490.0	32.70	.0045	5.0	4.5
		15.0	4729.0	33.40	.00061	5.0	16.7
		12.0	21921.0	34.35	.000351	20.0	21.0
T-8	850	25.0	32.0	28.20	-	43.0	86.0
		20.0	93.0	28.80	-	49.0	40.0
		15.0	730.0	30.00	-	55.0	69.0
		11.8	7765.0	31.30	-	56.0	68.0
		10.0	14987.0	31.70	-	49.0	47.0
	950	18.0	56.0	30.70	-	77.0	85.0
		14.0	43.0	30.55	-	69.0	90.0
		9.0	648.0	32.20	-	50.0	51.0
		6.5	5809.0	33.50	-	39.0	38.0
		5.7	10967.0	33.90	-	32.0	31.0
T-9	850	22.0	1272.0	30.25	-	69.0	-
		18.0	5607.0	31.10	-	71.0	-
	950	14.0	567.0	32.10	-	84.0	-
		11.0	2146.0	32.90	-	83.0	-
		9.0	20657.0	34.30	-	19.0	-
T-10	800	35.0	25.8	27.00	-	45.0	-
		30.0	190.0	28.10	-	43.0	-
		26.0	806.0	28.85	-	40.0	-

Table IV-T, continued

Code. No.	Temp. °F	1000 psi Stress	Test[1] Duration Hours	Larsen-[2] Miller Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
T-10	950	15.0	185.0	31.40	-	62.0	-
		13.0	410.0	31.90	-	67.0	-
T-11	800	31.0	109.0	27.75	-	50.0	-
		30.0	169.0	28.00	-	52.0	-
		29.0	271.0	28.25	-	51.0	-
		27.0	575.0	28.70	-	48.0	-
	950	17.0	137.0	31.25	-	67.0	-
		16.0	158.0	31.35	-	74.0	-
		15.0	263.0	31.65	-	72.0	-
		14.0	367.0	31.85	-	66.0	-
T-12	800	40.0	19.0	26.80	-	39.0	-
		35.0	108.0	27.75	.780	40.0	-
		32.0	207.0	28.10	.126	48.0	-
		28.0	846.0	28.90	.0350	50.0	-
		25.0	2308.0	29.40	.0119	54.0	-
		23.0	4300.0	29.75	.0068	55.0	-
	950	20.0	47.0	30.60	-	63.0	-
		17.0	208.0	31.50	.166	64.0	-
		15.0	593.0	32.15	.072	75.0	-
		13.0	944.0	32.40	.038	73.0	-
		10.0	4492.0	33.35	.0086	60.0	-
T-13	800	37.0	19.5	26.80	-	50.0	-
		34.0	74.4	27.55	-	48.0	-
		28.0	280.0	28.30	.101	57.0	-
		26.0	591.0	28.70	.0540	58.0	-
		22.0	3051.0	29.60	.0106	59.0	-
		20.0	5425.0	29.90	.0050	63.0	-
	950	20.0	26.7	30.25	-	70.0	-
		17.0	45.6	30.55	-	65.0	-
		15.0	231.0	31.55	.1620	65.0	-
		13.0	555.0	32.10	.0585	72.0	-
		9.0	4699.0	33.40	.0068	74.0	-
T-14	800	35.0	119.0	27.80	.2554	45.0	-
		32.0	362.0	28.40	.1050	43.0	-
		31.0	408.0	28.50	.1004	55.0	-
		28.0	1338.0	29.15	.0205	51.0	-
		25.0	3065.0	29.60	.0106	55.0	-
	950	20.0	65.5	30.80	-	55.0	-
		18.0	163.4	31.35	.2793	55.0	
		17.0	234.0	31.55	.1889	61.0	-
		17.0	342.0	31.80	.1006	60.0	-
		15.0	446.0	31.95	.1045	60.0	-
		15.0	534.0	32.05	.0638	60.0	-

Table IV-T, continued

Code No.	Temp. °F	1000 psi Stress	Test[1] Duration Hours	Larsen-[2] Miller Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
		14.0	997.0	32.45	.0318	56.0	-
		11.0	3031.0	33.10	.0116	53.0	-
T-20 a	1000	15.0	358.0	32.95	.02368	46.0	49.0
		13.5	440.0	33.05	.01478	38.0	53.0
		9.5	2190.0	34.05	.00391	43.0	62.0
		6.5	11557.0	35.10	.00017	41.0	55.0
T-21 a	1000	29.0	0.1	-	-	51.0	68.0
		28.0	0.3	-	-	47.0	61.0
		25.0	1.2	29.35	-	49.0	61.0
		22.0	4.5	30.20	-	53.0	57.0
		20.0	9.4	30.60	-	55.0	57.0
		17.5	23.9	31.20	.580	40.0	50.0
		15.0	107.0	32.20	.042	40.0	52.0
		13.0	405.0	33.00	.010	53.0	61.0
		11.5	813.0	33.45	.00169	68.0	64.0
		10.0	1822.0	33.95	.00286	43.0	52.0
		8.9	2920.0	34.25	.00365	38.0	65.0
		8.5	3475.0	34.40	.000897	32.0	52.0
		7.0	8592.0	34.95	.000439	30.0	37.0
T-22 a	1000	18.0	85.0	32.00	-	55.0	78.0
		15.0	225.0	32.60	.02475	41.0	66.0
		15.0	251.0	32.70	-	54.0	75.0
		13.5	725.0	33.40	.01012	40.0	56.0
		12.0	1280.0	33.75	.00739	37.0	59.0
		11.5	572.0	33.25	-	59.0	73.0
		9.5	3970.0	34.45	.00271	39.0	59.0
		9.0	3171.0	34.30	-	45.0	61.0
		8.0	8852.0	34.95	.00033	51.0	65.0
T-23	800	24.7	129.0	27.90	-	51.0	-
		22.0	225.0	28.20	.241	47.0	-
		21.0	720.0	28.80	.096	53.0	-
		18.0	1800.0	29.30	.039	63.0	-
		16.0	6359.0	30.00	.0097	68.0	-
	900	15.0	320.0	30.60	.218	63.0	-
		14.0	418.0	30.75	.129	62.0	-
		12.0	1169.0	31.35	.059	65.0	-
		10.0	4054.0	32.10	.0184	52.0	-
T-24	800	24.0	44.7	27.30	-	54.0	-
		21.0	311.0	28.35	-	54.0	-
		20.0	447.0	28.55	-	53.0	-
		18.0	1781.0	29.30	-	63.0	-
	900	17.0	47.5	29.45	-	71.0	-
		14.0	223.0	30.40	-	61.0	-
		13.0	484.0	30.85	-	68.0	-
		12.0	819.0	31.15	-	81.0	-

Table IV-T, continued

Code No.	Temp. °F	1000 psi Stress	Test(1) Duration Hours	Larsen-(2) Miller Parameter (10^{-3})	Min. Creep Rate %/hour	At Rupture - % Elong.	R.A.
T-25	800	25.0	74.0	27.60	-	51.0	-
		23.0	201.0	28.10	.345	56.0	-
		21.0	740.0	28.85	.074	53.0	-
		18.0	3683.0	29.70	.02	51.0	-
	900	17.0	101.0	29.90	-	66.0	-
		15.0	338.0	30.65	.152	63.0	-
		13.0	833.0	31.15	.066	60.0	-
		12.0	2285.0	31.75	.036	71.0	-
		11.0	4263.0	32.15	.019	67.0	-
T-26	800	28.0	22.0	26.90	-	52.0	-
		25.0	114.0	27.85	-	55.0	-
		24.0	166.0	28.00	-	55.0	-
		23.0	172.0	28.05	-	52.0	-
		20.0	746.0	28.85	-	54.0	-
	900	17.0	79.0	29.75	-	64.0	-
		16.0	168.0	30.20	-	63.0	-
		15.0	327.0	30.60	-	74.0	-
		13.5	685.0	31.05	-	80.0	-
T-27	800	24.0	37.0	27.20	-	59.0	-
		20.0	321.0	28.40	.186	58.0	-
		19.0	860.0	28.90	.071	64.0	-
		17.5	1221.0	29.10	.049	60.0	-
		16.0	3158.0	29.60	.022	57.0	-
	900	15.0	164.0	30.20	.51	67.0	-
		13.0	425.0	30.75	.148	57.0	-
		12.0	790.0	31.15	.07	53.0	-
		10.0	3177.0	31.95	.027	69.0	-
		9.5	4191.0	32.10	.014	75.0	-

Table IV-B

Creep and Rupture Data - Bar

Code No.	Temp. °F	1000 psi Stress	Test[1] Duration Hours	Larsen-Miller[2] Parameter (10^{-3})	Min. Creep Rate-%/hr	Percent Elong	Percent Red. Area
B-1	900	33.0	2.2	27.65	-	60.0	-
		30.0	6.7	28.35	-	60.0	-
		25.0	44.9	29.45	-	71.0	-
		22.0	162.0	30.20	-	67.0	-
		19.0	511.0	30.90	-	68.0	-
		17.0	959.0	31.25	-	60.0	-
	1050	20.0	-	-	-	70.0	-
		15.0	7.2	31.50	-	80.0	-
		12.5	19.4	32.15	-	77.0	-
		10.0	72.7	33.0	-	92.0	-
		8.0	242.0	33.80	-	85.0	-
		6.8	757.0	34.55	-	73.0	-
B-2	900	30.0	0.1	-	-	41.0	-
		25.0	1.9	27.55	-	65.0	-
		20.0	29.7	29.20	-	84.0	-
		15.0	224.0	30.40	-	93.0	-
		12.0	1180.0	31.35	-	92.0	-
	1050	19.0	0.3	-	-	87.0	-
		15.0	1.7	30.55	-	79.0	-
		9.0	57.0	32.85	-	76.0	-
		7.0	214.0	33.70	-	61.0	-
		5.5	760.0	34.55	-	73.0	-
B-3	900	29.0	0.4	-	-	65.0	-
		23.0	8.7	28.45	-	75.0	-
		20.0	41.4	29.40	-	80.0	-
		17.0	131.0	30.10	-	90.0	-
		15.0	251.0	30.50	-	96.0	-
		13.0	981.0	31.30	-	85.0	-
	1050	18.0	0.4	-	-	85.0	-
		15.0	2.7	30.85	-	95.0	-
		10.0	34.5	32.50	-	94.0	-
		7.0	376.0	34.10	-	80.0	-
		6.0	809.0	34.60	-	67.0	-

(1) All tests to rupture except those designated C, which were discontinued before rupture.
(2) $P=T(C+\log t)$, where T is degrees Rankine, t is time for rupture in hours, and C is a constant here assumed to have a value of 20.

Table IV-B, continued

Code No.	Temp. °F	1000 psi Stress	Test(1) Duration Hours	Larsen-(2) Miller Parameter (10^{-3})	Min. Creep Rate-%/hr	Percent Elong.	R. A.
B-4	900	35.0	1.8	27.55	-	51.0	-
		31.5	15.2	28.80	-	45.0	-
		29.0	41.1	29.40	-	56.0	-
		25.0	127.0	30.10	-	52.0	-
		20.0	805.0	31.15	-	50.0	-
	1050	18.0	3.1	30.95	-	75.0	-
		15.0	13.9	31.90	-	74.0	-
		12.0	55.2	32.85	-	66.0	-
		9.4	180.0	33.60	-	87.0	-
		7.0	559.0	34.35	-	55.0	-
		6.0	1227.0	34.85	-	54.0	-
B-5	800	35.0	189.0 C	-	.0276	-	-
		33.0	552.0 C	-	.00612	-	-
		28.0	2000.0 C	-	.000717	-	-
		24.0	3000.0 C	-	.000176	-	-
		22.0	3000.0 C	-	.0000933	-	-
	900	30.0	8.9	28.45	-	56.0	-
		27.5	63.0	29.65	-	46.0	-
		25.0	146.0	30.15	-	50.0	-
		22.0	410.0	30.75	-	51.0	-
		19.0	820.0	31.15	-	63.0	-
		18.0	259.0 C	-	.00556	-	-
		16.0	336.0 C	-	.00202	-	-
		11.0	1824.0 C	-	.000636	-	-
		9.0	3145.0 C	-	.000211	-	-
		6.0	3000.0 C	-	.0000194	-	-
		5.0	3000.0 C	-	.0000103	-	-
	1050	19.0	1.1	30.25	-	75.0	-
		17.0	3.3	31.00	-	65.0	-
		13.0	21.3	32.20	-	81.0	-
		8.6	234.0	33.75	-	86.0	-
		6.5	699.0	34.45	-	62.0	-
B-6	900	30.0	1.7	27.45	-	66.0	-
		25.0	22.0	29.05	-	76.0	-
		20.0	79.0	29.75	-	78.0	-
		15.5	501.0	30.90	-	89.0	-
		13.0	1424.0	31.50	-	85.0	-
	1050	20.8	0.6	-	-	78.0	-
		15.0	5.9	31.35	-	54.0	-
		10.0	44.0	32.65	-	53.0	-
		7.0	335.0	34.00	-	105.0	-
		5.8	869.0	34.60	-	94.0	-
B-7	900	30.0	2.6	27.75	-	71.0	-

Table IV-B, continued

Code No.	Temp. °F	1000 psi Stress	Test[1] Duration Hours	Larsen-[2] Miller Parameter (10^{-3})	Min. Creep Rate-%/hr.	Percent Elong.	Percent R. A.
	900	25.0	10.5	28.60	-	75.0	-
		20.0	66.8	29.65	-	65.0	-
		16.0	391.0	30.75	-	87.0	-
		14.5	689.0	31.05	-	88.0	-
	1050	18.0	1.1	30.25	-	75.0	-
		15.0	4.0	31.10	-	84.0	-
		12.0	23.6	32.25	-	97.0	-
		9.0	92.0	33.15	-	100.0	-
		5.6	704.0	34.50	-	65.0	-
B-8	900	29.0	0.3	-	-	64.0	-
		24.0	3.4	27.90	-	60.0	-
		20.0	23.9	29.05	-	60.0	-
		17.0	82.6	29.85	-	85.0	-
		12.0	858.0	31.20	-	87.0	-
	1050	15.0	1.5	30.45	-	78.0	-
		11.0	17.1	32.05	-	85.0	-
		8.0	121.0	33.35	-	79.0	-
		5.8	761.0	34.55	-	67.0	-

Table V

Ratio of Elevated Temperature Yield and Tensile Strengths

to Strengths at Room Temperature

Carbon Steel

	Yield Strength Ratio					Tensile Strength Ratio			
Temp.°F	CG-NT	CG-T	FG-NT	FG-T	(CG+FG)-T	CG-NT	CG-T	FG-NT	FG-T
75	1.00	1.0	1.0	1.0	1.0	1.0	1.00	1.0	1.0
100	.978	.975	.99	.987	.985	.988	.980	.975	.975
200	.927	.911	.959	.936	.928	.961	.941	.932	.919
300	.945	.908	.943	.875	.880	1.073	1.015	1.013	.930
400	.938	.879	.918	.801	.830	1.162	1.094	1.090	.953
500	.891	.813	.881	.748	.780	1.172	1.117	1.106	.962
600	.825	.738	.836	.708	.732	1.101	1.075	1.048	.935
700	.773	.688	.790	.674	.688	.976	.978	.931	.864
800	.750	.673	.748	.637	.649	.833	.848	.785	.753
900	.728	.640	.703	.583	.606	.689	.702	.639	.614
1000	.608	.554	.635	.503	.542	.519	.541	.511	.467
1100			.500			.385		.391	
1200						.265		.227	

CG - Coarse-grained deoxidation practice

FG - Fine-grained deoxidation practice

NT - Not tempered

T - Tempered

Table VI

Summary of 10,000-Hour Rupture Strengths (1000 psi)

Code No.	Temperature °F 800	850	900	950	1000	1050	1100
<u>Plate</u>							
P-1 a	23.0				6.4		
P-1 b	24.0				6.6		
P-2	25.0		14.1		6.8		
P-3 a			15.4				
P-3 b			15.0				
P-4					6.4		
P-5	30.0		16.2				
P-8 a	21.8		10.1		5.7		
P-8 b	21.5		10.3		5.6		
P-10 a	24.5		13.0		7.4		
P-10 b					6.0		
P-20					7.1		
P-21					5.4		
P-22					6.3		
P-23 a					7.3		
P-24 a					6.9		
P-25					7.0		
P-26 a			15.2		-		3.4
<u>Pipe-tube</u>							
T-1		15.6		8.6			
T-2 a		19.0		8.4			
T-2 b		15.4		8.5			
T-3		19.9		11.1			
T-4		12.1		6.5			
T-5	(same as T-20 a)						
T-6	(same as T-22 a)						
T-7		25.1		13.8			
T-8		10.6		5.8			
T-9		16.4		9.5			
T-10	20.5						
T-11	19.5						
T-12	20.8			8.8			
T-13	18.8			8.4			
T-14	21.5			8.7			
T-20 a					6.6		
T-21 a					6.7		
T-22 a					7.6		
T-23	15.1		8.7				
T-24	15.2		9.0				
T-25	16.6		10.0				
T-26	15.2		10.0				
T-27	14.7		8.4				

Table VI, continued

Code No.	Temperature °F 800	850	900	950	1000	1050
Bar						
B-1			12.1			4.4
B-2			8.8			3.3
B-3			9.5			4.0
B-4			14.2			3.8
B-5			12.8			3.5
B-6			9.6			3.4
B-7			9.4			3.0
B-8			8.2			3.0
SB-2		13.2				
SB-3		13.0				
SB-4	26.8		15.0		6.8	
SB-10		20.7				
SB-11		13.1				
Sb-12		13.1				
SB-13		17.1				
SB-15		19.2				
SB-17		17.0				
SB-18		20.0				
SB-22		--				
SB-24		14.2				
SB-25		17.2				

Table VII

Summary of 0.1% per 1000 Hour Creep Strengths (1000 psi)

Code No.	Temperature °F						
	800	850	900	950	1000	1050	1100
Plate							
P-1 a	21.1				3.3		
P-1 b	22.8				2.7		
P-2	23.2		9.5		4.8		
P-3 a			12.8		-		
P-3 b	25.2		9.2		4.1		
P-5	36.0		15.0				
P-8 a	23.0		6.5		3.7		
P-8 b	22.0		8.1		4.5		
P-10 a	20.2		9.0		3.4		
P-10 b	26.0		10.0		-		
P-20					3.9		
P-21					4.8		
P-22					5.1		
P-23 a					?		
P-24 a					?		
P-25					?		
P-26 a			14.0				
Pipe-tube							
T-2 b		18.5		-			
T-7		21.5		10.5			
T-20 a					5.4		
T-21 a					5.3		
T-22 a					6.1		
Bar							
B-5	22.0		8.2				
SB-1					3.9		
SB-4	26.5		16.5		5.6		1.9
SB-7 a	17.0				3.3		
SB-7 b					7.1		
SB-7 c					5.5		
SB-7 d					5.2		
SB-8 a					12.5		
SB-8 b					9.9		
SB-8 c					6.2		
SB-8 d					5.8		
SB-9 a					2.6		
SB-9 b					3.8		
SB-9 c					2.2		
SB-10		17.5					

Table VII, continued

Code No.	Temperature °F						
	800	850	900	950	1000	1050	1100
SB-13		13.0					
SB-14	19.2		11.2		7.1		
SB-15		17.2					
SB-16	12.2				3.4		
SB-17 a		7.1					
SB-23	13.8		8.1		3.0		
SB-26					2.2		
SB-27	13.3				4.3		

Table VIII

Summary of 100,000-Hour Rupture Strengths (1000 psi)

Code No.	Temperature °F					
	800	850	900	950	1000	1100
Plate						
P-1 a	15.0				4.0	
P-1 b	15.3				4.5	
P-2	16.0		8.7		4.1	
P-3 a			11.5			
P-3 b			10.5		5.3	
P-4					3.7	
P-5	22.0		10.1			
P-8 a	14.0		6.0		3.5	
P-8 b	14.0		6.5		3.5	
P-10 a	16.5		8.8		5.0	
P-10 b	**		**		**	
P-20					5.2	
P-21					3.4	
P-22					4.2	
P-23 a					5.3	
P-24 a					4.6	
P-25					4.7	
P-26 a			11.0			2.1
Pipe-tube						
T-1		11.8		6.0		
T-2 a		13.5		4.8		
T-2 b		10.4		5.6		
T-3		16.4		8.0		
T-4		8.9		4.4		
T-5					3.9	
T-6					4.7	
T-7		19.0		9.1		
T-8		7.7		3.9		
T-9		11.9		7.2		
T-10	17.0*			*		
T-11	17.0*			*		
T-12	16.1			5.7		
T-13	14.3			5.3		
T-14	16.5			5.6		
T-20 a	(same as T5)					
T-21 a					4.1	

* Data relatively inadequate or scattered; value not included in further evaluation

** Longest test <1000 hrs. No extrapolation attempted.

Table VIII, continued

Code No.	Temperature °F 800	850	900	950	1000	1050
T-22 a	(same as T6)					
T-23	12.0		6.3			
T-24	12.8					
T-25	13.9		7.8			
T-26	*		*			
T-27	12.1		6.3			
<u>Bar</u>						
B-1			8.8*			3.0*
B-2			6.4			2.2*
B-3			7.0			2.8*
B-4			10.5*			2.3
B-5			8.6*			2.1*
B-6			6.6			2.1*
B-7			6.6*			1.8*
B-8			5.9*			2.4*
SB-2		10.0				
SB-3		9.6				
SB-4	21.0		10.8		2.8	
SB-10		16.8*				
SB-11		9.0*				
SB-12		**				
SB-13		13.5				
SB-15		15.0				
SB-17		13.5*				
SB-18		15.5*				
SB-22		**				
SB-24		12.0*				
SB-25		14.5				

* Data relatively inadequate or scattered; value not included in further evaluation.

** Longest test <1000 hrs. No extrapolation attempted.

TABLE IX

Summary of 0.01% per 1000 Hours Creep Strengths (1000 psi)

Code No.	Temperature °F 800	850	900	950	1000	1100
Plate						
P-1 a	15.0*				2.0*	
P-1 b	14.9				1.4	
P-2	14.0		5.0		2.4	
P-3 a			6.0			
P-3 b	14.8		5.5		2.2	
P-5	26.0		9.0*			
P-8 a			4.1		2.1	
P-8 b			5.5*		3.0	
P-10 a	11.5					
P-10 b	13.8		7.1			
P-20					2.0	
P-21					2.9	
P-22					3.4	
P-23 a					?	
P-24 a					?	
P-25					?	
P-26 a	-		-			
Pipe-tube						
T-2 b		-		-		
T-7		-		-		
T-20 a					3.2*	
T-21 a					3.1*	
Bar						
B-5	17.0		5.1			
SB-1					1.9	
SB-4	18.5		12.5		2.6	0.8
SB-7 a	12.0				1.8	
SB-7 b					5.7	
SB-7 c					4.0	
SB-7 d					2.6	
SB-8 a					7.0	
SB-8 b					4.9	
SB-8 c					3.0	
SB-8 d					2.8	
SB-9 a					-	
SB-9 b					-	
SB-9 c					-	
SB-10		14.0				

* Extrapolation by more than 1 log cycle. Excluded from further analysis.

