SUPPLEMENTAL REPORT ON THE ELEVATED-TEMPERATURE PROPERTIES OF CHROMIUM-MOLYBDENUM STEELS (An Evaluation of 2¹/₄Cr-1Mo Steel)

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

ASTM DATA SERIES PUBLICATION DS 6S2

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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Report on the Elevated-Temperature Properties of Chromium-Molybdenum Steels, DS 6 (1953), $4.75

Supplemental Report on the Elevated-Temperature Properties of Chromium-Molybdenum Steels, DS 6S1 (1966), $2.25

Contents

REFERENCE: Smith, G. V., "Supplemental Report on the Elevated Temperature Properties of Chromium-Molybdenum Steels (An Evaluation of 2¼Cr-1Mo Steel)," ASTM DATA SERIES, DS 6S2, American Society for Testing and Materials, 1971.

ABSTRACT: This report offers evaluations of elevated temperature strength properties of 2¼Cr-1Mo steel in various conditions of heat treatment and for diverse product forms. The data evaluated include test results previously included in ASTM Data Series DS 6 (1953) and DS 6S1 (1966), as well as newly generated data gathered by the Metal Properties Council.

The data for wrought material are separated into a number of strength categories corresponding to current specifications for annealed, normalized and tempered, and quenched and tempered grades. Data for castings and for weld-metal are evaluated separately.

Rupture strength and creep strength have been evaluated at two levels, respectively, as the stresses to cause rupture in 10,000 or 100,000 hours and as the stresses corresponding to secondary creep rates of 0.1 and 0.01 percent 1000 hours. The temperature dependencies of these properties as well as of yield strength (0.2 percent offset) and tensile strength are developed in such a form as to be useful for establishing allowable working stresses. Elongation and reduction of area data, although not of direct usefulness in setting stresses, are also included.

The body of the report provides in tables, text, and figures, details concerning the indentification of the individual lots of material, the evaluation procedures, and the results. Several summary figures immediately following this abstract, Figs. 1-5, depict the temperature dependence of important strength properties for a number of grades of practical interest. Figure 6 provides a comparison of the temperature dependence of yield and tensile strength, expressed in the form of strength ratios, for several conditions of heat treatment and product form.

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

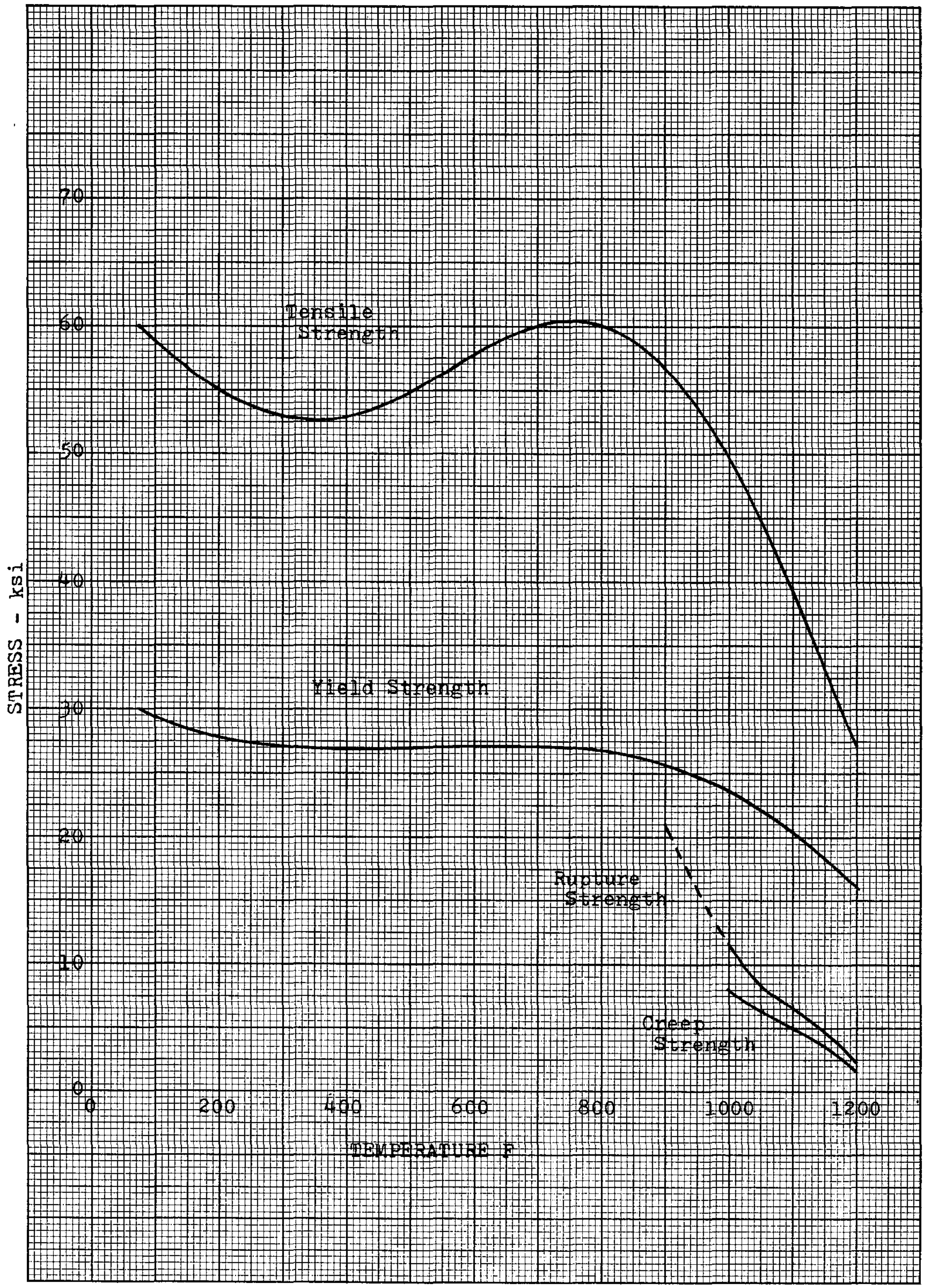

Figure 1 - Effect of temperature on yield strength, tensile strength, creep strength (0.01 % per 1000 hours) and rupture strength (100,000 hours) of annealed 2 1/4 Cr - 1 Mo steel in wrought or cast form. Yield and tensile strengths have been adjusted to 30 and 60 ksi at 75 F. Creep and rupture strengths are averages of available data.