Table IX, continued

Code No.	Temperature °F					
	800	850	900	950	1000	1100
SB-13		10.0				
SB-14	13.2		8.4		2.1	
SB-15		13.5				
SB-16	7.6				2.1	
SB-19 a		4.7				
SB-23	8.5		5.5		1.4	
SB-26					1.4	
SB-27 b	9.6				3.1	

Table X

Summary - Stress for Rupture in 10,000 Hours (1000 psi)

Average

Temp. °F	Log-Log Extrap. All data	Log-Log Extrap. C.G.	Log-Log Extrap. F.G.	Larsen-Miller Extrap. All data	Larsen-Miller Extrap. C.G.	Larsen-Miller Extrap. F.G.	Larsen-Miller Extrap. Bar	Larsen-Miller Extrap. Pipe-Tube	Larsen-Miller Extrap. Plate
800	21.35	24.83	18.2	21.6	24.8	18.3	21.0	19.0	25.1
850	15.58	17.2	13.4	16.5	18.4	14.3	15.8	15.2	18.5
900	11.37	12.4	10.0	12.3	13.4	11.0	11.5	12.0	13.3
950	8.30	8.7	7.4	9.1	9.6	8.5	8.0	9.4	9.4
1000	6.05	6.31	5.53	6.7	6.8	6.5	5.5	7.4	6.8
1050	4.41	4.4	4.05	4.9	4.7	*	*	*	5.1

* Beyond limit of data

Minimum - 90% Confidence

Temp. °F	Log-Log Extrap. All data	Log-Log Extrap. C.G.	Log-Log Extrap. F.G.	Larsen-Miller Extrap. All data	Larsen-Miller Extrap. C.G.	Larsen-Miller Extrap. F.G.	Larsen-Miller Extrap. Bar	Larsen-Miller Extrap. Pipe-Tube	Larsen-Miller Extrap. Plate
800	15.7	19.2	13.8	15.3	19.6	14.0	15.8	13.6	19.5
850	11.3	13.7	10.0	11.8	14.7	10.9	11.8	10.9	14.3
900	8.2	9.7	7.5	8.8	10.7	8.4	8.6	8.6	10.3
950	6.0	6.9	5.5	6.5	7.6	6.5	6.0	6.8	7.4
1000	4.4	4.9	4.1	4.8	5.4	4.9	4.1	5.3	5.3
1050	3.2	3.5	3.05	3.5	3.7	*	*	*	4.0

Table XI

Summary - Stress to Rupture in 100,000 Hours (1000 psi)

Average

	Log-Log Extrap.					Larson-Miller Extrapolation					
				Spec. Min. T.S.							
Temp. °F	All Data	C.G.	F.G.	<60 Ksi	≥60 Ksi	All Data	C.G.	F.G.	Bar	Pipe-Tube	Plate
800	15.85	15.94	14.2	12.8	17.7	16.2	18.0	14.1	15.5	15.0	18.3
850	11.35	11.40	9.6	9.0	12.3	11.9	13.0	10.8	11.1	11.9	12.8
900	8.11	8.18	6.94	6.4	8.8	8.7	9.2	8.1	7.7	9.2	9.1
950	5.80	5.90	5.36	4.5	6.3	6.4	6.4	6.2	5.2	7.1	6.5
1000	4.15	4.17	4.42	3.35	4.5	4.6	4.3	*	*	*	4.8
1050											

*Beyond limit of data

Minimum - 90% Confidence

	Log-Log Extrap.					Larson-Miller Extrapolation					
				Spec. Min. T.S.							
Temp. °f	All Data	C.G.	F.G.	<60 Ksi	≥60 Ksi	All Data	C.G.	F.G.	Bar	Pipe-Tube	Plate
800	11.0	12.0	11.2	10.8	13.2	11.7	14.5	10.8	11.7	10.8	14.1
850	7.8	8.5	7.7	7.7	9.4	8.6	10.3	8.2	8.3	8.4	10.0
900	5.6	6.1	5.5	5.4	6.7	6.3	7.3	6.2	5.8	6.6	7.1
950	4.0	4.15	4.25	3.9	4.7	4.6	5.1	4.7	3.9	5.1	5.1
1000	2.9	3.1	3.55	2.75	3.3	3.7	3.4	*	*	*	3.8
1050											

*Beyond limit of data

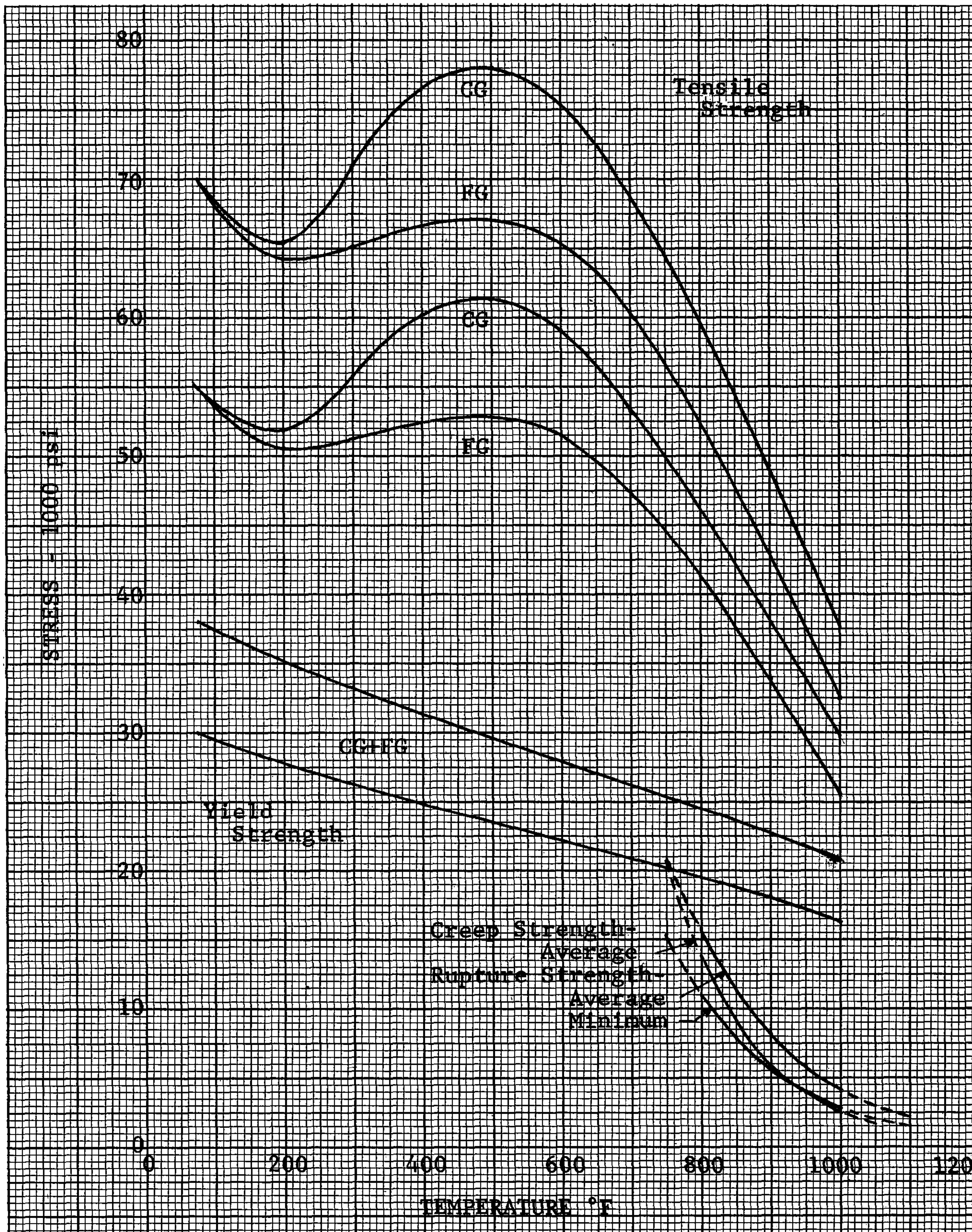

Fig. 1 Effect of temperature on yield, tensile, creep and rupture strengths of carbon steel. Yield and tensile strength curves have been adjusted to 30,000 or 38,000 psi and 55,000 or 70,000 psi at 75 F, and represent material that was stress-relieved or tempered after hot working or normalizing. CG - coarse grain; FG - fine grain deoxidation practice. Creep and rupture strengths represent all available data treated as a single population.

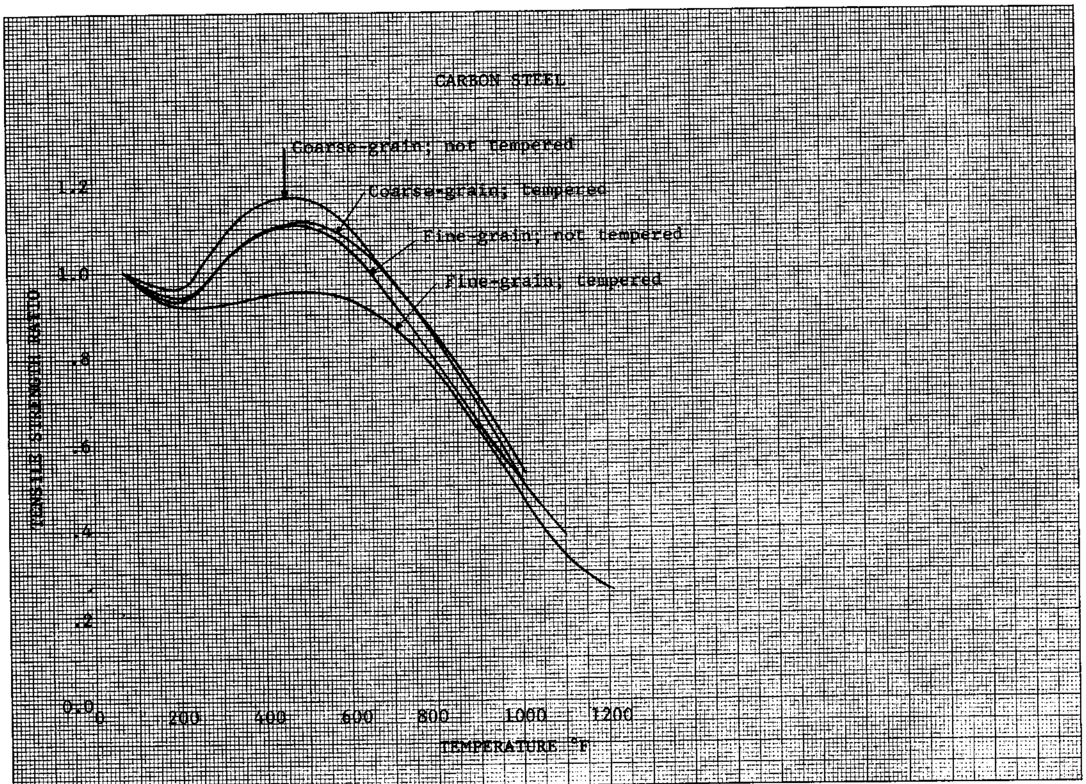

Fig. 2. Comparison of tensile strength ratios for different carbon steel categories.

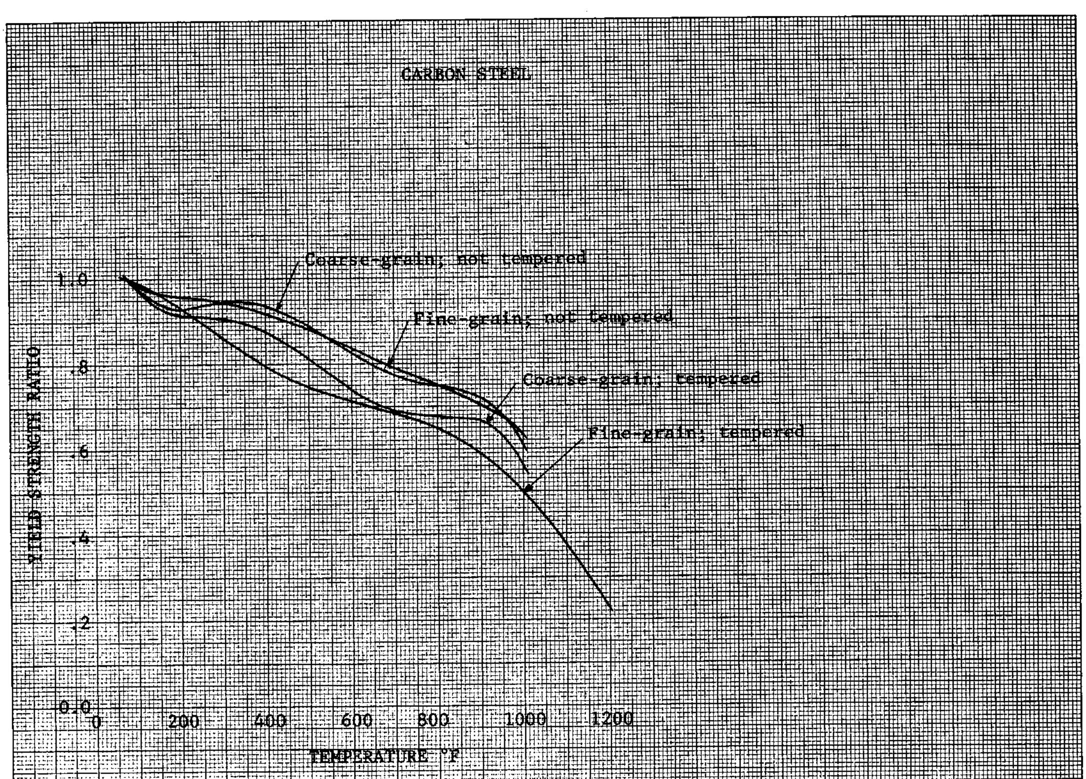

Fig. 3 Comparison of yield strength ratios for different carbon steel categories.

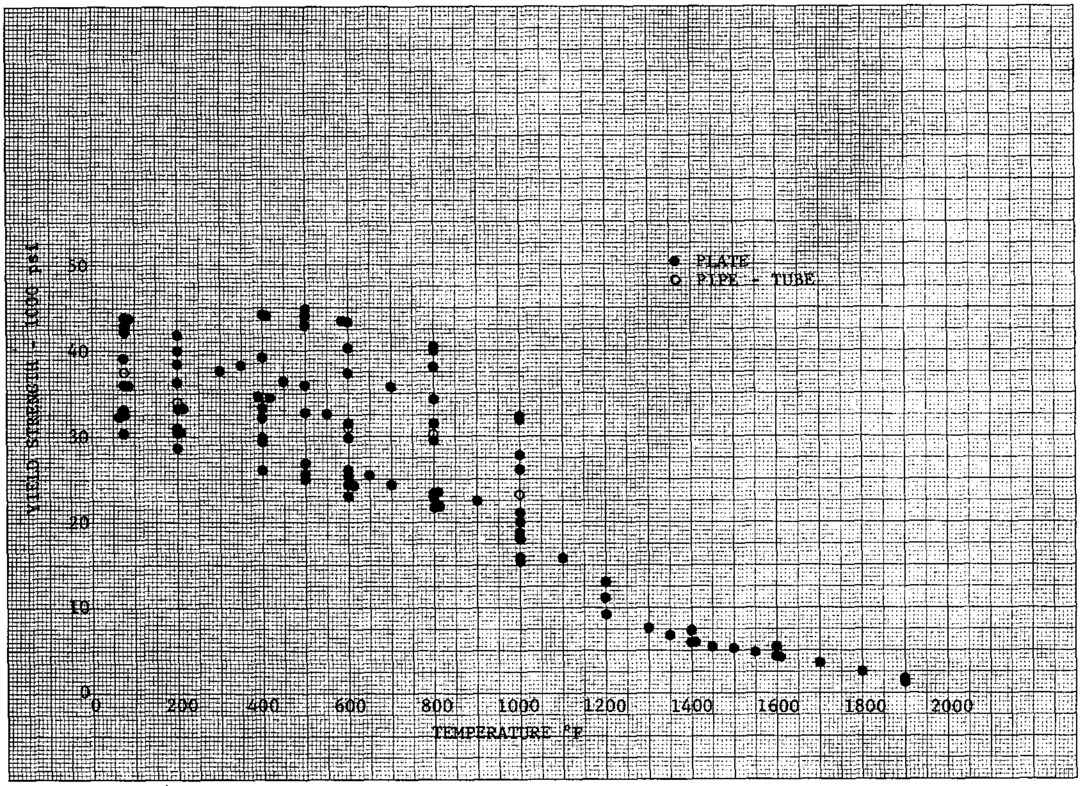

Fig. 4a Variation of yield strength with temperature; coarse-grain, not tempered

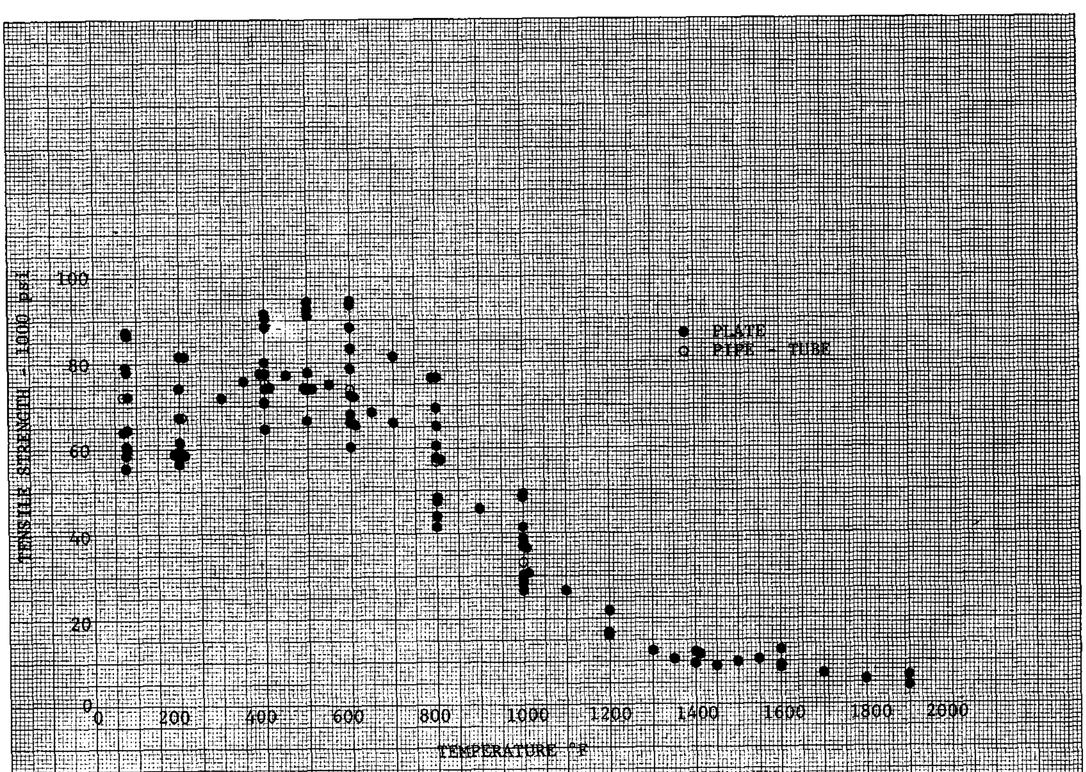

Fig. 4b Variation of tensile strength with temperature; coarse-grain, not tempered

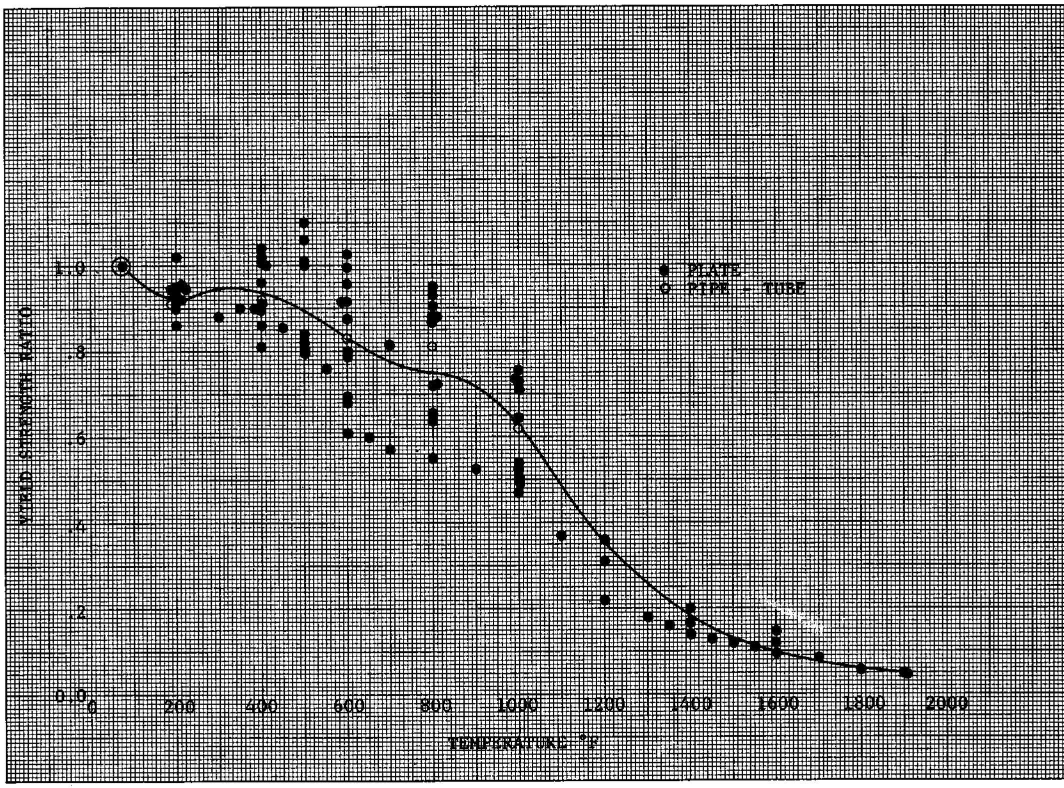

Fig. 4c Variation of yield strength ratio with temperature; coarse grain, not tempered

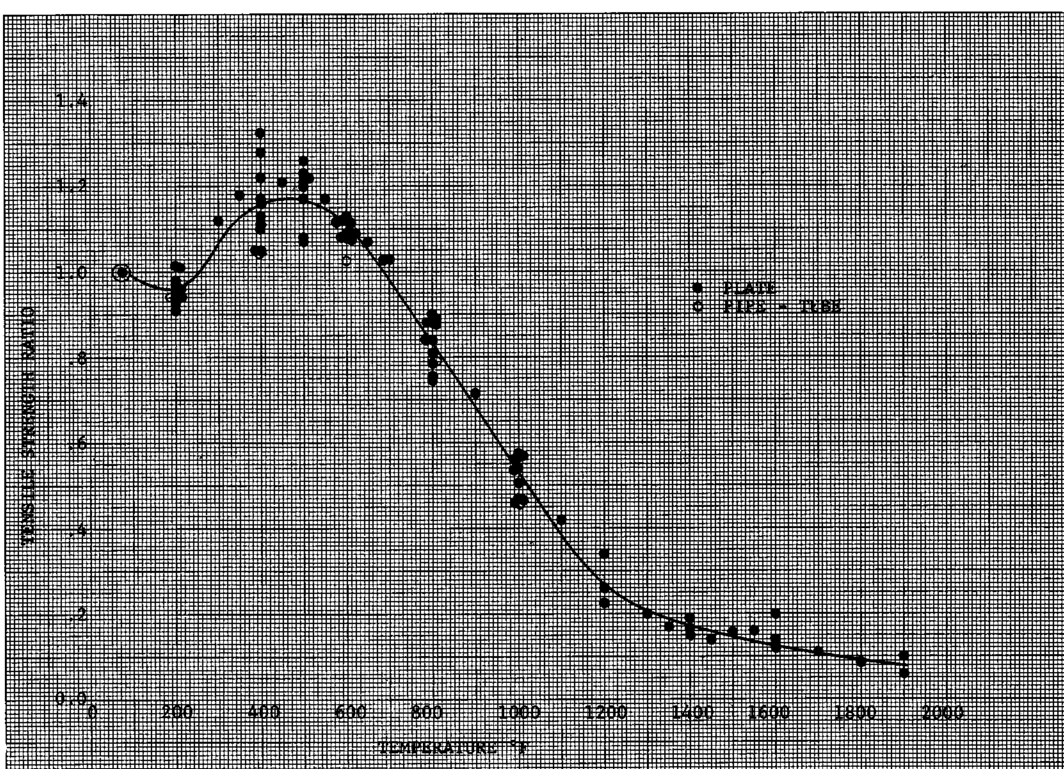

Fig. 4d Variation of tensile strength ratio with temperature; coarse-grain, not tempered

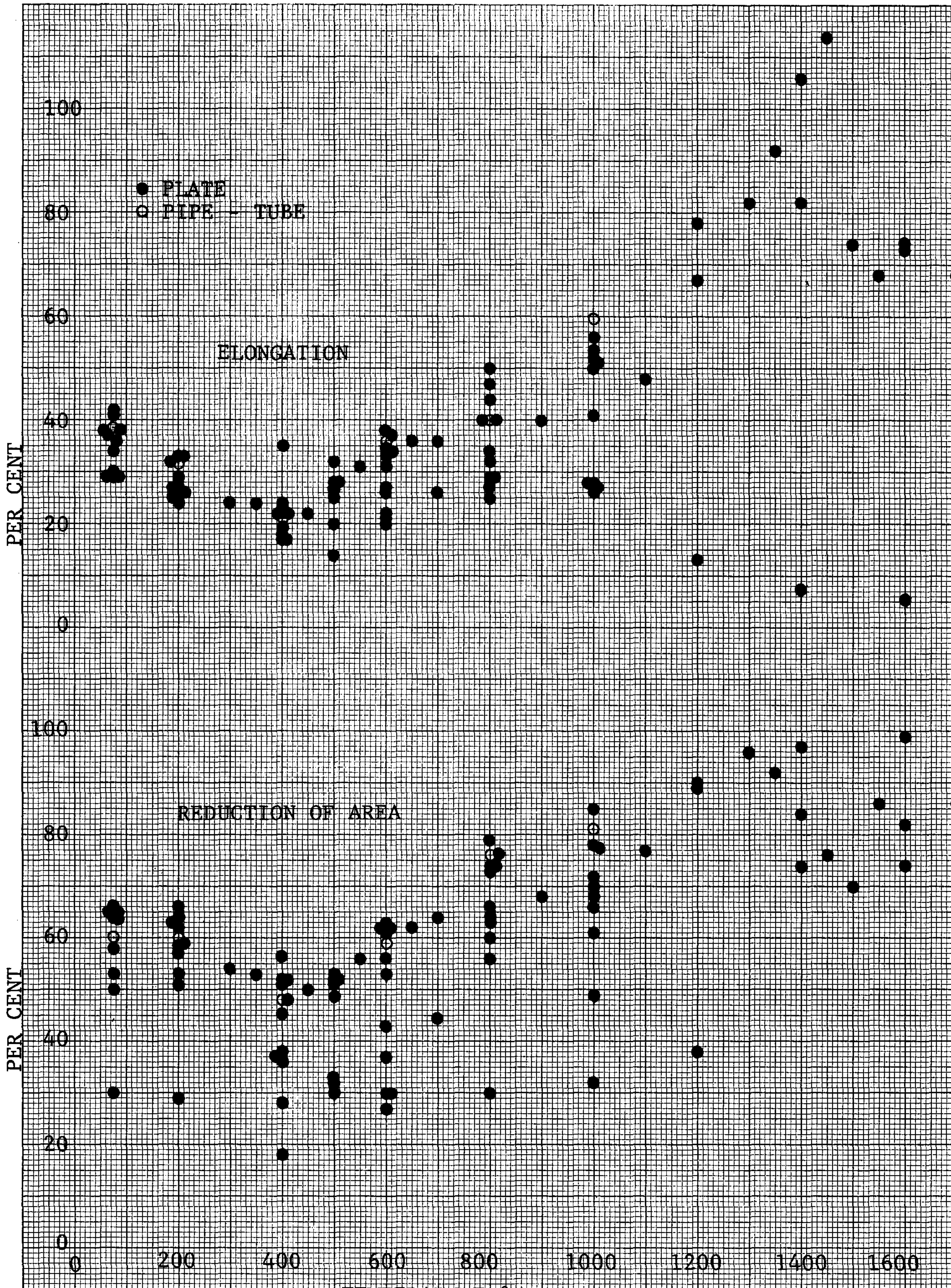

Fig. 4e Variation of fracture ductility with temperature; coarse-grain, not tempered

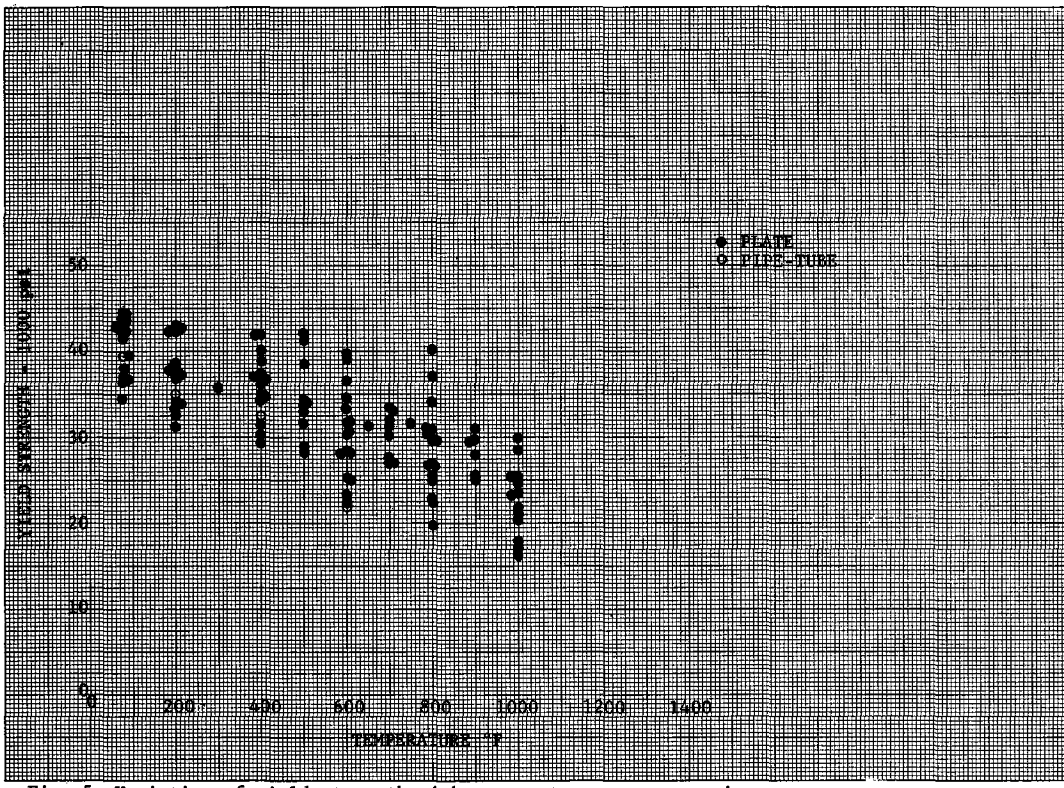

Fig. 5a Variation of yield strength with temperature; coarse-grain, tempered.

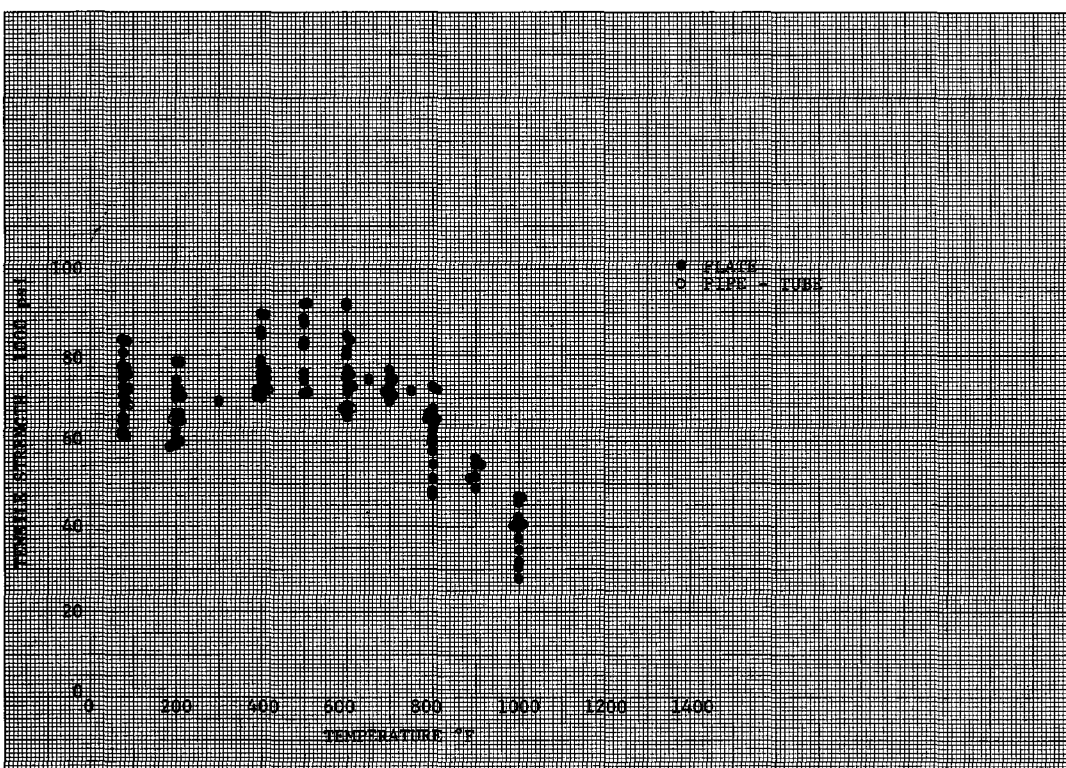

Fig 5b Variation of tensile strength with temperature; coarse-grain, tempered.

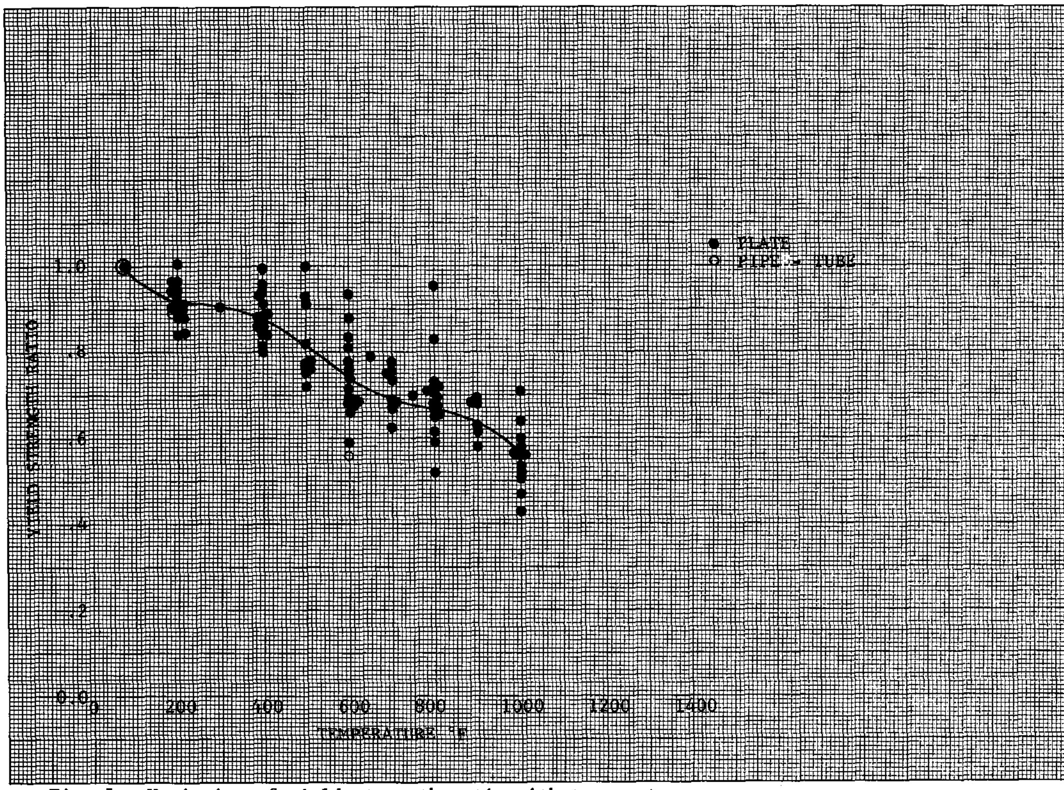

Fig. 5c Variation of yield strength ratio with temperature; coarse-grain, tempered.

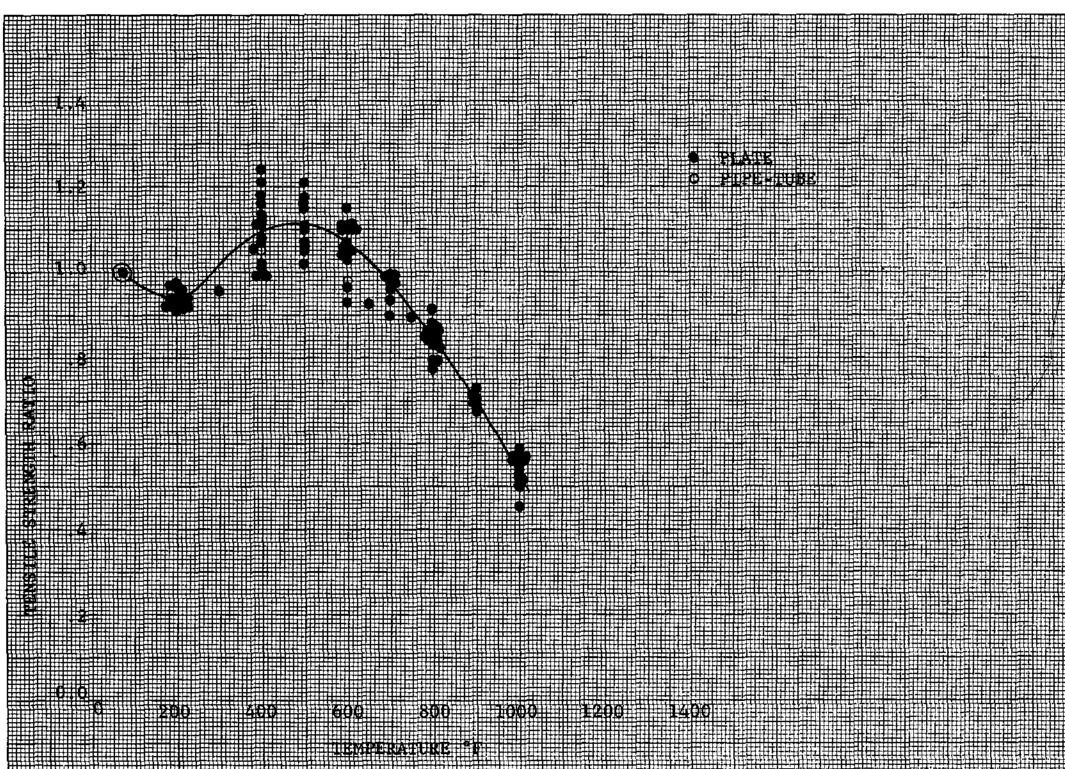

Fig. 5d Variation of tensile strength ratio with temperature; coarse-grain, tempered.

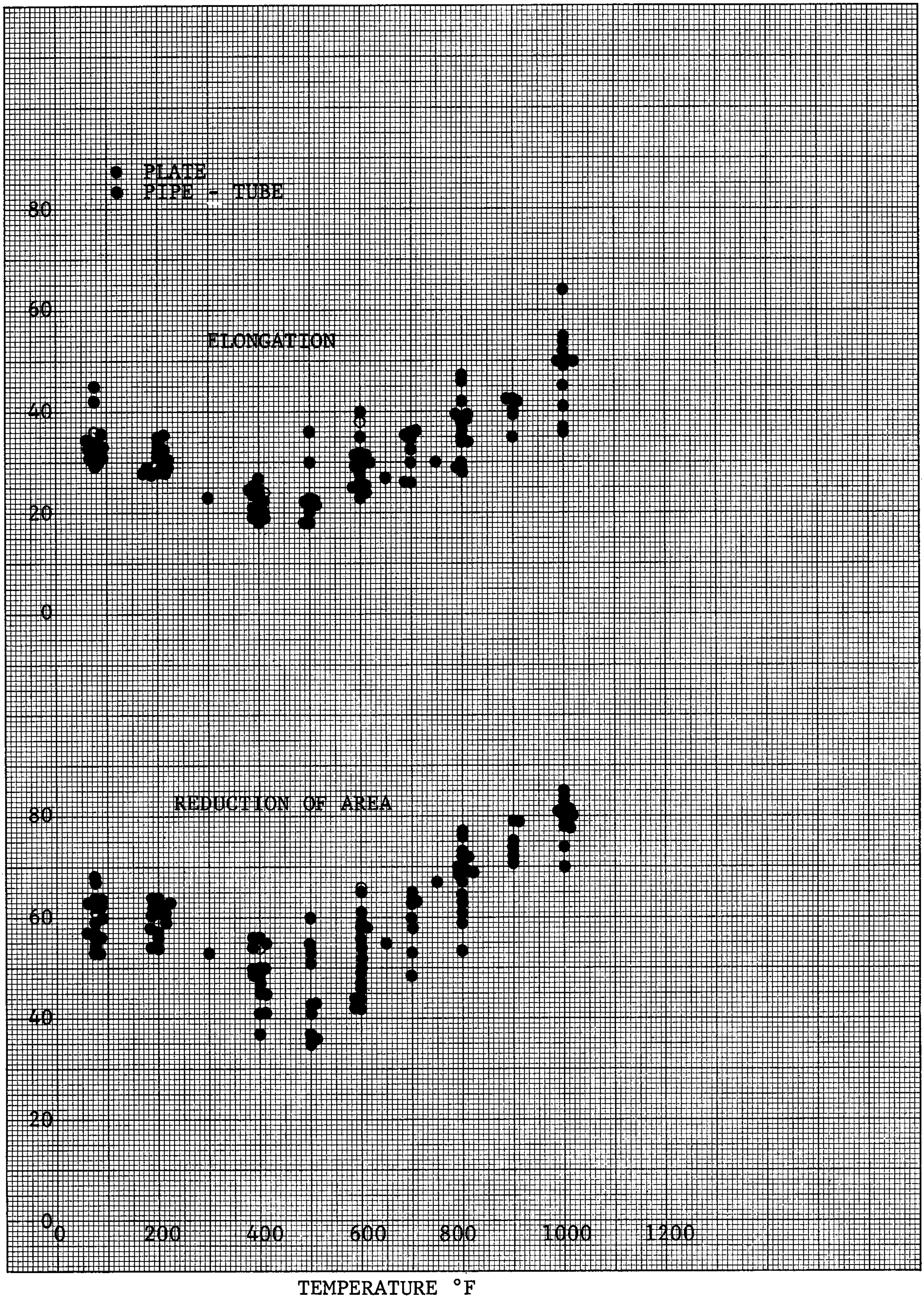

Fig. 5e Fracture ductility of coarse-grain, tempered steels.