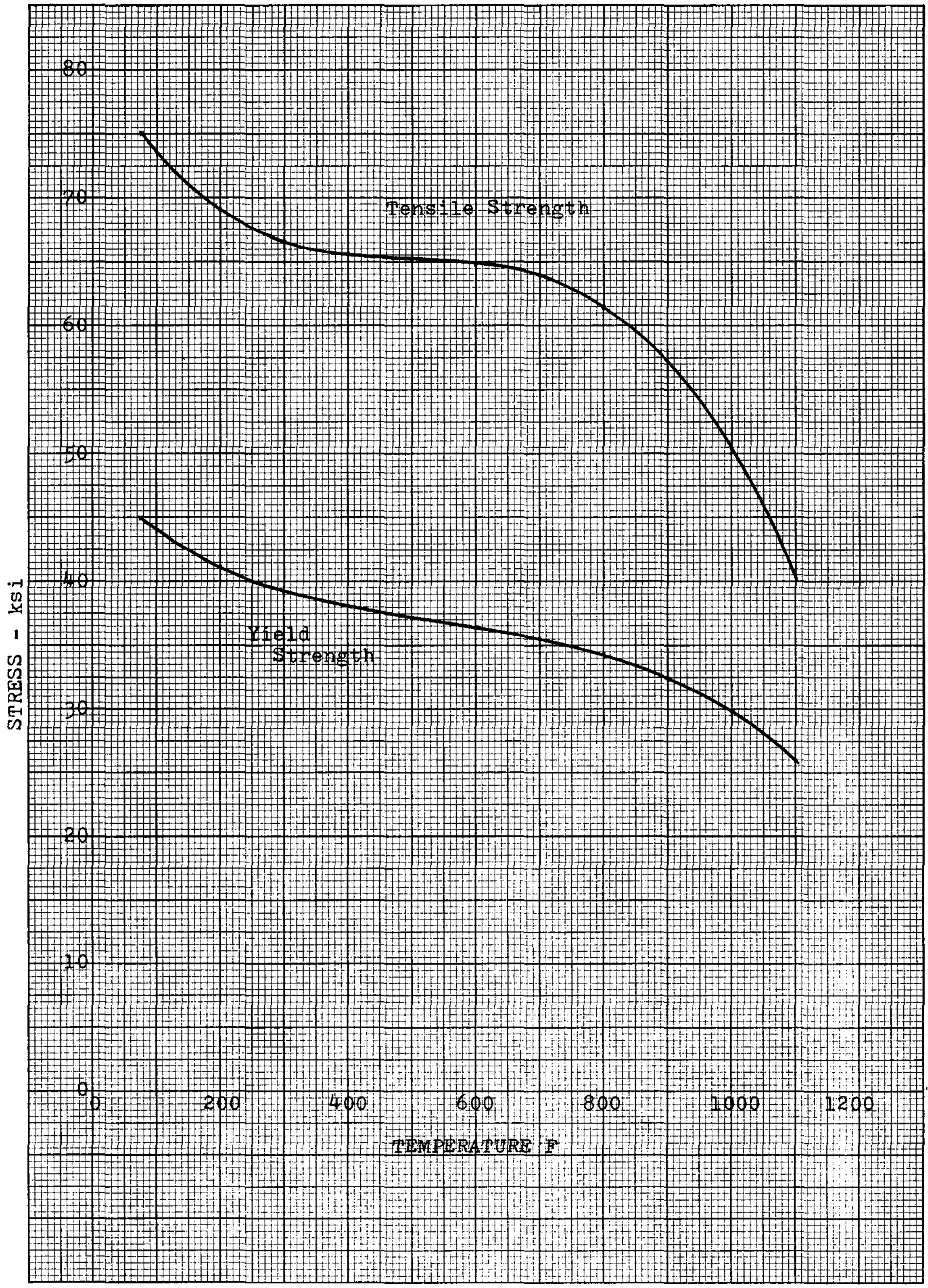

Figure 2 - Effect of temperature on yield strength and tensile strength of normalized and tempered 2 1/4 Cr - 1 Mo steel. Yield and tensile strengths have been adjusted to 45 and 75 ksi at 75 F.

adjusted to 30 and 60 ksi at 75 F. Creep and rupture strengths are averages of available data.