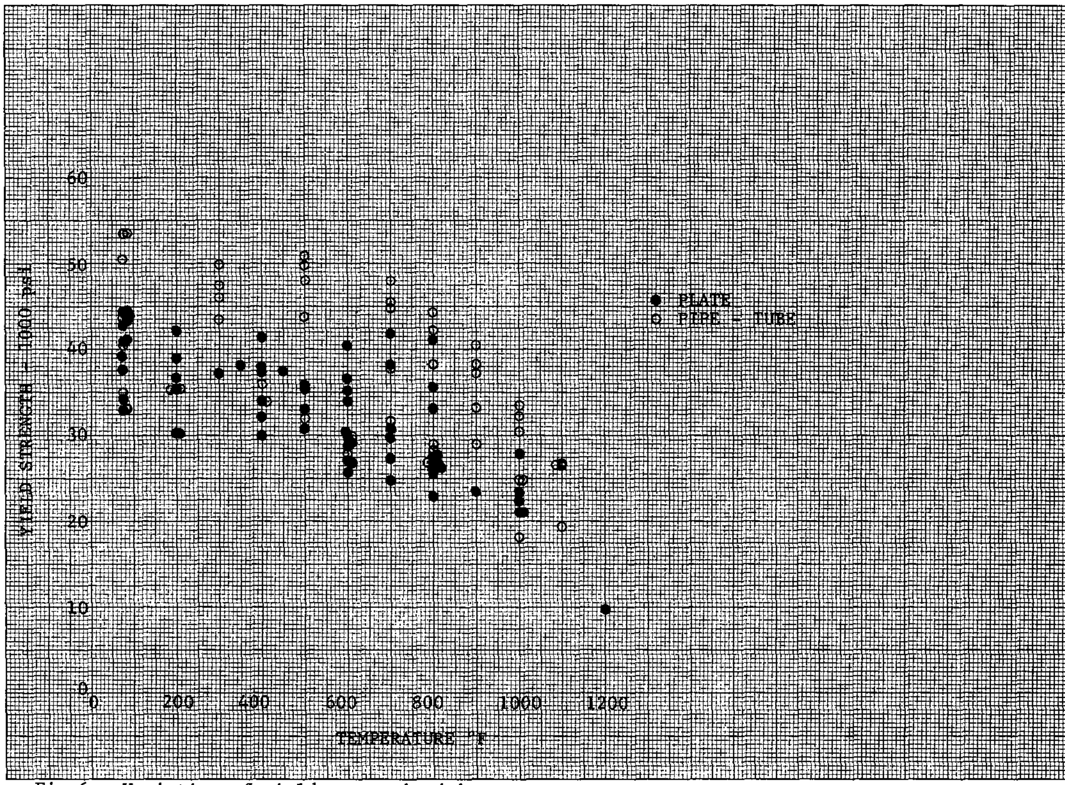

Fig.6a Variation of yield strength with temperature; fine-grain, not tempered.

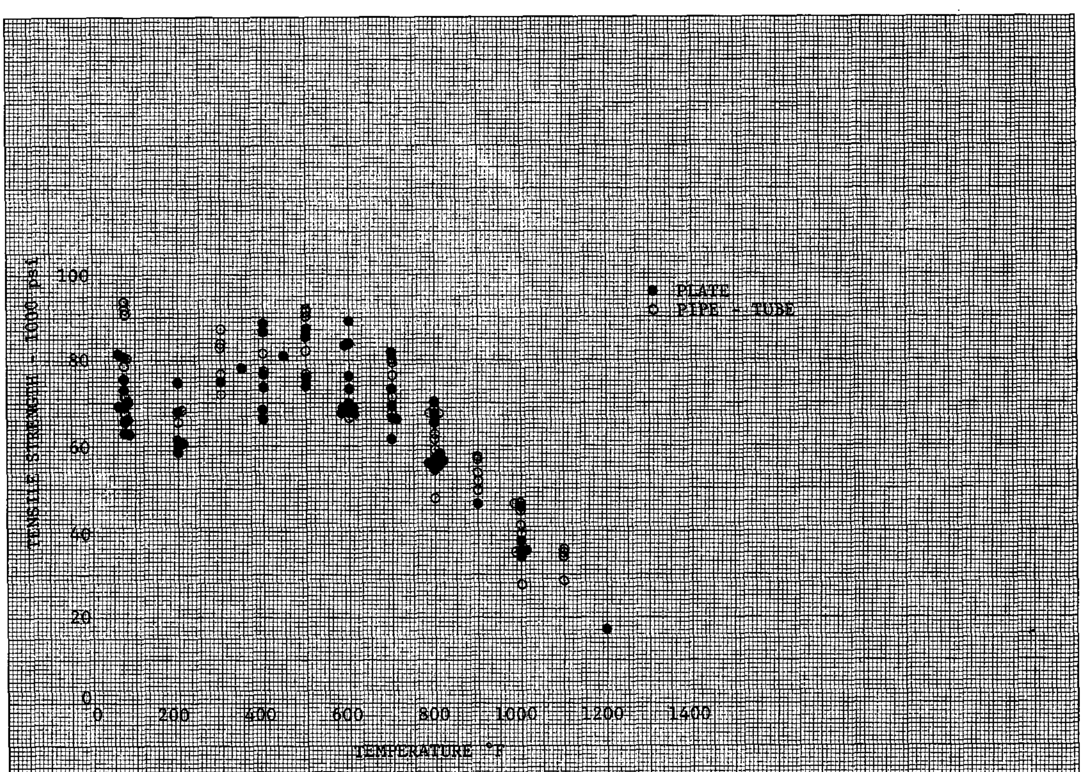

Fig. 6b Variation of tensile strength with temperature; fine-grain, not tempered.

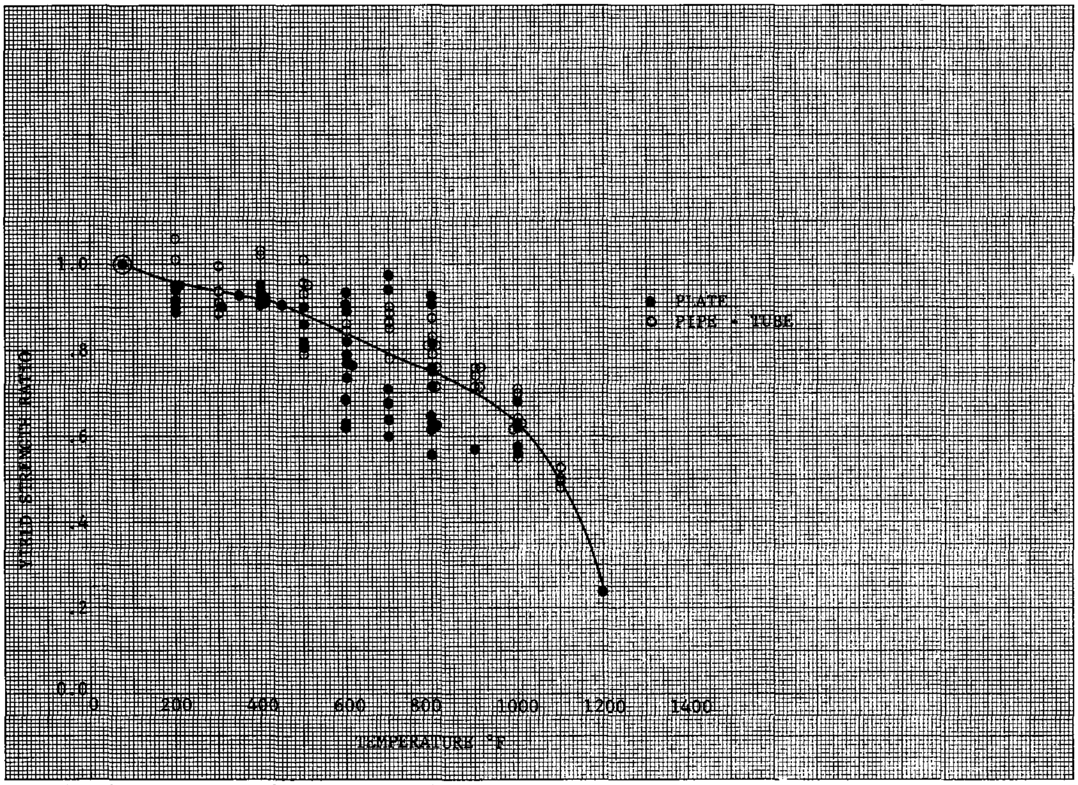

Fig. 6c Variation of yield strength ratio with temperature; fine-grain, not tempered.

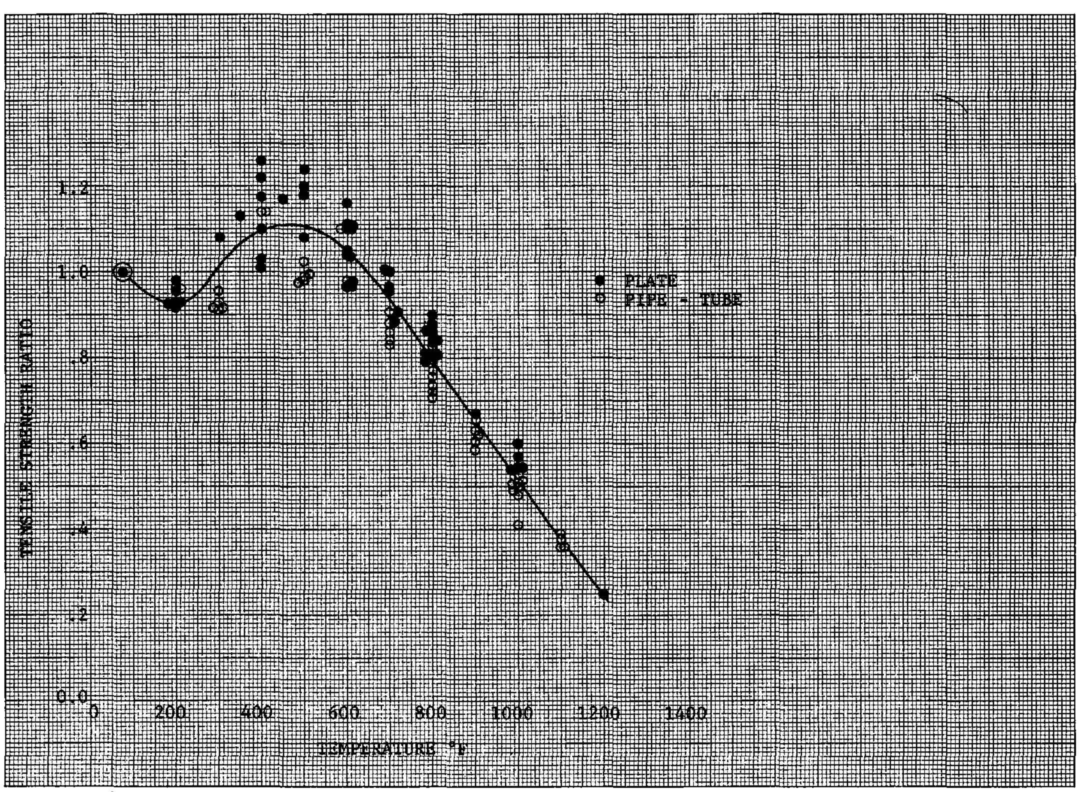

Fig. 6d Variation of tensile strength ratio with temperature; fine-grain, not tempered.

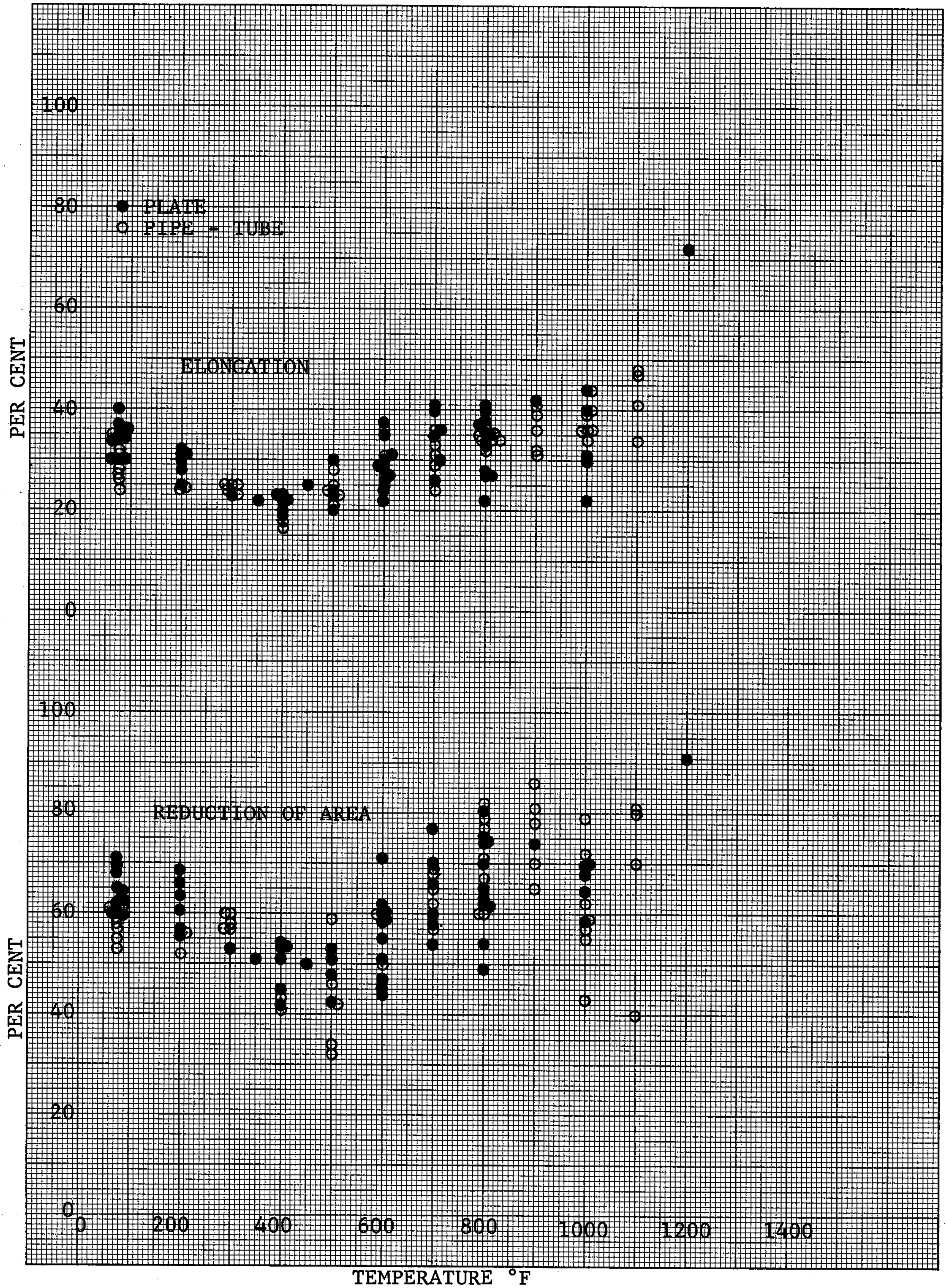

Fig. 6e Fracture ductility of fine-grain, not-tempered steels.

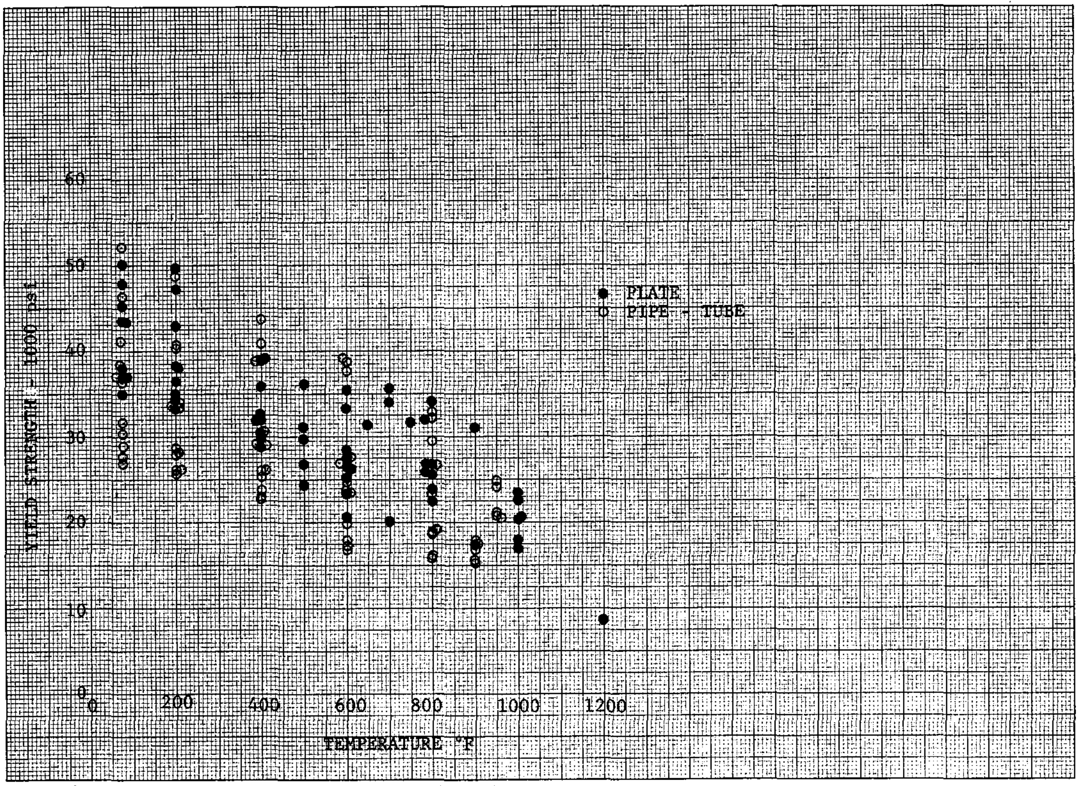

Fig. 7a Variation of yield strength with temperatuee;
fine-grain, tempered

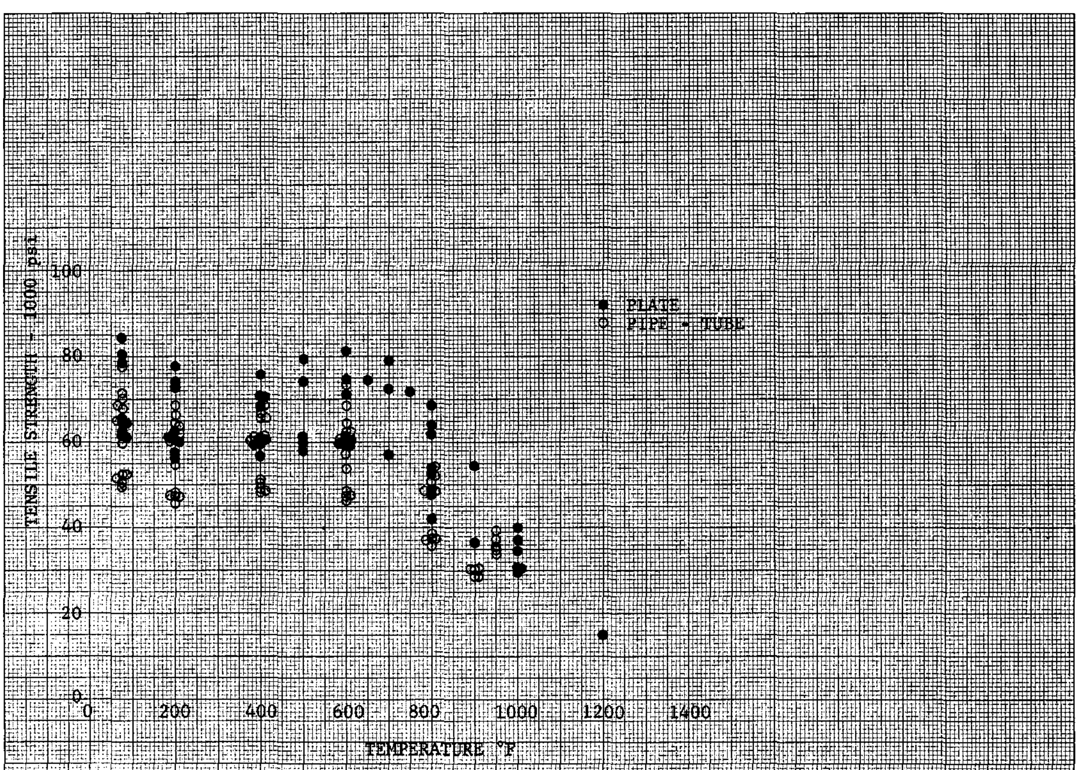

Fig.7b Variation of tensile strength with temperature;
fine-grain, tempered.

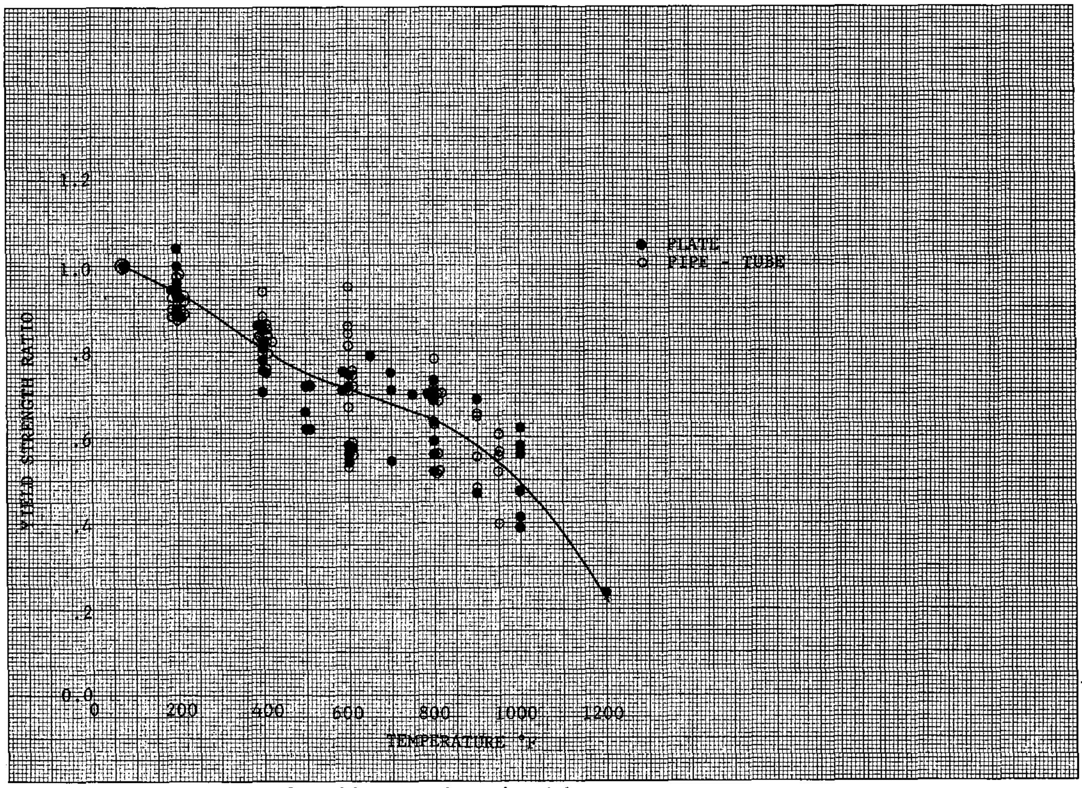

Fig. 7c Variation of yield strength ratio with temperature; fine-grain, tempered.