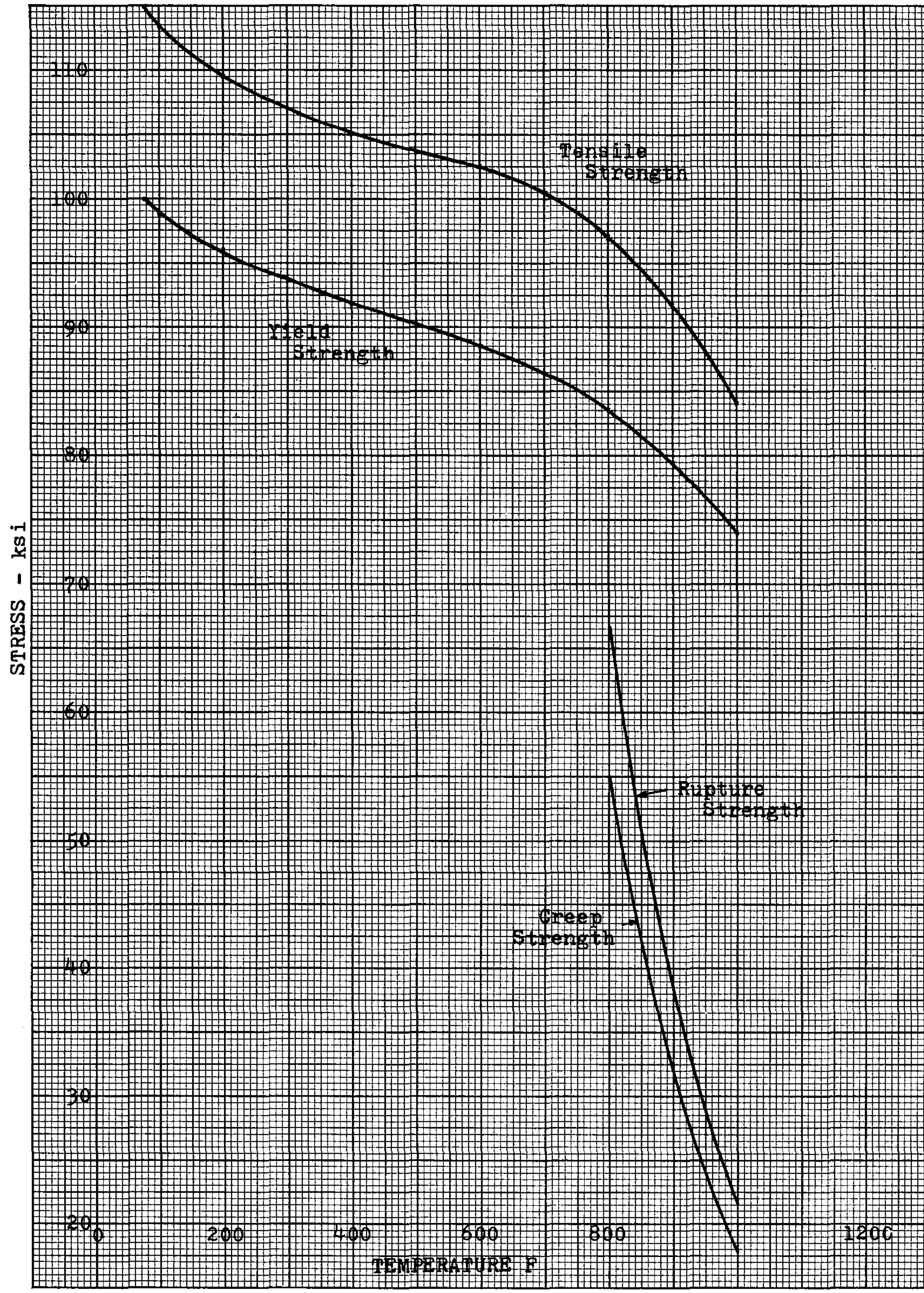

Figure 3 - Effect of temperature on yield strength, tensile strength, creep strength (.01 % per 1000 hours) and rupture strength (100,000 hours) of quenched and tempered material. Yield and tensile strengths have been adjusted to 100 and 115 ksi at 75 F; creep and rupture strengths represent averages of data adjusted to a specified tensile strength of 115 ksi at 75 F

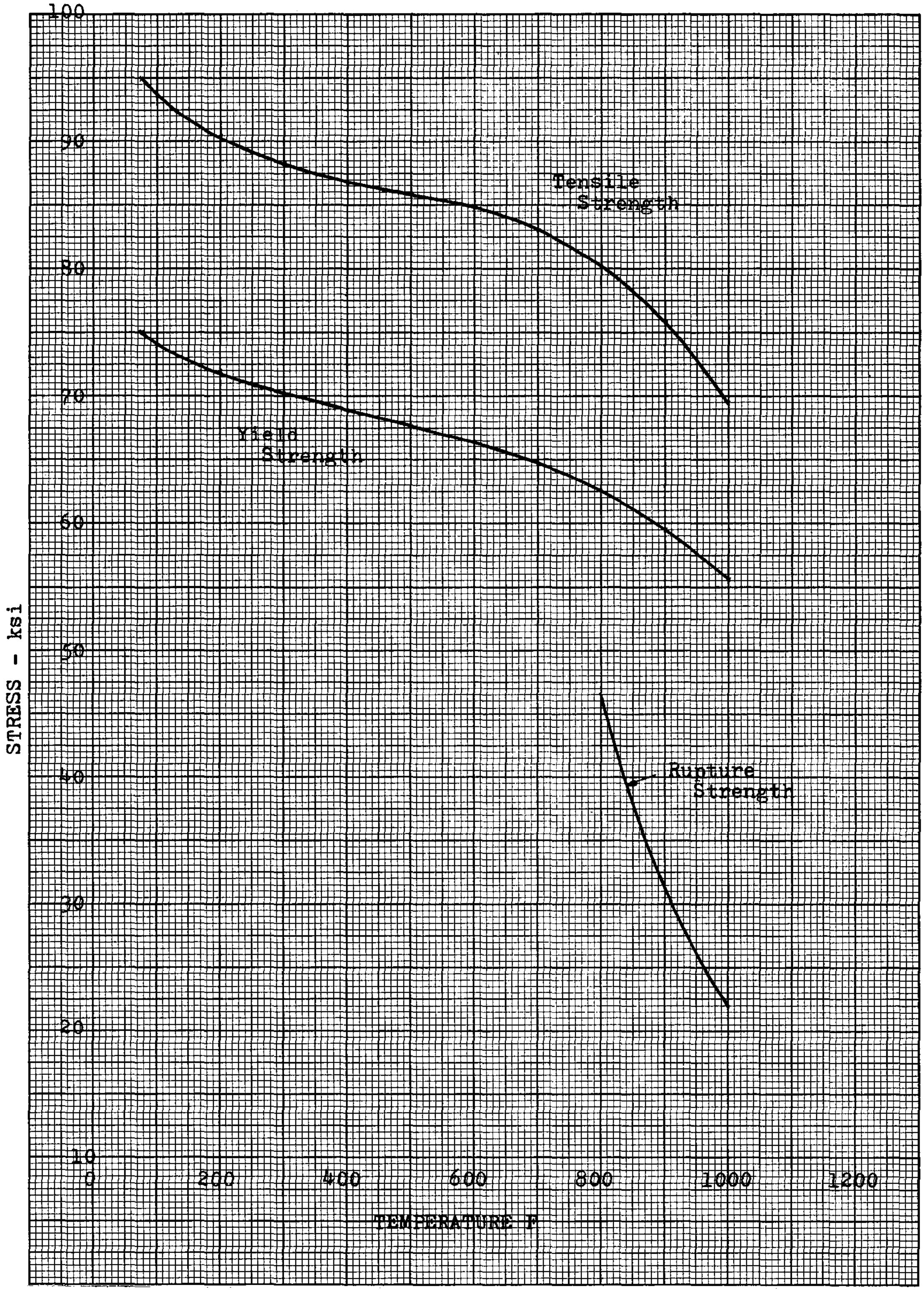

Figure 4 - Effect of temperature on yield strength, tensile strength, and rupture strength (100,000 hours) of quenched and tempered material. Yield and tensile strengths have been adjusted to 75 and 95 ksi at 75 F; rupture strength represents averages of data adjusted to a specified tensile strength of 95 ksi at 75 F.