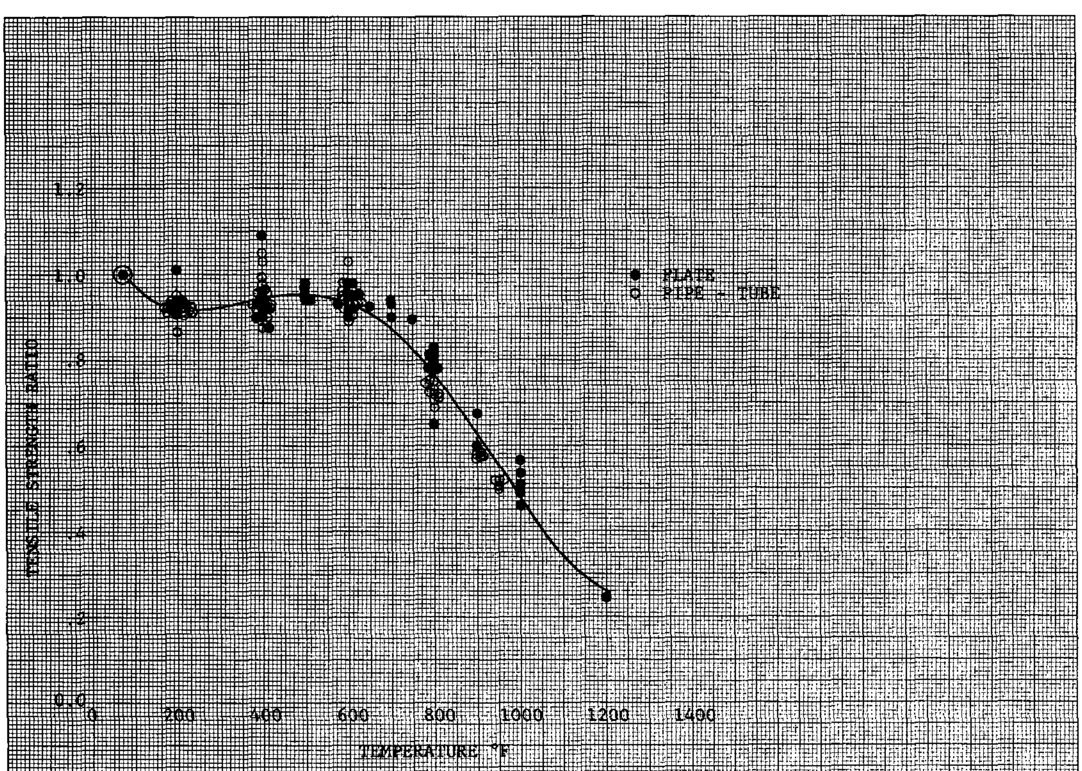

Fig. 7d Variation of tensile strength ratio with temperature; fine-grain, tempered.

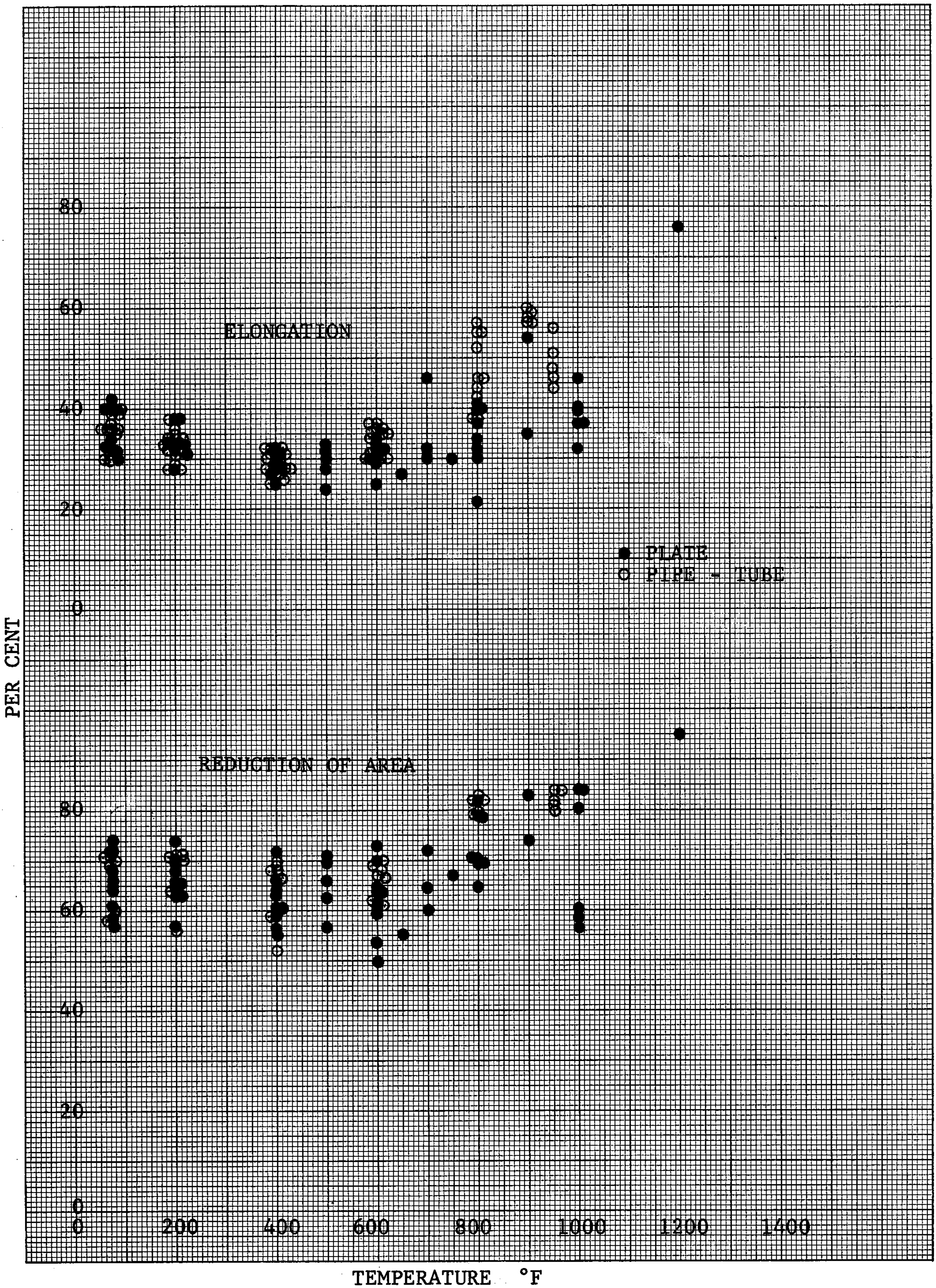

Fig. 7e Fracture ductility of fine-grain, tempered steels.

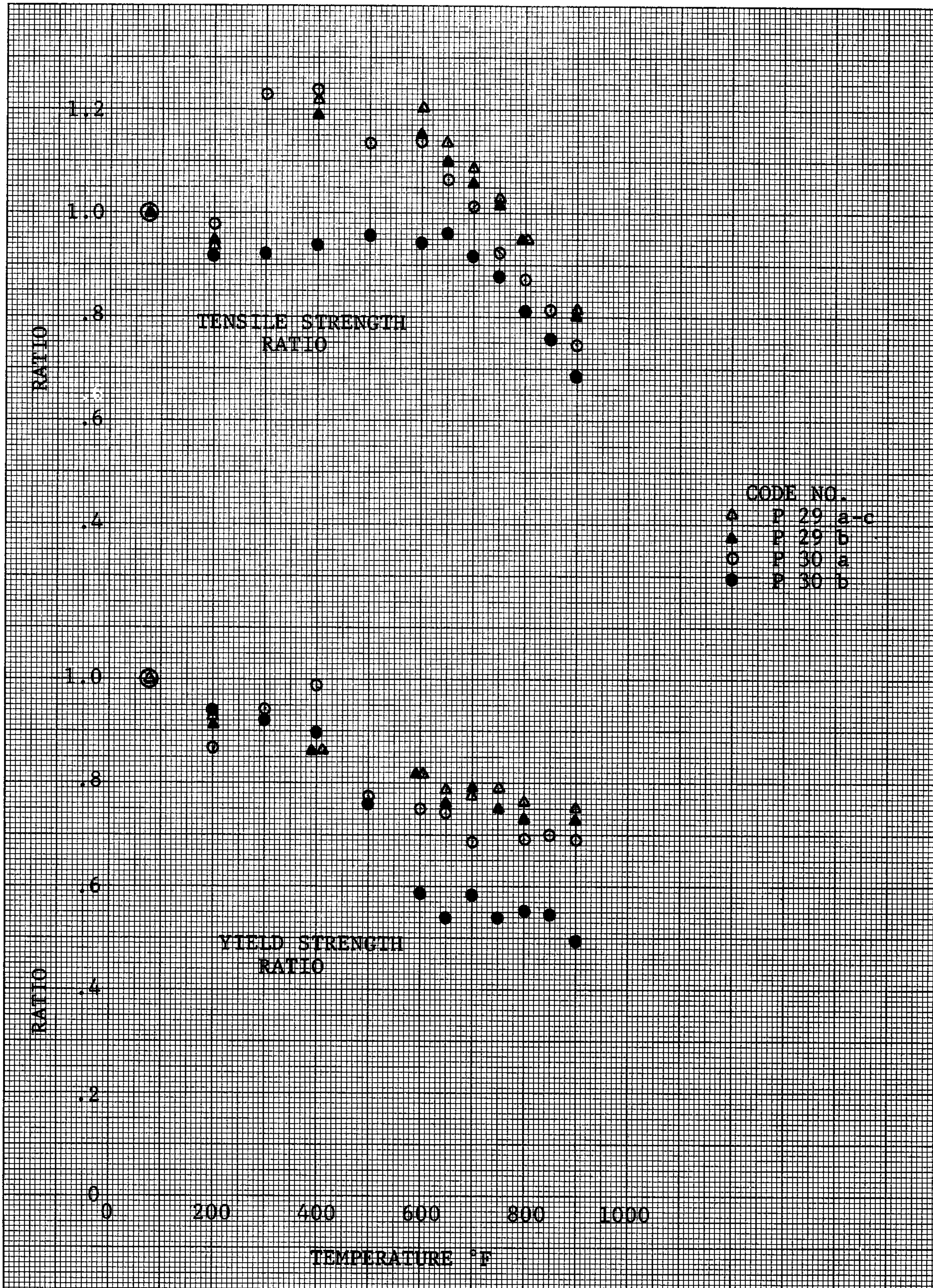

Fig. 8a Variation of yield and tensile strength ratios with temperature for miscellaneous carbon steels.

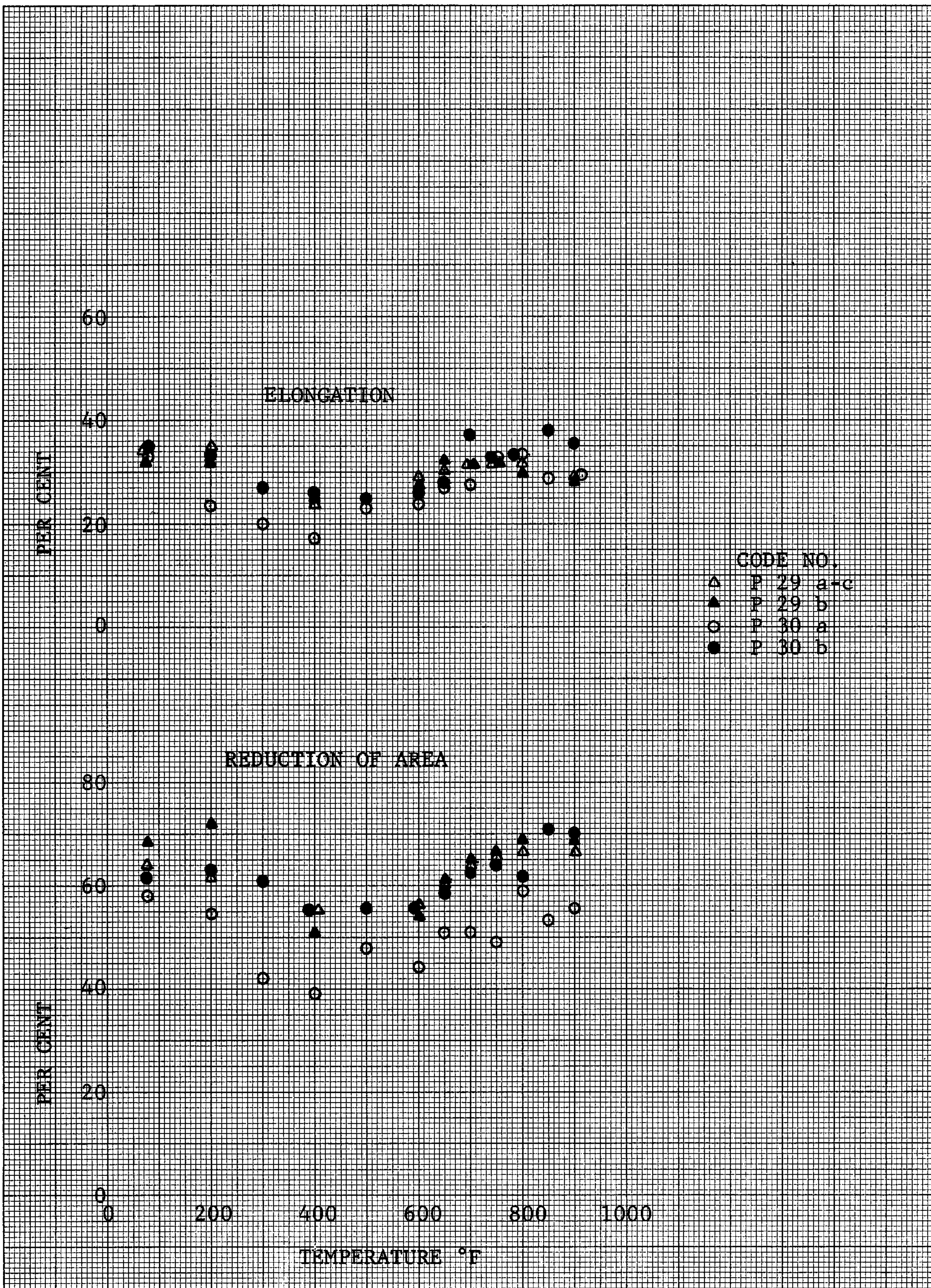

Fig. 8b Variation of fracture ductility with temperature for miscellaneous carbon steels.

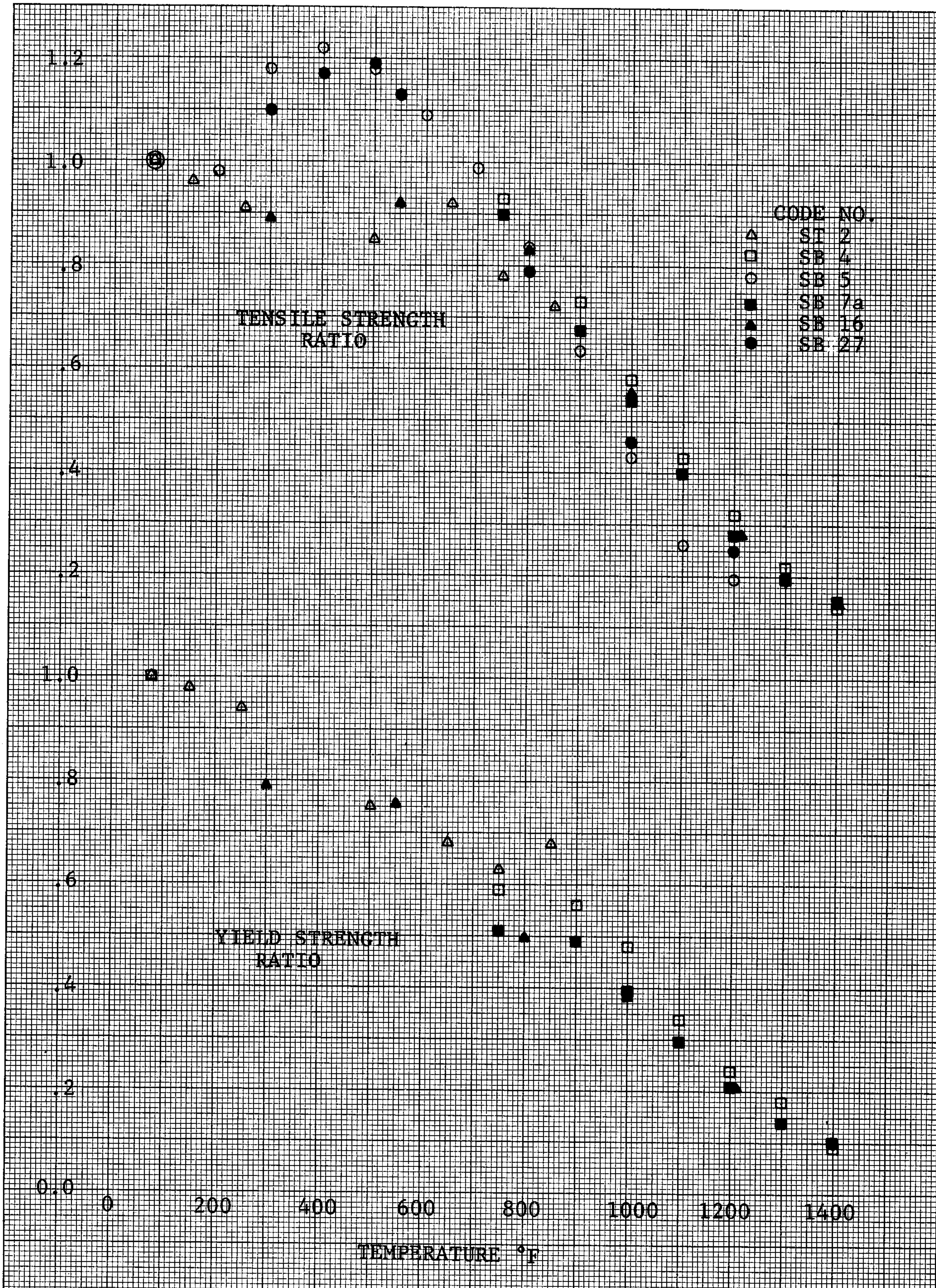

Fig. 9a Variation of yield and tensile strength ratios with temperature for miscellaneous carbon steels from DS 11.

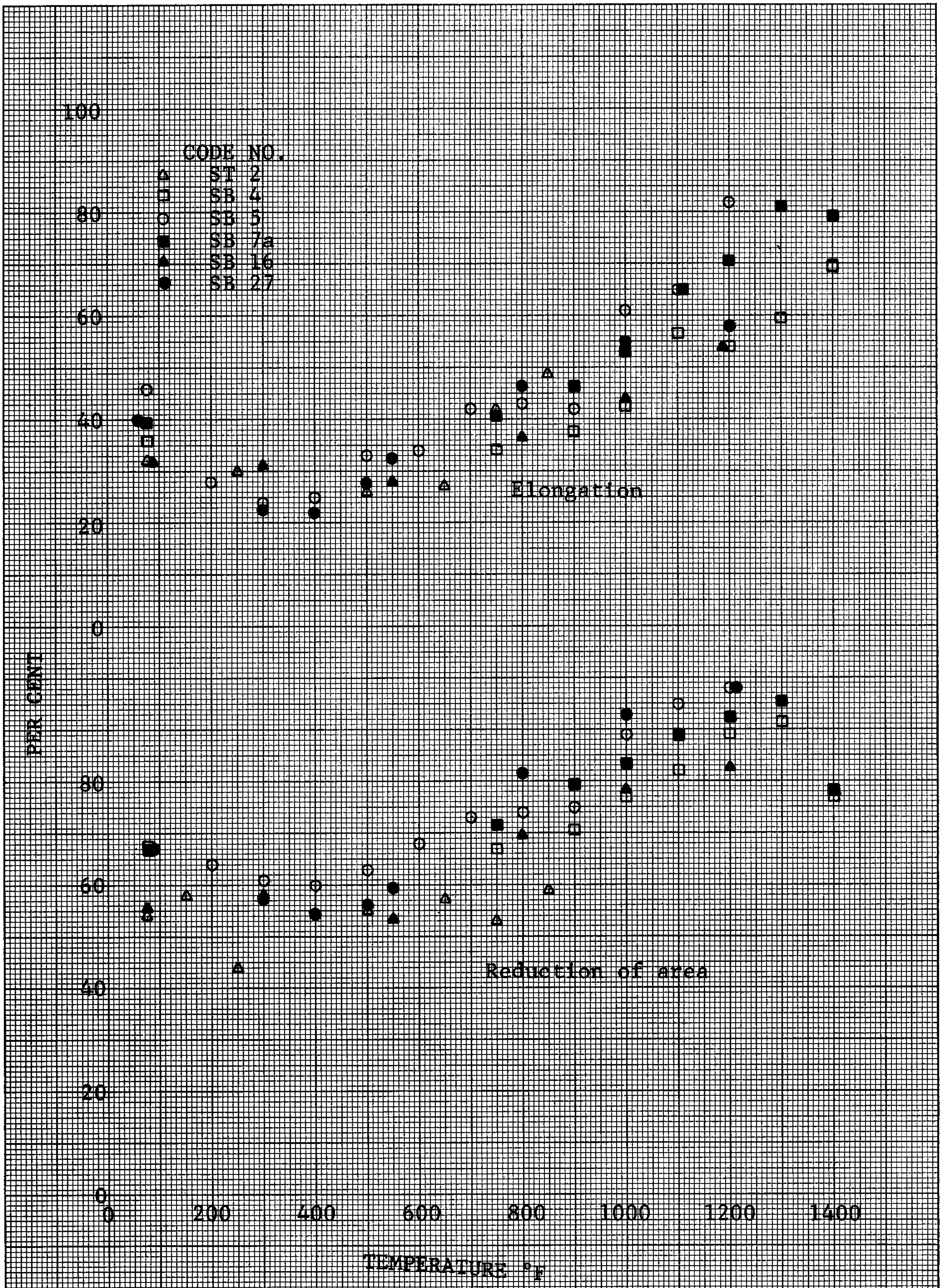

Fig. 9b Variation of fracture ductility with temperature for miscellaneous carbon steels from DS 11.