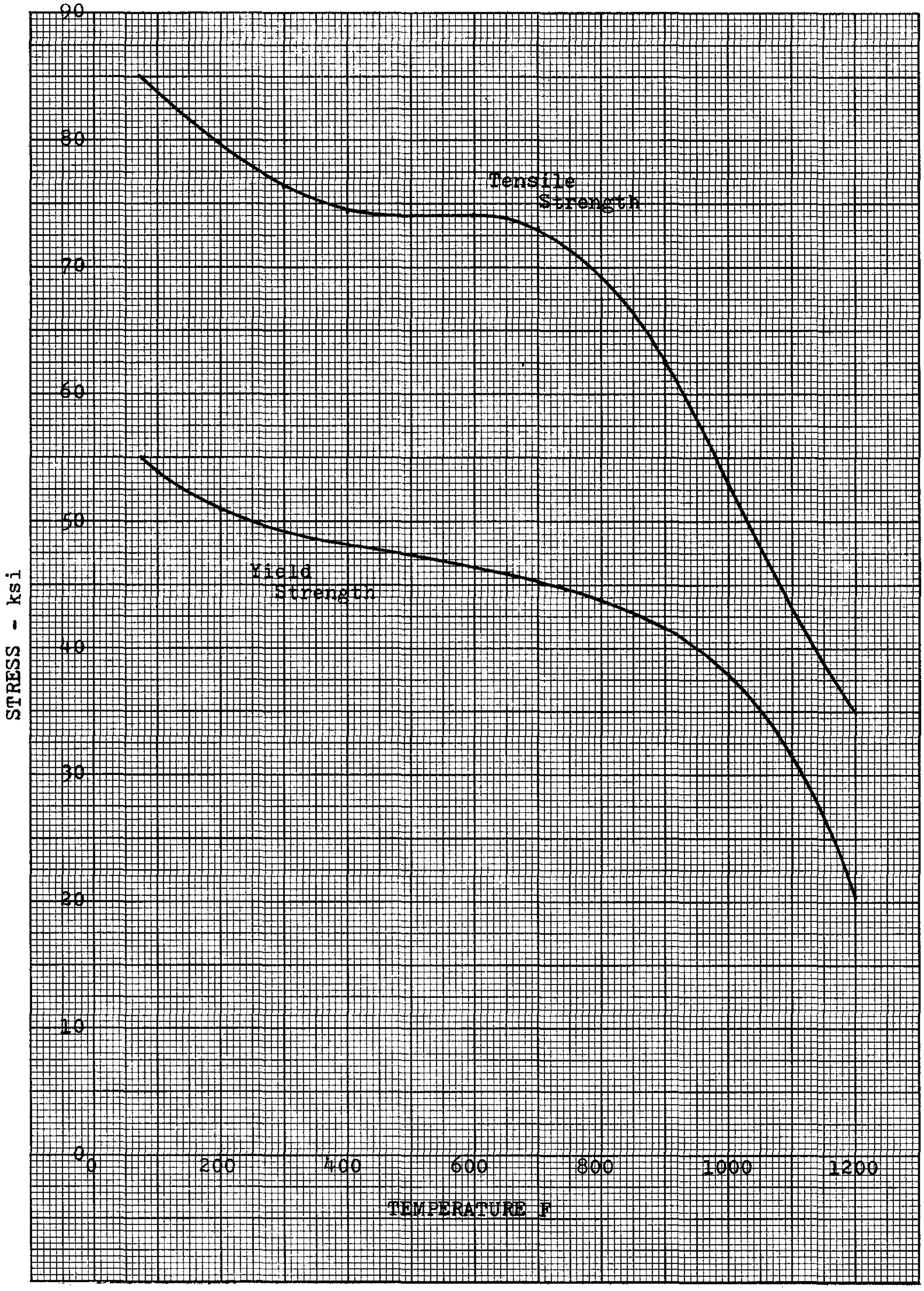

Figure 5 - Effect of temperature on yield strength and tensile strength of normalized-and-tempered and quenched-and-tempered cast 2 1/4 Cr - 1 Mo steel, adjusted to 55 and 85 ksi at 75 F.

justed to 75 and 95 ksi at 75 F; rupture strength represents averages of data adjusted to a specified tensile strength of 95 ksi at 75 F.