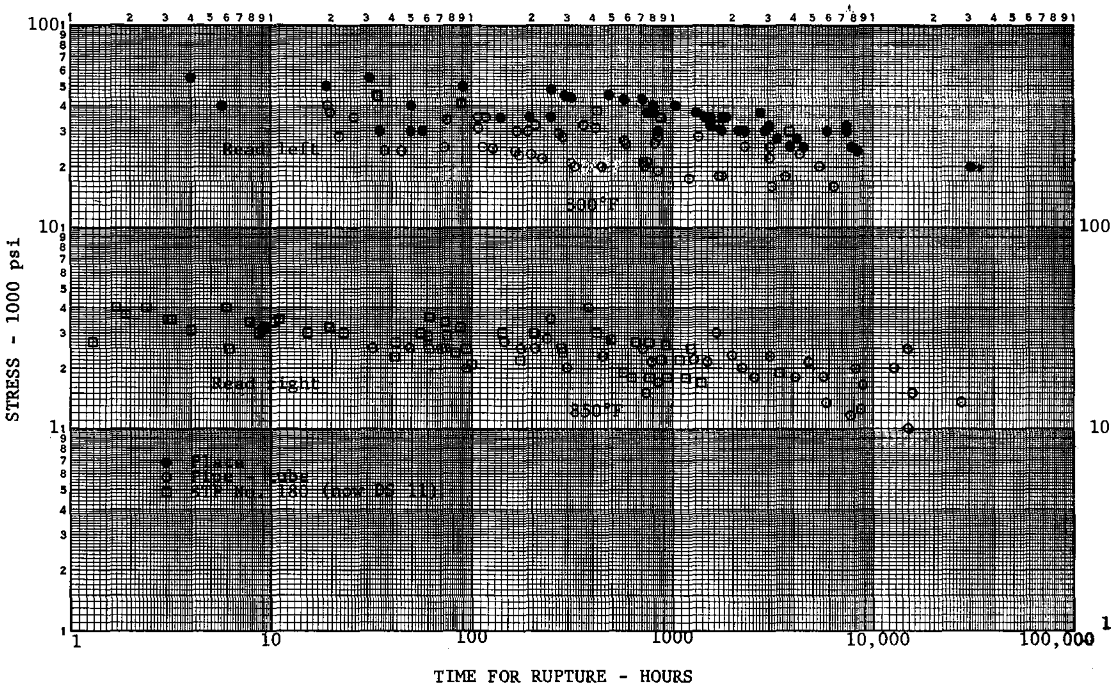

Fig. 10a Stress vs time for rupture; all data: 800 and 850 F.

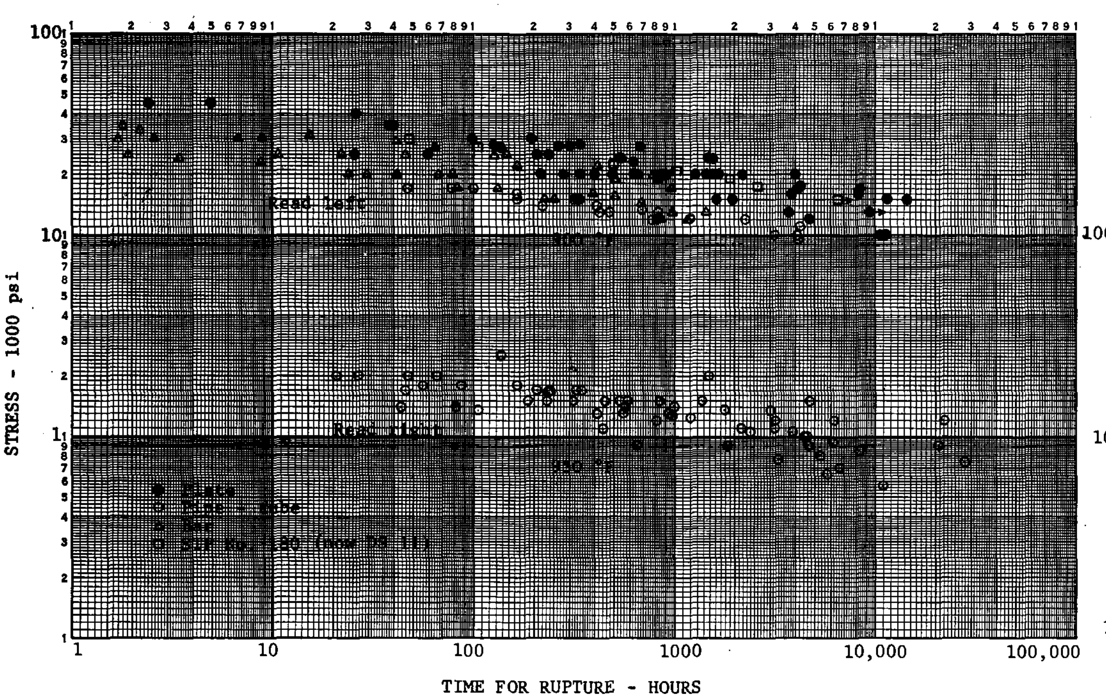

Fig. 10b Stress vs time for rupture; all data: 900 and 950 F

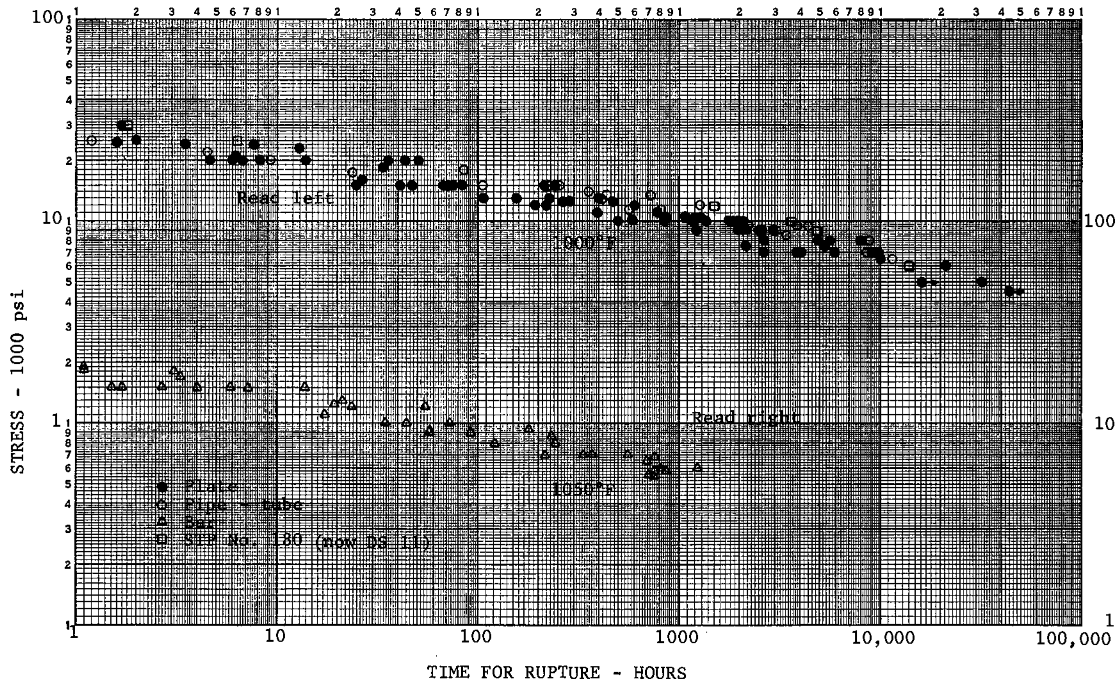

Fig. 10c Stress vs time for rupture; all data: 1000 and 1050 F.

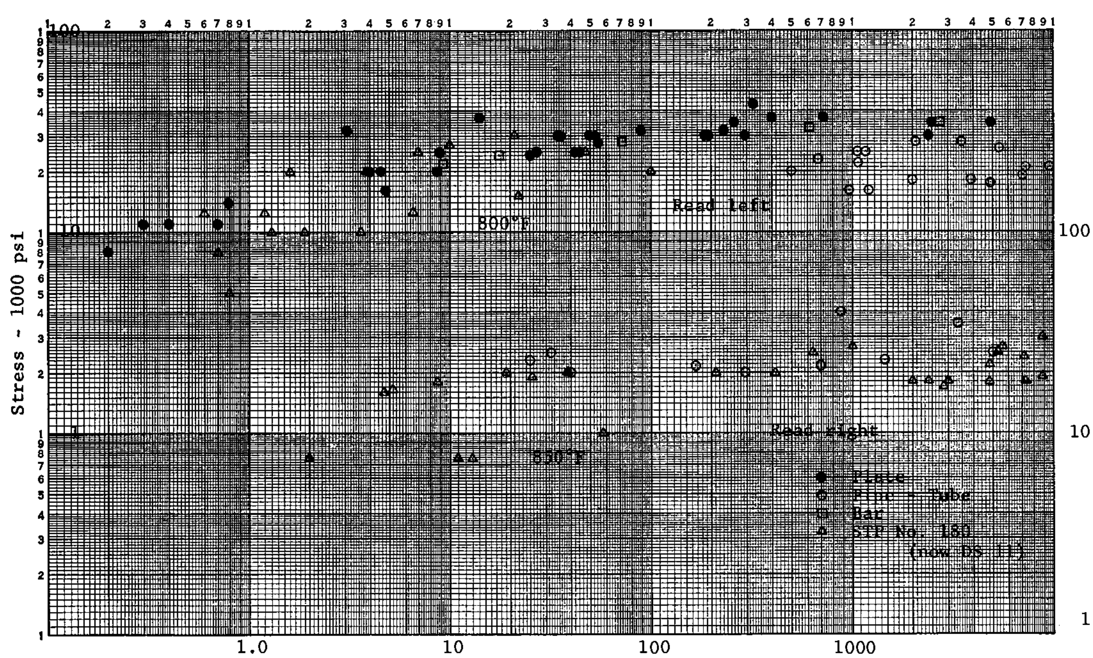

Fig. 11a Stress vs secondary creep rate; all data: 800 and 850 F.

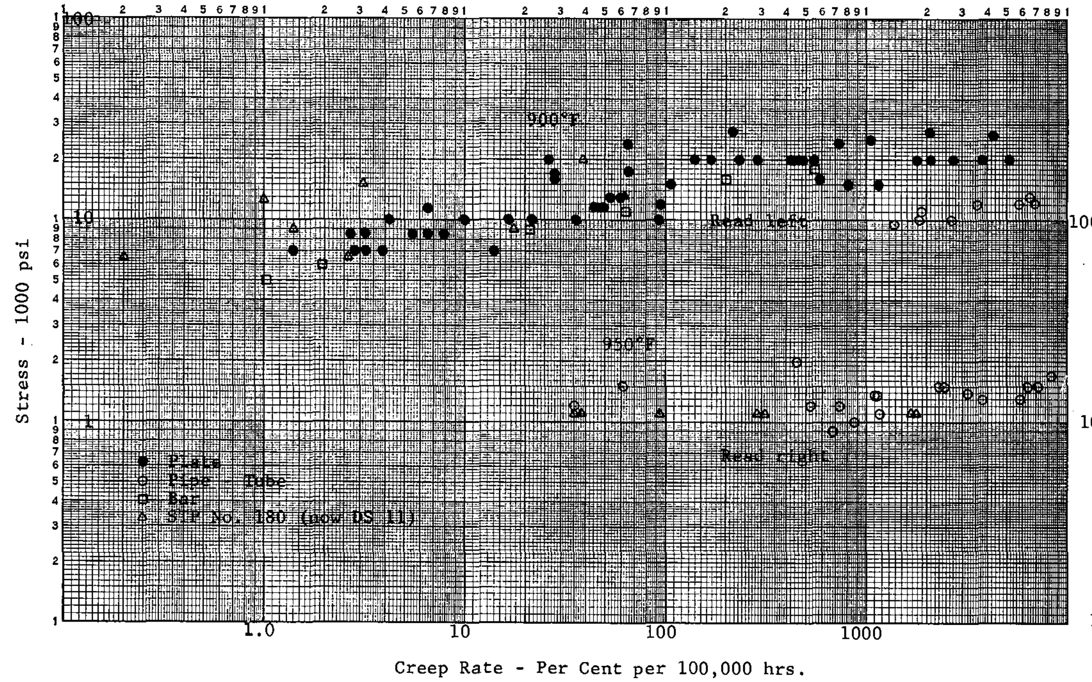

Fig. 11b Stress vs secondary creep rate; all data: 900 and 950 F.

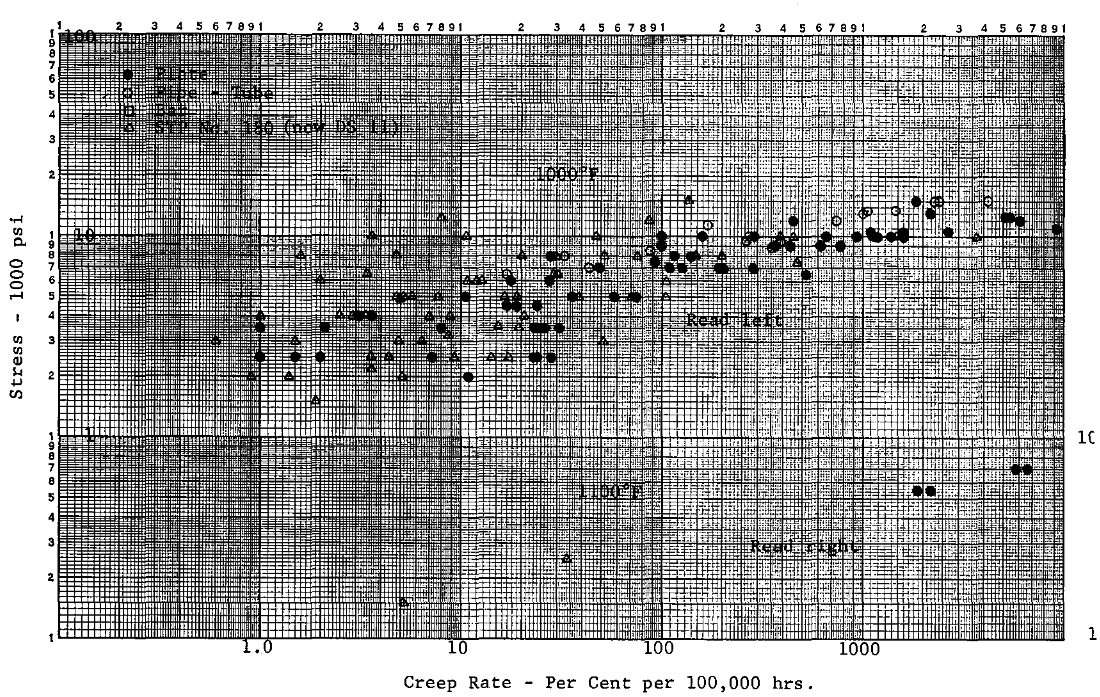

Fig. 11c. Stress vs secondary creep rate; all data: 1000 and 1050 F.

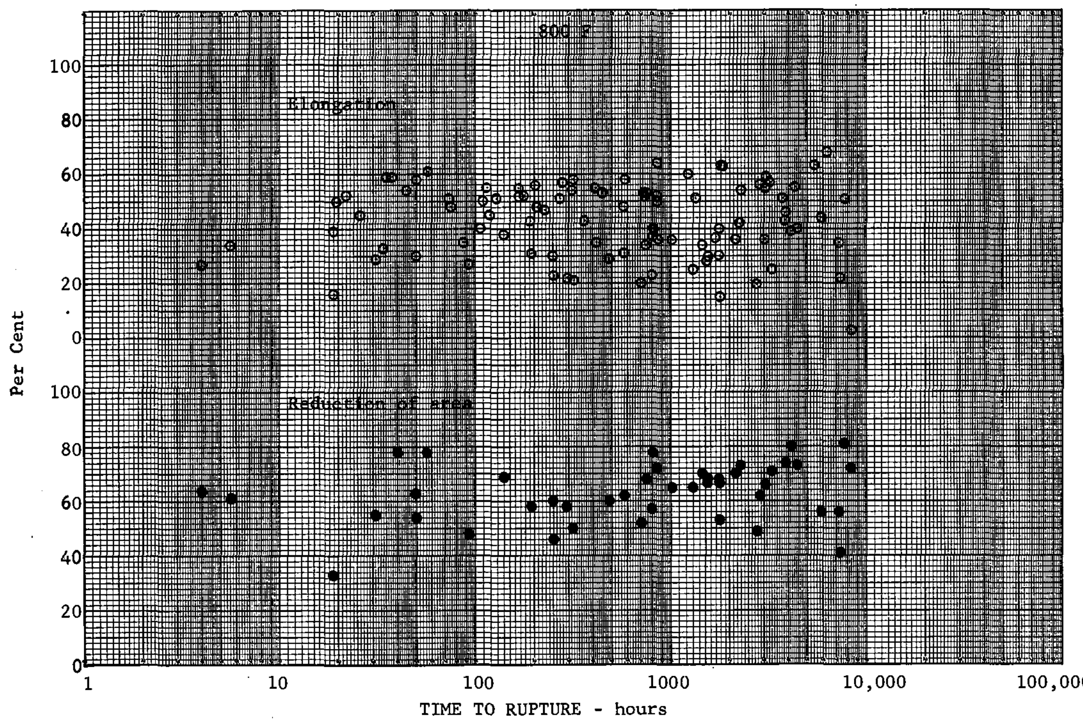

Fig. 12a Variation of rupture ductility with time for rupture; all data: 800 F.

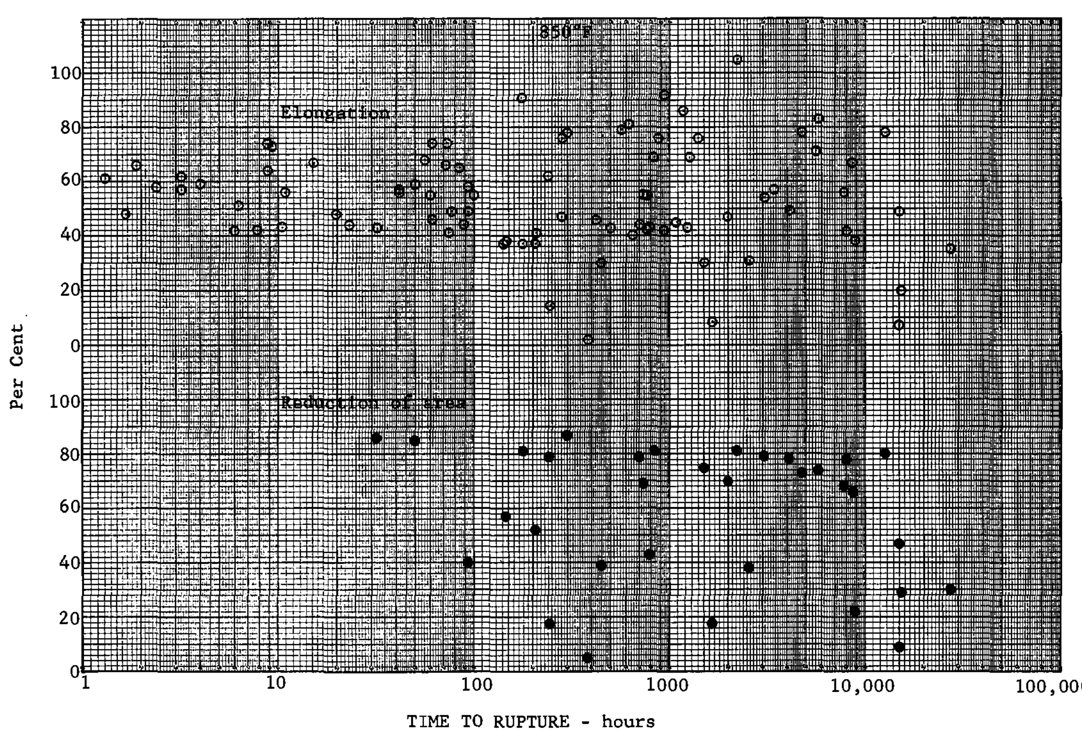

Fig. 12b Variation of rupture ductility with time for rupture; all data: 850 F

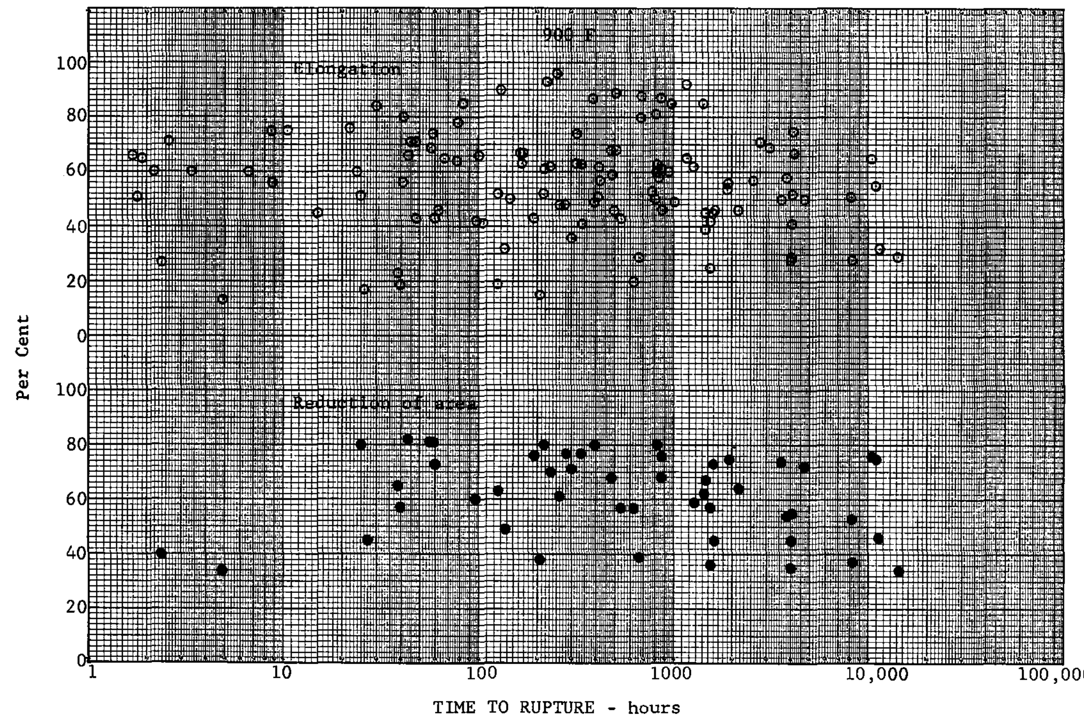

Fig 12c Variation of rupture ductility with time for rupture; all data: 900 F.