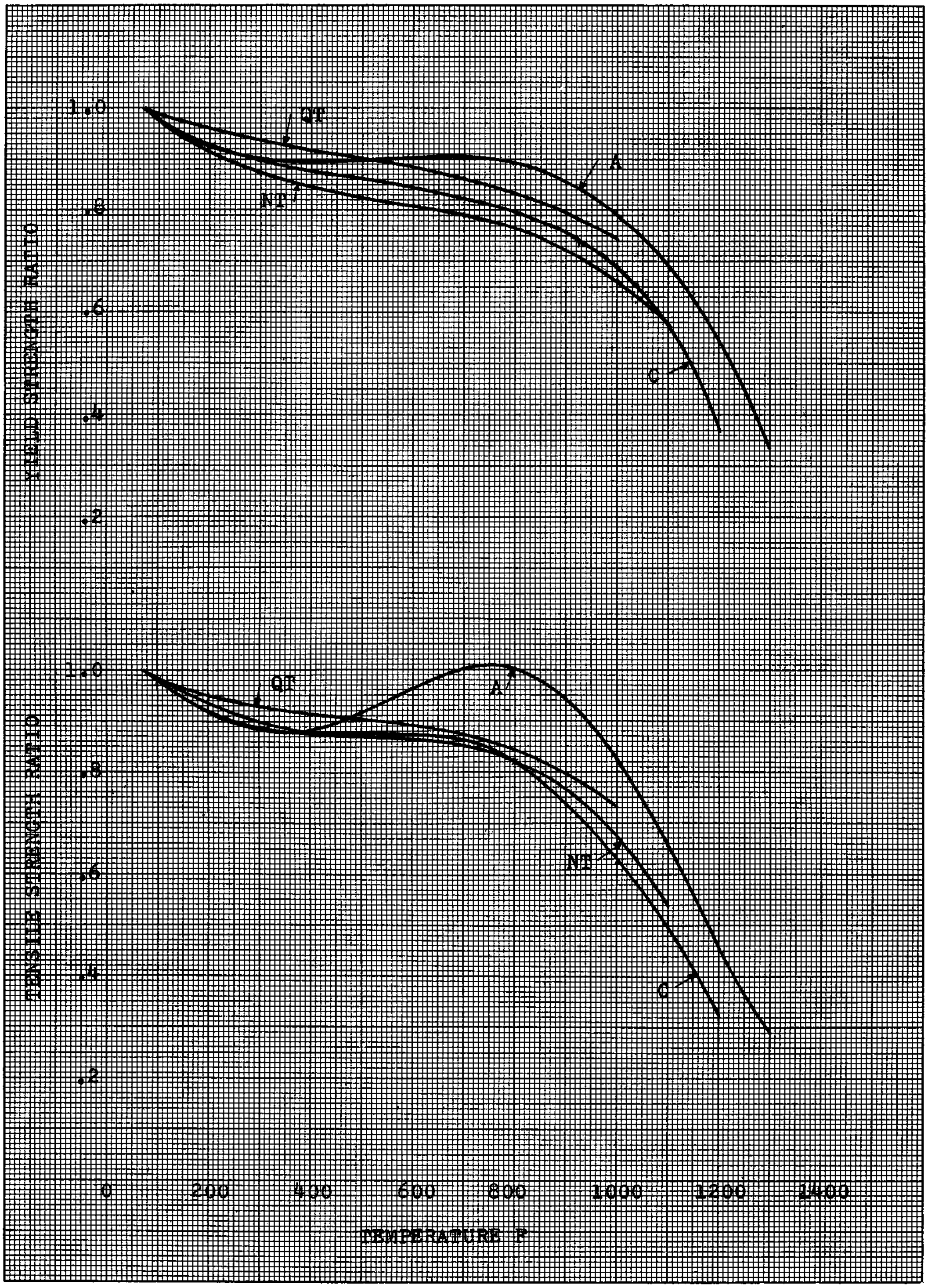

Figure 6 - Comparison of the temperature dependencies of yield and tensile strengths, expressed as strength ratios, for annealed (A), normalized and tempered (NT), and quenched and tempered (QT) wrought material and normalized and tempered and quenched and tempered cast material (C).

INTRODUCTION

Since publication in 1966 of ASTM Data Series Publication DS 6S1 "Supplemental Report on the Elevated-Temperature Properties of Chromium-Molybdenum Steels," not only have additional data on 2-1/4 Cr-1 Mo steel become available, but also, considerable interest has developed in the use of this material at the higher strength levels, ranging up to tensile strengths of 135 ksi, that can be achieved by normalizing or quenching followed by tempering at relatively low temperatures. It has therefore seemed desirable for the Metal Properties Council (MPC) to undertake a re-evaluation of the elevated temperature properties of this popular grade of steel and, in particular, to assess the effects of heat treatment and product form upon the basic trends of behavior.

The evaluation covers data gathered by MPC from industrial and other laboratories, and from published literature, as well as the data previously included in ASTM's Data Series Publications.[1,2,13] A coding key is provided in Table I to the data from the ASTM Data Series, and the newly gathered data are appended to this report. The data are identified in Tables I and II, as to specification, heat treatment, product form and size, chemical composition, and source. Some of the data sets from DS6 and DS6-S1 were excluded from the evaluation owing to inadequate identification, and nonconformity with specifications, including the use of unconventional heat treatments. A distinction has been preserved in the early stages of the evaluation as to product form although such differences later proved to be unimportant in a number of instances. In a few instances, steel produced to a specific specification was tested in another form, as when material produced to a pipe specification was actually tested in the form of bar. Also, when, in a few instances, material was identified only as wrought, it was arbitrarily categorized as bar.

The properties that have been evaluated in this report include yield and tensile strengths, and creep and rupture strengths. The latter two properties have been evaluated at two levels each: as the stresses causing a secondary creep rate of 0.1% or 0.01% per 1000 hours and causing rupture in 10,000 or 100,000 hours. These latter properties are of interest for setting allowable stresses for boiler and pressure vessel systems in the range of temperatures in which creep is important, whereas yield and tensile strengths are employed in establishing allowable stresses at lower temperatures. No attempt was made to assess creep strength in terms of the stress causing a specific creep strain in a given time interval as stipulated in a number of foreign codes, for the reason that the available data are unsuitable for that purpose.

Although not directly useful to designers, elongation and reduction of area at fracture in the tensile and rupture tests are included in this report, where available, and some comments are offered concerning the trends of behavior. Since the individual strength properties needed for setting allowable stresses are each required over the temperature range in which they may govern, an effort has been made to develop the evaluations in terms of trend curves defining the variation of strength with temperature, rather than in terms of strengths at individual temperatures.

Yield Strength and Tensile Strength

The original tensile test results, not previously reported in the ASTM Data Series publications, are tabulated in Table III, separated according to product form. As with previous evaluations, the tests are presumed to have been conducted generally at strain rates within the limits permitted by ASTM recommended practice E 21. 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 yield point. The tabulated elongation values were measured on a 2-inch gage length and the test specimens were taken from the quarter thickness position unless otherwise noted.

In previous reports covering wrought austenitic stainless steels and carbon steel,[25,26] it has proved helpful in evaluating yield and tensile strengths to normalize the test results by ratioing the elevated temperature strengths of individual lots to the corresponding strengths of the same lots at room temperature, and then to establish by the method of least squares the regression curve of best fit -- the trend curve -- for the variation of strength ratio with temperature. This same procedure has been employed in the present evaluations, and its effectiveness in normalizing the data will again be apparent.

In assessing the effect of strength level upon yield and tensile strength of 2-1/4 Cr-1 Mo steel at elevated temperatures, it has proved convenient to adopt for the wrought products a categorization that reflects current plate steel specifications:

Category 1: All annealed material, whatever the strength level, and normalized and tempered material having a tensile strength at room temperature less than 75 ksi.

Category 2: Normalized and tempered material having a tensile strength at room temperature greater than 75 ksi (ASTM Spec. 387, Grade D).

Category 3: Quenched and tempered material having a tensile strength at room temperature less than 115 ksi (ASTM Spec. 542, Classes 1 and 3).

Category 4: Quenched and tempered material having a tensile strength at room temperature of 115 ksi or more (ASTM Spec. 542, Class 2).

A few data for forgings reported to have been quenched and tempered corresponded better with levels to be expected of normalized and tempered plate material, and were so categorized. After it was discovered that the strength ratios of quenched and tempered material are essentially independent of strength level (as also appears to be true within the other categories, as well)[27], a few data not meeting the minimum tensile strength of current specifications (95 ksi) were included in category 3, and a few data exceeding the maximum of current specifications (135 ksi) were included in category 4. However, in the latter instance, ductility data were not incorporated into the plots.

The few data for quenched and tempered castings having a tensile strength greater than 105 ksi were first considered separately from those for normalized and tempered castings, but when the resulting regression curves proved to be essentially identical, the two sets of data were combined into a common category. The elongation and reduction of area results for quenched and tempered castings fell within the scatter band of the other data.

Data representing weld metal that had received a post weld heat treatment were evaluated as a separate category. Data representing tests of weldments, i.e. of specimens including weld metal, base metal and heat affected zone, were not evaluated, owing to the basic inhomogeneous character of this type of test specimen, and the dependence of the results upon geometrical and other factors.

Finally, a few data became available after the regression analyses had been completed, and whereas these data are included in the tabulation and plots, the regression analyses may not have been rerun, when inspection indicated that any change in the regression result would be inconsequential.

The tensile test results for the different categories are plotted as dependent upon temperature in figures 7 through 12. In each figure, part (a) charts yield strength and yield strength ratio, part (b) charts tensile strength and tensile strength ratio, and part (c) charts elongation and reduction of area. In the plots for the four wrought categories, data for the different product forms, plate, pipe and tube, bar, and forging have been differentiated. However, relatively few data representing bar or forgings were available, and most of the data in the normalized and tempered or quenched and tempered categories represented plate materials. Inspection of the ratio plots does not suggest the need to distinguish amongst the wrought product forms of a particular strength category, but clearly the sample sizes are limited.

The ratioing procedure proved generally effective in reducing the scatter of results in the strength plots, especially for the tensile strength of the wrought products at temperatures below about 500°F. At higher temperatures, there is reason to believe that the scatter may reflect structural changes within the material, sensitive to composition and prior treatment, that in turn result in differences in strength ratio. The rise in tensile strength ratio exhibited by the annealed category at intermediate temperatures is characteristic of materials that exhibit dynamic strain aging, and it seems probable that the scatter of strength ratios in this range for this category may therefore reflect differences in susceptibility to such aging. Normalized and tempered as well as quenched and tempered materials do not exhibit dynamic strain aging, at least to the extent of a rise in tensile strength at intermediate temperatures. However, the leveling of tensile strength of the normalized and tempered material, as well as the increased scatter, cited above, may reflect some tendency to dynamic aging.[27] In any event, the scatter does not appear to be related to differences in strength level, as revealed by plots of strength ratio at individual elevated temperatures, e.g. 800°F, in dependence upon strength at room temperature.[27]

The scatter in yield strength ratios is substantially greater than for tensile strength ratios, but whereas some of the scatter may be associated with the same factors causing scatter of tensile strength ratios, a significant portion is certainly inherent, reflecting testing difficulties in the measurement of yield strength, the possible presence of residual straightening stresses, and possibly differences in strain rate, factors which are less important in measuring tensile strength.

A question of interest to some engineers is whether there is an effect of section thickness upon the behavior, particularly in plate, and accordingly the test results were examined in this respect. The available data represented sections ranging upwards to more than 7 inches. The reported observation[27] that strength ratio at elevated temperature is independent of strength level, within a specific heat treatment category, indicates that although there might be expected to be a dependence of strength, measured at a specific subsurface location, upon section size, owing to the dependence of cooling rate upon section size, there should not be any effect upon strength ratio. A comparison of individual strength ratios at 800°F in different section sizes, for both normalized and tempered and quenched and tempered plate failed to reveal any dependence of ratio upon section size.

Except for weld metal the ratio plots were evaluated by the method of least squares, and with no distinction as to product form for the wrought materials, to establish the best-fit curves defining the dependence of strength ratio upon temperature. The resulting "trend curves" have been superimposed upon the plots, and tabulated in Table V. Because the trend curves for the two categories of quenched and tempered material were essentially identical, a ratio trend curve was developed for the combined groups and is given also in Table V. A graphical comparison of the ratio trend curves is given in Figure 6 (following the abstract) for the following categories: annealed, normalized and tempered, quenched and tempered, and castings.

The trend curves for annealed material are strikingly different than those for the other categories, particularly for tensile strength. As indicated previously, the maximum in tensile strength of annealed material at intermediate temperatures is characteristic of materials that exhibit dynamic strain aging. The shift in peak temperature from the range 400 to 500°F observed for carbon steel to 700 to 800°F for 2-1/4 Cr-1 Mo steel is to be associated with the presence of strong carbide forming elements.[27] The trend curves for the remaining categories are essentially similar in form. Differences are somewhat greater for yield strength than for tensile strength. As a matter of possible interest all of the data excepting the annealed category have been grouped together to develop common ratio trend curves; the ratios are tabulated in Table V.

With the dependence of strength upon temperature expressed in terms of strength ratios, it is possible to compute absolute values of strength, adjusted to any specific level within the limits encompassed by the original data. Summary Figures 1-5, referred to in the Abstract of this report, include plots showing the variation of yield and tensile strength with temperature, adjusted to the specified minimum levels of several purchase specifications of general interest.

Although there are too few data available for weld metal, especially at temperatures between 75 and 800°F, to warrant an attempt to develop trend curves, the ratio trend curves developed for cast steel have been superimposed over the ratio plots for the weld metal to provide a basis for assessment of weld metal, Figure 12 a and b. Examination of these plots suggest that the available data are not inconsistent with the trend curves for cast steel.

Elongation and reduction of area of the annealed material fall off slightly at intermediate temperatures, possibly reflecting the dynamic strain aging, mentioned earlier, and then increase progressively to the maximum temperature for which there were data, 1300°F. The normalized and tempered, the quenched and tempered, and the cast materials also exhibit a slight loss in ductility at intermediate temperatures. The ductility scatter bands of the various categories overlapped extensively especially for reduction of area. However, annealed material did exhibit somewhat greater elongation at room and slightly higher temperatures than did the other categories, and the quenched and tempered material having a tensile strength of 115 ksi or greater exhibited elongation slightly inferior on the whole to the other categories.

Creep and Rupture Properties

The original data not previously reported in DS 6 and DS 6S1 (References 1 and 2) are tabulated in Table IV, separated according to product form. The data are plotted in various groupings in Figures 13-20.

The creep and rupture data have been evaluated with the primary objective of developing best current assessments of these properties in a form directly useful by Code groups for establishing allowable stresses. In the ASME Boiler and Pressure Vessel Code, the criteria for setting stresses in the "creep" range of temperatures include the average and minimum stresses to cause rupture in 100,000 hours, reduced by appropriate fractional factors, the purpose of which is to insure a reasonably long safe period of usefulness. The allowable stress is also limited in the ASME Code to the average stress to produce a secondary creep rate of 0.01 percent per 1000 hours, which corresponds to a rate of 1 percent per 100,000 hours, if the rate were to remain unchanged. The stress for rupture in 100,000 hours can ordinarily be developed only by extrapolation of the results of tests of shorter duration, since tests lasting 100,000 hours are seldom made. Determination of the stress causing a secondary creep rate of 0.01 percent per 1000 hours may require extrapolation, but may be obtained by interpolation.

The data have been evaluated also for the stress to cause rupture in 10,000 hours, which frequently involved the need for extrapolation, and for the stress to cause a secondary creep of 0.1 percent per 1000 hours. Rupture and creep strengths for still shorter rupture times and faster creep rates have not been explicitly assessed, but can be readily approximated by inspection of the scatter band data plots.