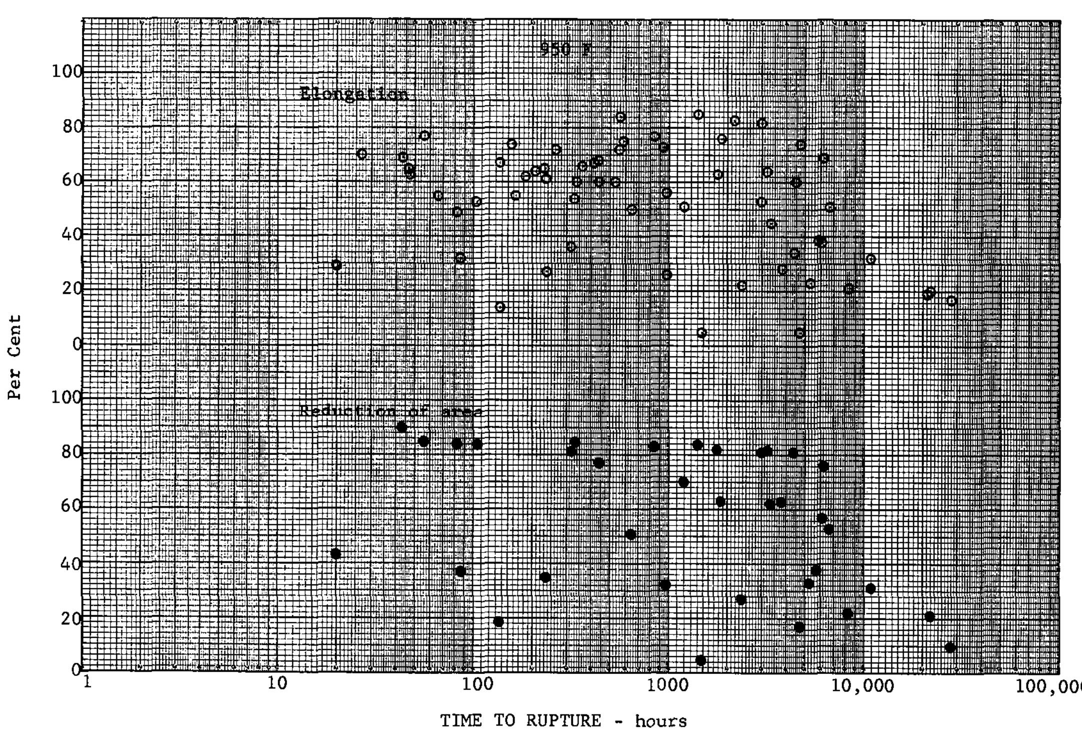

Fig. 12d Variation of rupture ductility with time for rupture; all data: 950 F.

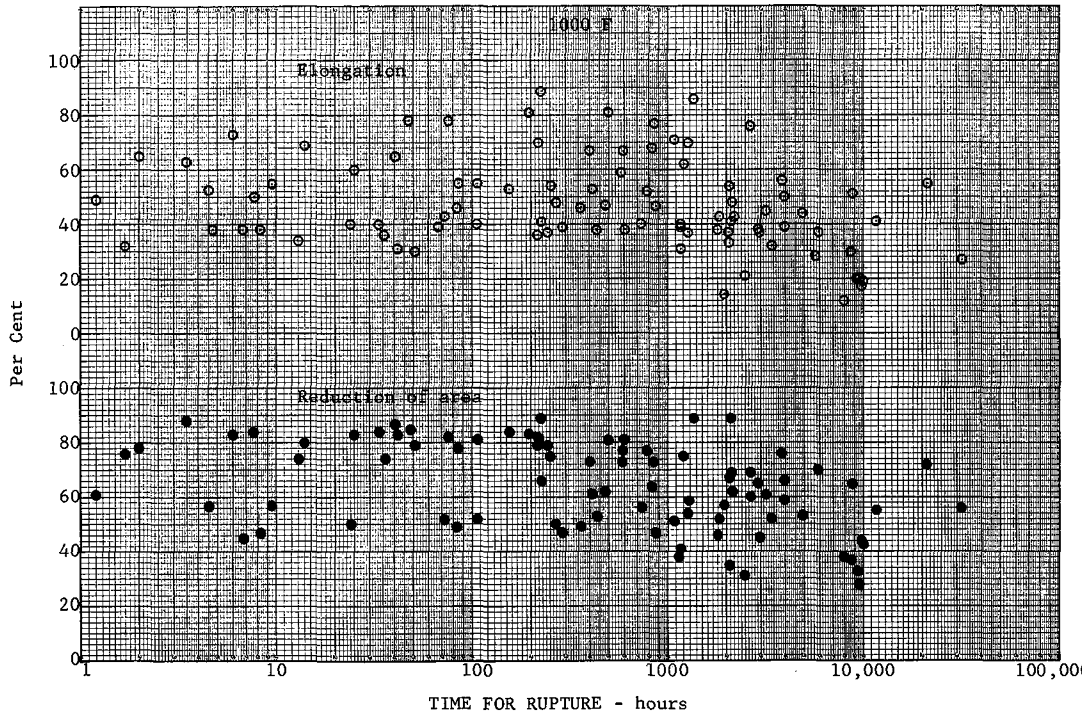

Fig. 12e Variation of rupture ductility with time for rupture; all data: 1000 F.

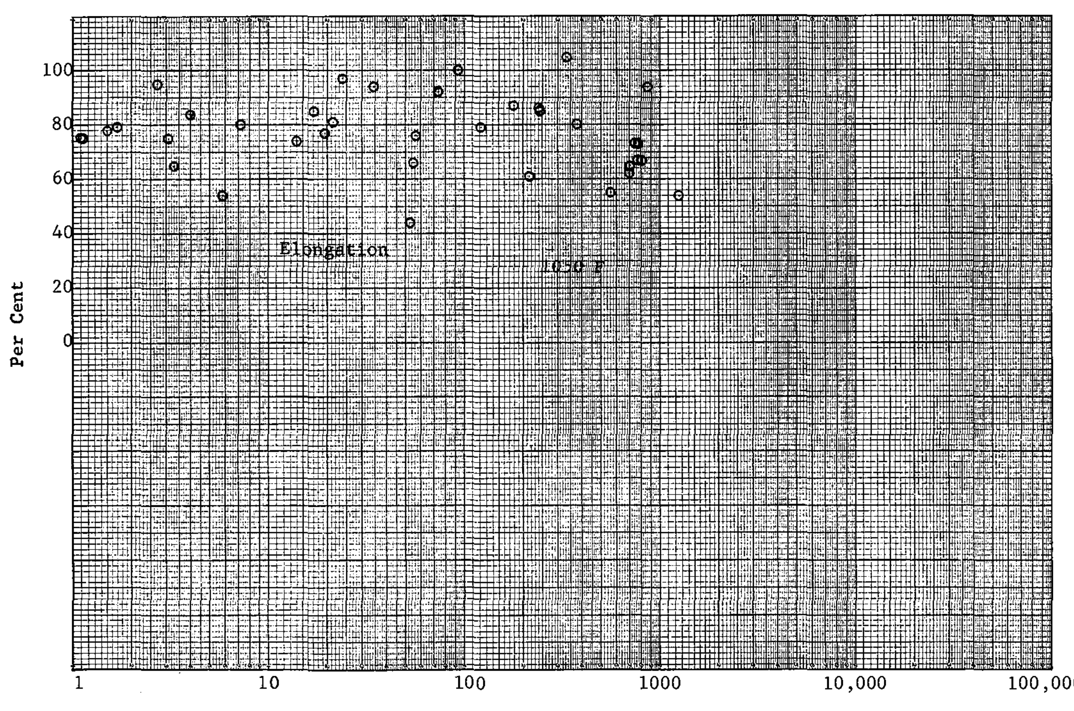

Fig. 12f Variation of rupture ductility with time for rupture; all data: 1050 F

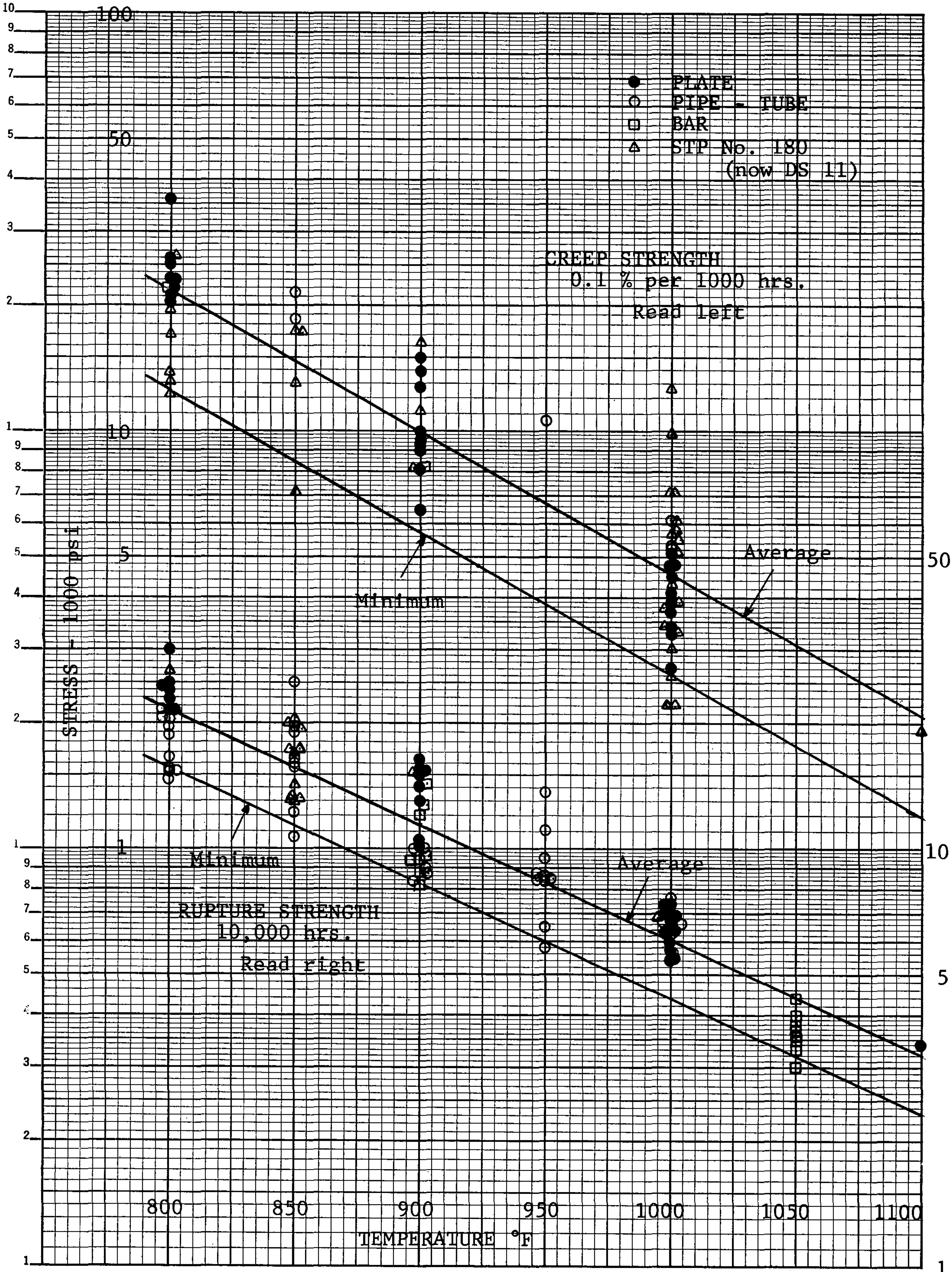

Fig. 13a Variation of creep strength (0.1% per 1000 hrs) and rupture strength (10000 hrs) with temperature; all data.

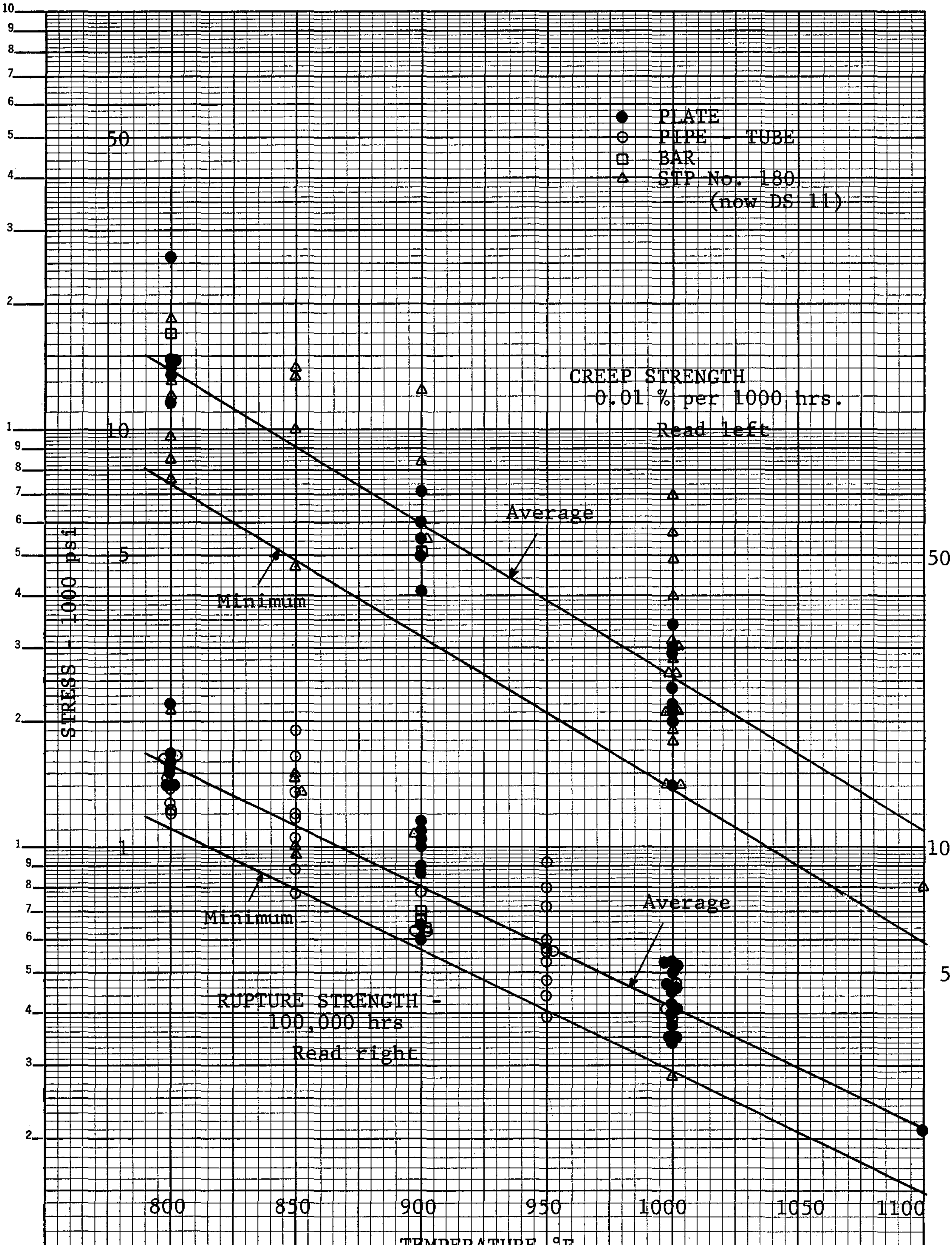

Fig. 13b Variation of creep strength (0.01% per 1000 hrs) and rupture strength (100,000 hrs) with temperature; all data.

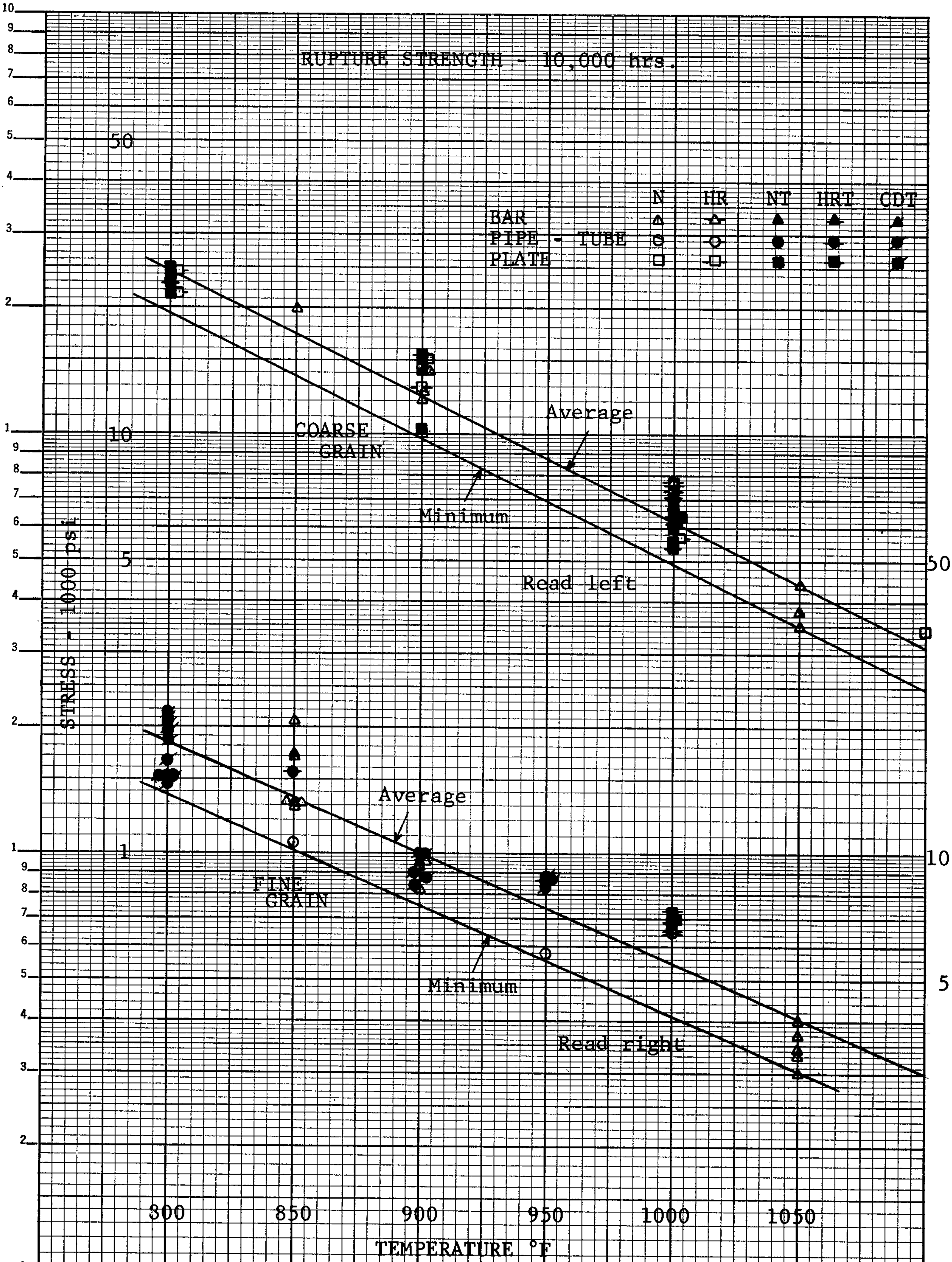

Fig. 14a Effect of deoxidation practice on rupture strength (10,000 hrs)

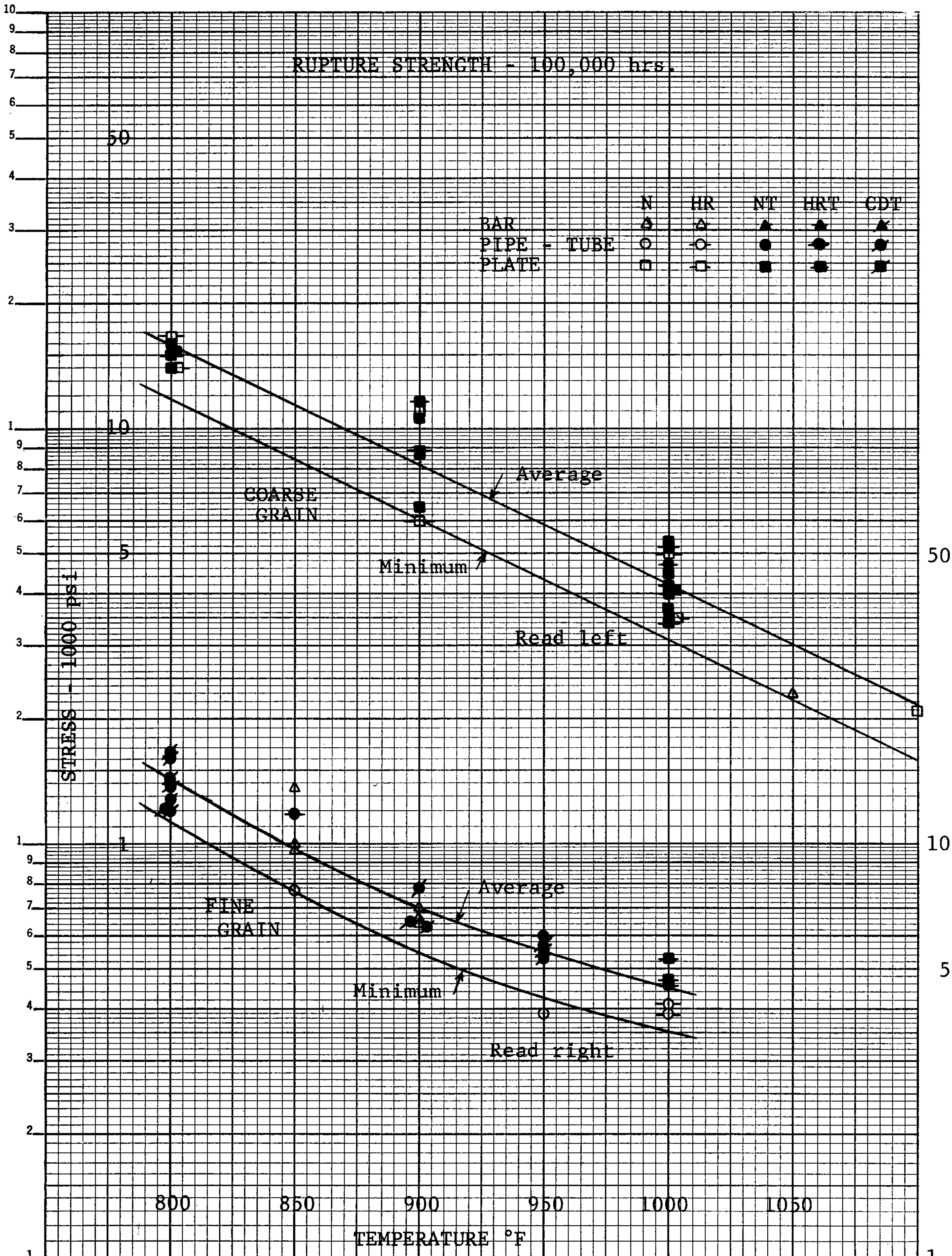

Fig. 14b Effect of deoxidation practice on rupture strength (100,000 hrs)

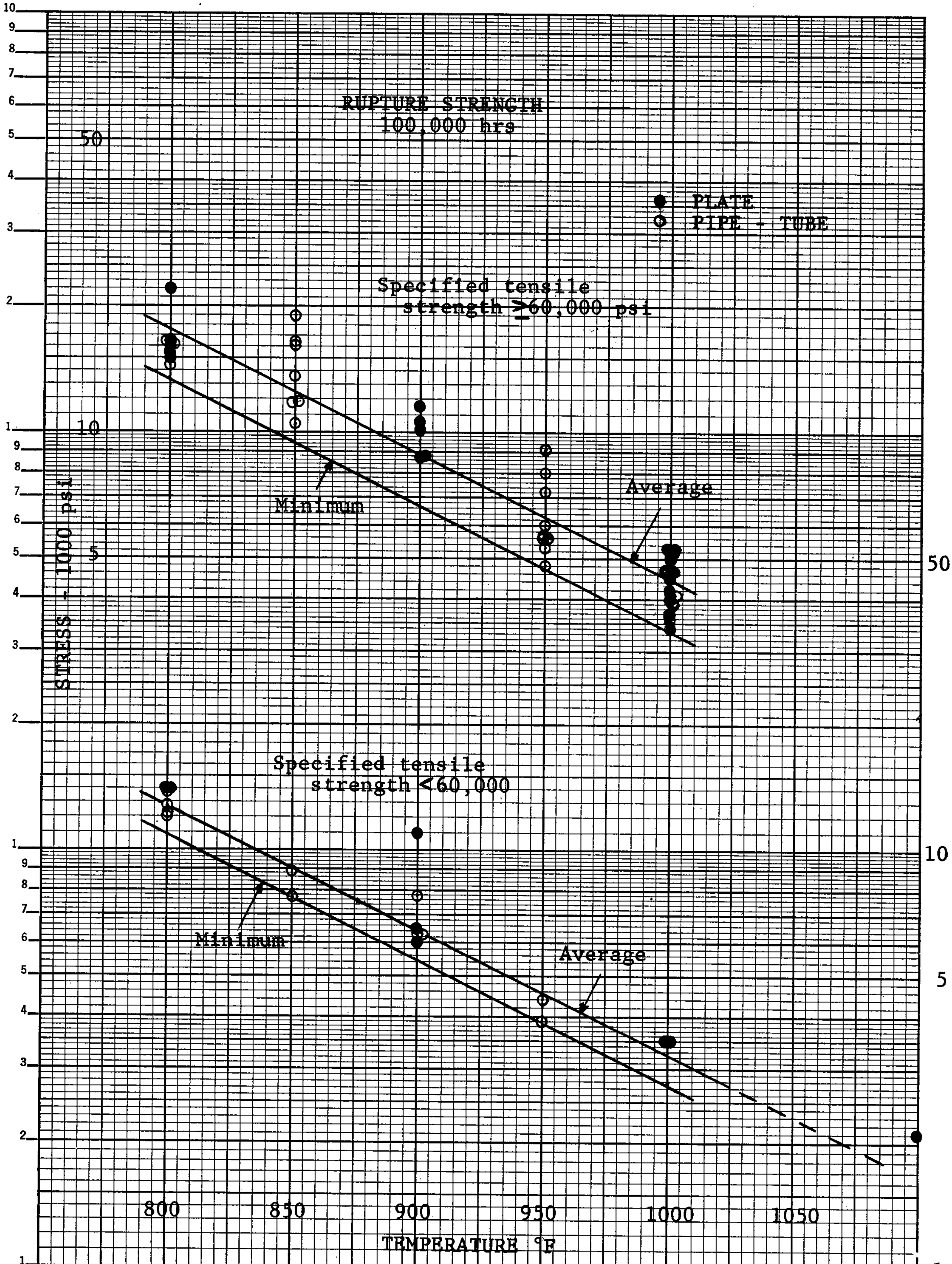

Fig. 15 Effect of specified minimum tensile strength on rupture strength (100,000 hrs)

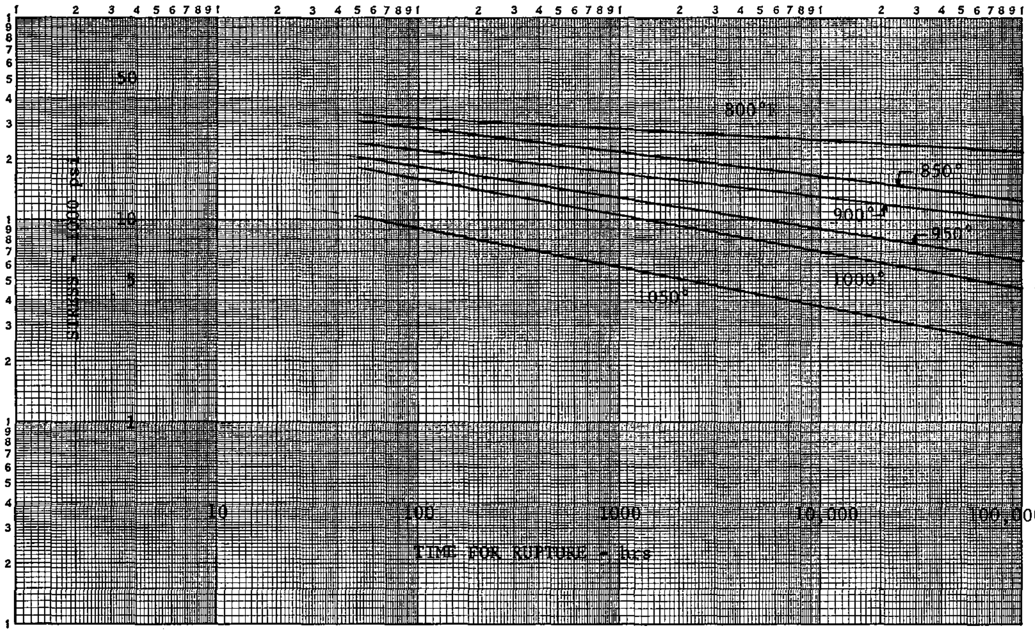

Fig. 16 Linear regression lines for log-log scatter bands of stress vs rupture time, extended to 100,000 hrs. Time taken as independent variable.

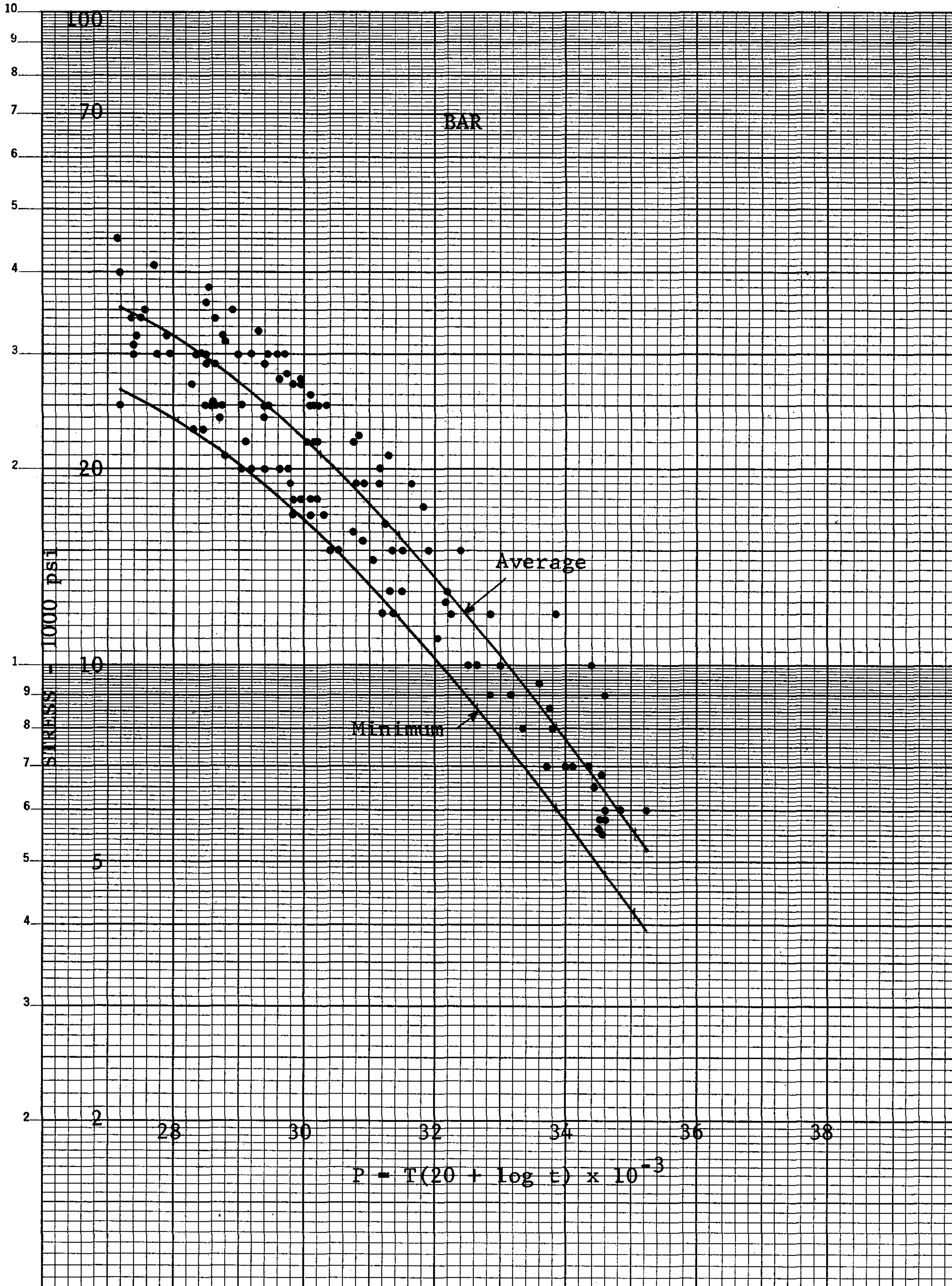

Fig. 17a Variation of Larson-Miller parameter with stress for rupture of carbon steel bar.

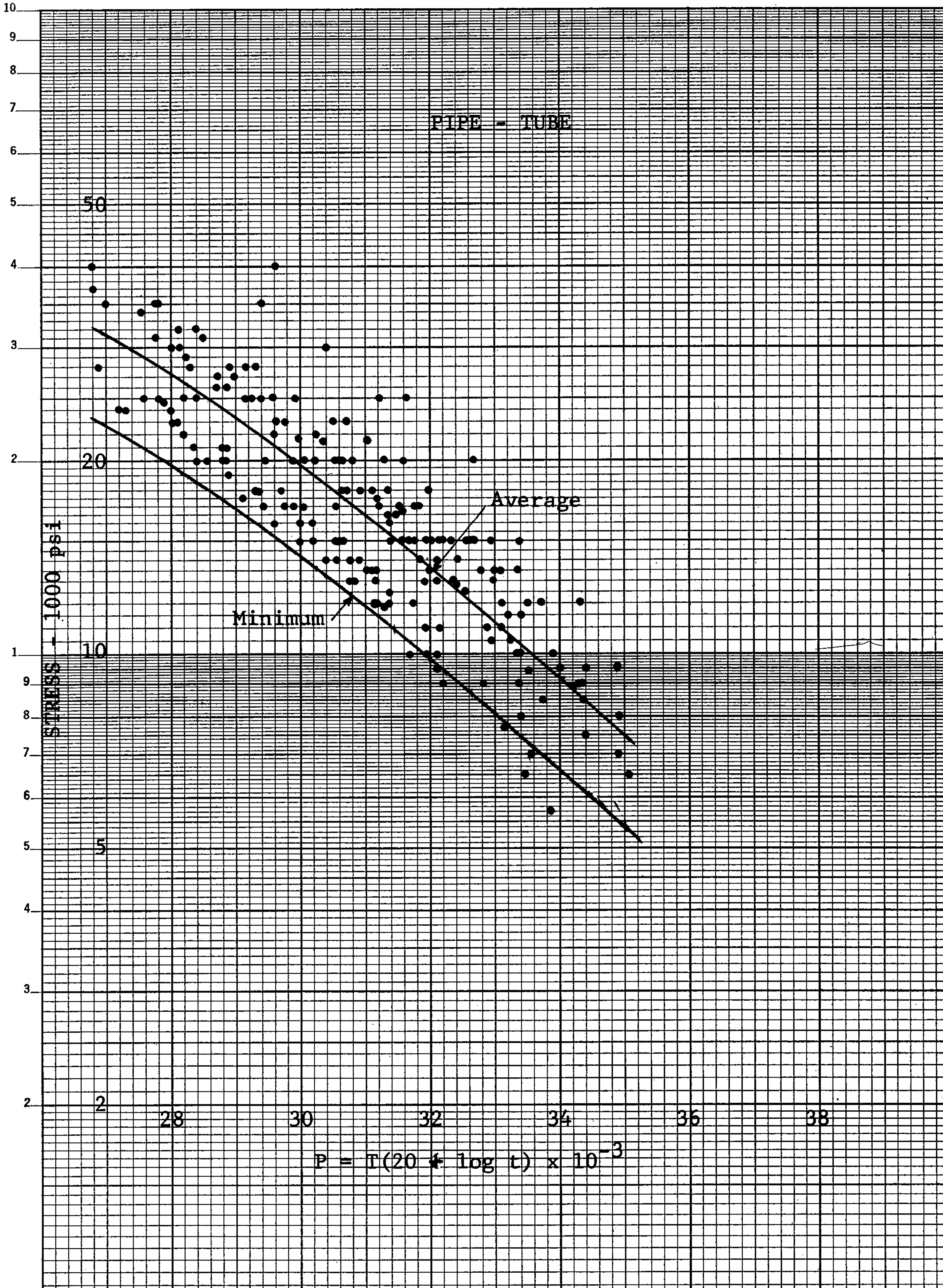

Fig. 17b Variation of Larson-Miller parameter with stress for rupture of carbon steel pipe and tube.

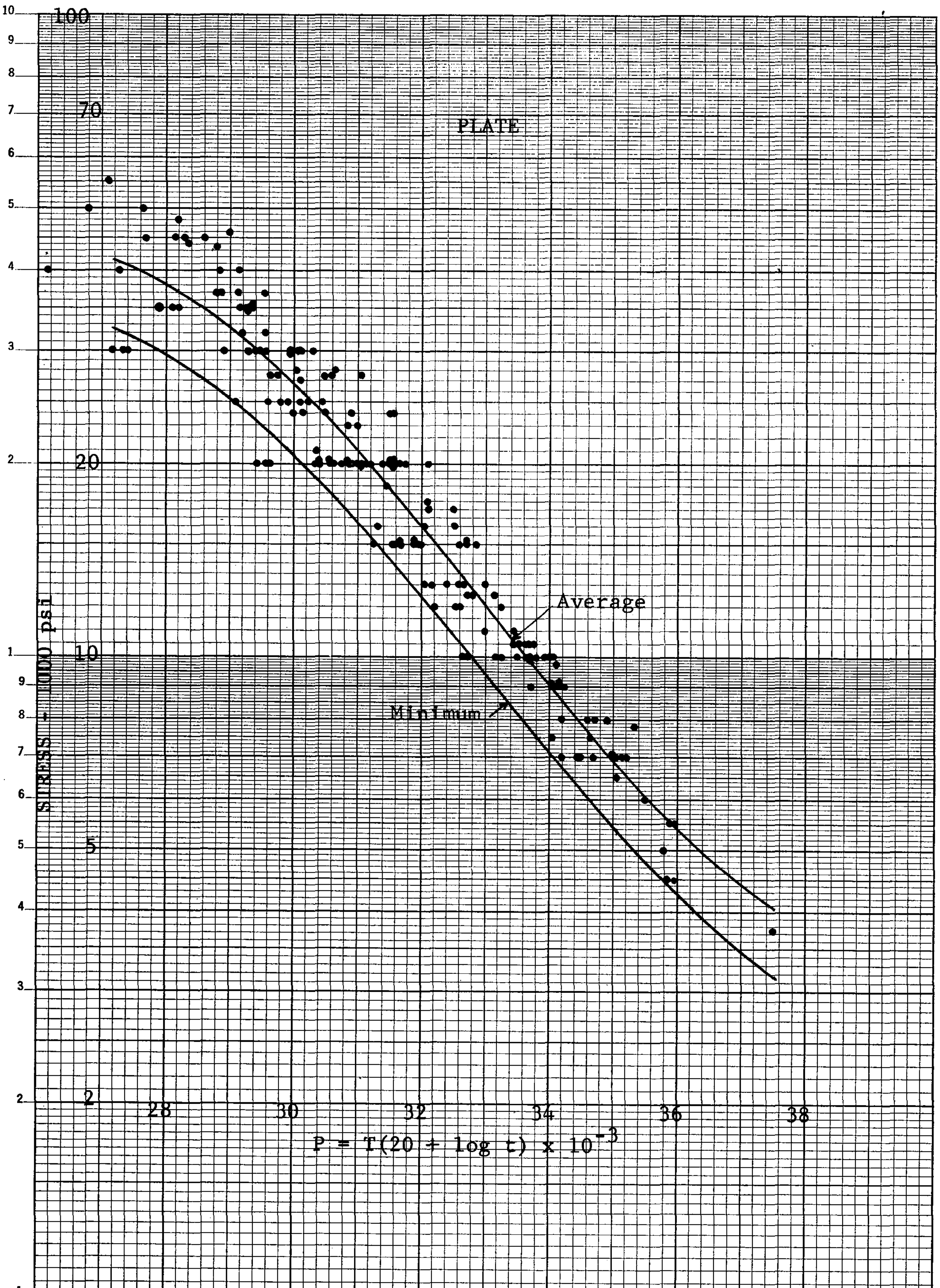

Fig. 17c Variation of Larson-Miller parameter with stress for rupture of carbon steel plate.

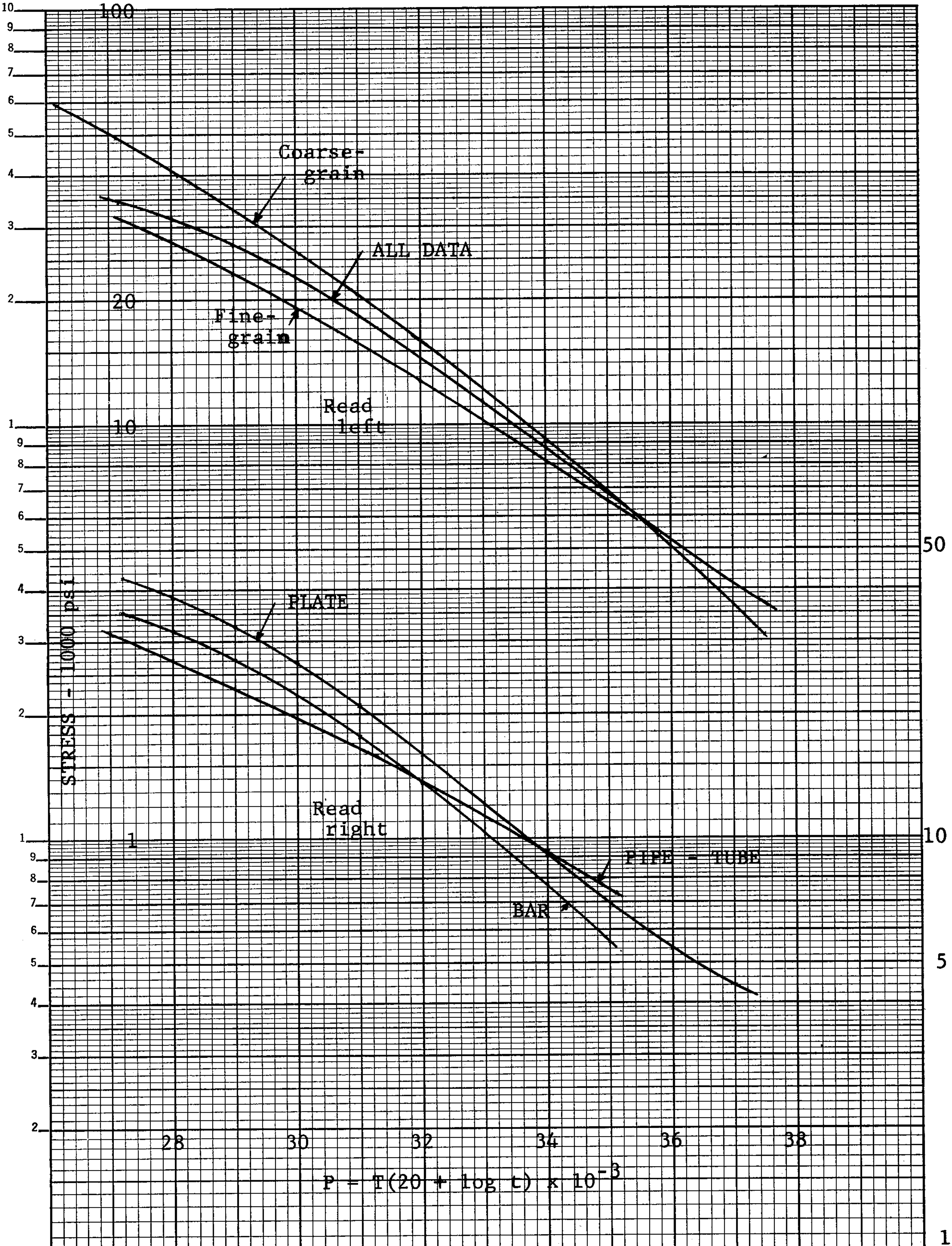

Fig. 18 Effect of deoxidation practice and product form on average Larson-Miller parameter regression curves.