Past evaluations in this series have been concerned with annealed material or material normalized and tempered at relatively high temperatures to produce relatively soft material, and it has been generally common practice in such evaluations to ignore a possible dependence of creep and rupture strength upon microstructure, which is known to have an important influence upon strength at room temperature. In the present evaluation, a possible dependence of creep and rupture strength on microstructure has also been ignored, and all data for annealed material, including material normalized and tempered at a relatively high temperature, have been grouped together without distinction as to strength level. In fact, in the present instance, as frequently true, room temperature strength data are so generally lacking as to preclude the possibility of assessing the dependence of creep rupture strength on room temperature strength. However, it is clear that the creep and rupture strengths of the higher strength categories of 2-1/4 Cr-1 Mo steel are not independent of room-temperature strength, certainly in the range of greatest practical interest, 800 to 900°F, or slightly higher. Consequently, the creep and rupture strengths of the higher strength grades have been evaluated in such a way as to recognize their dependence upon strength level.

For extrapolating time-for-rupture data to permit assessing the stress to produce rupture in 100,000 hours, there are two broad types of procedures. In the first, or direct procedure, the relation between log stress and log time-for-rupture at constant temperature is extended to 100,000 hours. In the second procedure, extrapolation is effected indirectly by means of one or another time-temperature parameter. Both procedures have been employed in the present evaluation.

Annealed Material - Direct Extrapolation

It is possible to effect direct extrapolation either by treating different lots individually, or alternatively by defining and then extending the best fit curve for the scatter band of all data. The merits of the alternatives have been reviewed in the prior evaluations of the current series as well as in published literature.[25-28] To permit comparisons, both procedures have been employed in evaluating the rupture strength of annealed material, but for reasons given in the cited references, principal emphasis is placed on individual lot extrapolations. To show both the volume and the scatter of the data, all of the data, including applicable data from DS 6 and DS 6S1[1,2], are shown in isothermal scatter band plots of log stress versus log time for rupture (Fig. 13 a,b,c and d); of log stress versus log of secondary creep rate (Fig. 14 a,b, and c); and of percent elongation and reduction of area at rupture versus log time for rupture (Fig. 15 a,b,c,d and e). In each figure, data for different product forms are differentiated, although in the end it does not seem reasonable to attempt to distinguish amongst product forms. Data for weld metal are considered separately in a later section.

Because there was no evidence either in the scatter bands or in the individual lots that log stress and log time-for-rupture were related other than linearly, at least at temperatures below 1150°F, the time-for-rupture data, whether considered as individual lots or as scatter bands, were extended linearly to 100,000 hours. (See also prior discussion of this question in references 25-28). On the other hand, log secondary creep rate tended often to vary curvilinearly with log stress in the range below 0.1 percent per 1000 hours; the variables were so treated, either for interpolation or extrapolation. The secondary creep rate data were evaluated only in terms of individual lots not as scatter bands. The individual lot extrapolations for both rupture and creep strength were developed visually, giving weight to the longer-time or slower-rate data.

The results of the individual-lot extrapolations or interpolations, which were made on individual plots too numerous to include here, are tabulated in Tables VI-IX, along with similar results for the high strength categories, to be discussed later. The results have also been plotted in Figs. 21 and 22 as dependent upon temperature. Semilogarithmic coordinates were chosen for the plots of Figs. 21 and 22 because in past evaluations they have frequently tended to linearize the relation between the variables. Most of the data plotted in Fig. 21 and 22 represent pipe and tube. The few data representing bar and castings appear to agree reasonably well with the overall scatter and, in the further evaluation, are treated as belonging to the same sample population. There were no data for annealed plate.

The isothermal scatter bands, except those at 1150 and 1250°F, for which there were few results, were evaluated by the method of least squares, and the mean curve of best fit extended to 100,000 hours. In these evaluations the longer-time test results were weighted by arbitrarily excluding rupture times less than 40 hours, and time was taken as the independent variable, for reasons given previously.[28] In the regression analyses, no significant improvement in variance was observed in going beyond a linear dependence between log stress and log time-for-rupture, except at 1200°F. At this temperature, an improvement in variance was realized by assuming a second or even a third order dependency, but the number and character of the data are such as to inhibit placing complete confidence in the regression result. The best fit lines from the least squares analyses are superimposed upon the individual isothermal scatter bands, and the values of 100,000 hour rupture strength obtained by extending the regression lines are included in Tables X and XI for later comparison with strengths developed by other evaluation procedures.

The family of linear isothermal regression lines, shown in Fig. 23, reveal that the slope for the data at 1050°F is greater than those for 1000 and 1100°F, such that the 1000 and 1050°F lines intersect at about 100 hours, and the 1050 and 1100°F curves would intersect shortly beyond 100,000 hours. It might be argued that the near identity of strengths at 100,000 hours is not possible. Yet there can be no question that the scatter bands of actual test results at 1000 and 1050°F do overlap at 100 hours, and it is not unknown for a material to exhibit the same strength at two or even three temperatures (see, for example, Fig. 7b). Alternatively, it might be argued that the data at 1050°F represent a unique population, but this seems unlikely since relatively few heats were tested only at 1050°F and not at another temperature. Still another possibility is that the 1050°F slope breaks upwards, or that the 1100°F slope breaks downward (or both). Some support for the view that the 1050°F slope does break upwards is found if data less than 500 hours are excluded from the regression analyses. The extended regression line for 1050°F then intersects the 100,000 hour abscissae at 8.87 ksi instead of 7.67 ksi; the extended regression lines for 1000 and 1100°F are altered only slightly by the exclusion of data less than 500 hours (to 11.87 and 7.25 ksi respectively). This general problem, particularly with respect to the linearity of the isothermal relations, has been considered at some length in another publication[27] and the conclusion drawn that the behavior must be accepted at face value, pending the availability of further test results that would provide a more positive basis for disputing the observed behavior.

The perturbation apparent in the family of isothermal regression lines is also evident, though less prominently, in the results of the individual-lot extrapolations, plotted in Figures 21 and 22. Particularly for rupture in 100,000 hours, Figure 22, the rupture strength values for 1100°F mass above the line of best fit for the data at 1000, 1050 and 1200°F, or considered alternatively, the data at 1050°F lie on the low side. This behavior is evident also in Figure 21 for rupture in 10,000 hours, but less prominently. Inspection of Fig. 22 reveals that the results at 1050°F are weighted importantly by the three lowest values but no valid reason could be found for rejecting these values; attention might also be called to the weighting on the high side at 1050°F, resulting from three sets of data for bar. Note also the weighting for rupture in 10,000 hours, Figure 21. And, of course, the trend evident in Figure 22 receives support from the regression analysis of the isothermal scatter bands, Figure 23. The mean regression lines drawn on the rupture data of Figures 21 and 22 represent best fits for the data and correspond to equations of third degree. Minimum curves at a confidence level of 90% have also been developed from the mean curves on the assumptions that the data exhibit a log normal distribution in strength, that the mean curve is without error in slope and that the variance is independent of temperatures. At a confidence level of 90%, 95% of the individual values should lie above the minimum, which is at least approximately true. The mean and minimum values defined by the regression lines in Figures 21 and 22 are included in Tables X and XI. The arithmetic means of the individual values at the different temperatures are also included in Tables X and XI, along with minimum values at the 90% confidence level, on the assumption of a normal distribution in strength.

The stresses to cause secondary creep rates of 0.1 and 0.01 percent per 1000 hours have also been plotted in Figs. 21 and 22. Unfortunately, the distribution of the data points suggests that the relation between log strength and temperature may be nonlinear, as was true for rupture strength. Thus, in Figure 22, the strengths at 1050°F fall within the scatter band of strengths at 1000°F. Moreover, inspection of the plots of log stress versus log secondary creep rate, Figure 14, reveals extensive overlapping of the scatter bands. However, since there are only about one third as many data at 1050 as at 1000 or 1100°F, it seemed possible that the 1050°F data sample might be unrepresentative. Examination of the temperature dependence of the strength of individual heats showed that the highest two values at 1050°F, Figure 22, corresponded with the highest individual values at 1000 and 1100°F, respectively, indicating that the data at 1050°F are, in fact, unrepresentative.

In view of the character of the data, it has not seemed appropriate to develop the trend curve by regression analysis.* Instead, pending the availability of sufficient additional data that would preclude the need for subjective judgment, it has seemed best to define the "trend curve" of creep strength, on Figures 21 and 22, by a linear line connecting the averages at 1000 and 1100°F, and another linear line between the averages at 1100 and 1200°F. The creep strengths so defined are tabulated in Table XII. Further, owing to the character of the data, it has not seemed appropriate to attempt to develop minimum values. (These are not required for setting stresses in the ASME Code.) Approximate minimum values may be estimated by inspection of the plots of Figs. 21 and 22.

Annealed Material -- Indirect (Parameter) Extrapolation

It is commonly agreed that extrapolation by time-temperature parameter should preferably be undertaken on an individual heat basis, but to do this requires more data, particularly at different temperatures, than are generally available for the data collected by the Metal Properties Council. However, it is possible to adopt a "universalized" approach, which assumes values for the parameter constants, and to "parameterize" and evaluate all of the data on a scatter band basis. In spite of inherent reservations concerning such an approach, all of the data, for rupture times exceeding 5 hours, were evaluated by this procedure employing both the well-known Larson-Miller parameter, with an assumed value of 20 for the constant:

$$T(20 + \log t) = F_1(S)$$

and the recently proposed Manson compromise** parameter:[29]

$$\log t + \frac{1}{40} \log^2 t - \frac{40,000}{T+460} = F_2(S)$$

In either parameter T is temperature in degrees Rankin, t is the time for rupture in hours, and $F_1(S)$ and $F_2(S)$ denote that the parameters are different functions of the stress S.

*Such an analysis of the data on the assumption of a linear relation between log stress and temperature, resulted in a mean value at 1000°F that was significantly above the average of the values at 1000°F.

**The compromise is between the Larson-Miller and Manson-Haferd parameters, the one sometimes tending to be nonconservative, the other too conservative.

A scatter band plot showing the variation of log stress with L-M parameter for the annealed material is shown in Fig. 24. Values of the parameter corresponding to 100,000 hours at 1000, 1050 and 1100°F are marked on the figure. The data plotted in Fig. 24 were evaluated by the method of least squares to define the mean curve of best fit, which corresponds to an equation of second order; temperature was taken as the independent variable for the regression analysis. The mean curve is drawn on the plot together with a minimum curve (90% confidence level) derived from the mean curve. The mean and minimum values for rupture in 10,000 and 100,000 hours are included in Tables X and XI. It is of interest to note in Fig. 24 that the portion of the data encompassing parameter values that define 100,000 hour rupture strength at temperatures above 1000°F represents only a small fraction of the total volume of data, and that the position of the regression line in this range is importantly dependent upon the mass of data at lower parameter values.

A scatter band plot for the Manson compromise parameter has not been prepared, but it is presumed that the plot would resemble Fig. 24. However, the mean and minimum values resulting from regression analysis of the Manson compromise parameter are plotted in Fig. 25, and 10,000-hour and 100,000-hour strengths are included in Tables X and XI.

A number of features of the parameter scatter band approach to the evaluation of data for 2-1/4 Cr-1 Mo steel are considered at length in another publication[27], and are not repeated here. However, the important observation was made that if rupture strength actually varies in the complex manner, that is depicted in Fig. 22, then the universalized parameter procedure, by its inherent nature, is incapable of giving correct values.

No effort was made to evaluate creep strength by parameter evaluation procedures.

Annealed Material -- Comparison of Rupture Strengths for Different Evaluation Procedures

Reflecting the limitation associated with one of its inherent characteristics (trading off of higher temperature tests for long time at lower temperature), the parameter procedures do not give 100,000 hour strengths at 1150 and 1200°F (unless a questionable extrapolation of the regression lines to higher parameter values is made). The parameter procedures do provide rupture strengths at 950 and 900°F, and even lower, but there were too few tests at 950 and 900°F to permit assessing strength by the direct procedures. Consequently across-the-board comparisons of 100,000 hour rupture strength can be made only at 1000, 1050, and 1100°F. When compared to the 100,000 hour rupture strengths obtained by the several direct procedures, the Larson-Miller procedure gives a lower value at 1100°F, and higher values at 1000 and 1050°F, as predictable.[27] On the other hand, the more conservative Manson compromise parameter gives a lower strength at all temperatures, except for 1050°F in the case of the procedure involving extension of the isothermal scatter band regression line. The most favorable comparisons are afforded by the means of the individual extrapolations and the values developed by regression of the individual-lot strengths as dependent upon temperature. The latter procedure has the advantage that the data can be considered as a whole, thereby also providing a better basis for interpolation, as at 1150°F. It is of interest to note that both of these direct procedures lead to a more reasonable difference between the strengths at 1050 and 1100°F than that indicated by extending the isothermal scatter band regression lines. This observation offers further evidence, as argued in an earlier publication,[28] that a scatter band may mask individual differences.

The differences between the results of the two parameter procedures were always less than 10 per cent, and neither parameter result differed more than about this same amount from the strength-temperature regression result. The Larson-Miller parameter results agreed slightly better with the strength-temperature regression result, except at 1050°F, where the compromise parameter result was in exact agreement. All factors considered, it seems best to give greatest weight to the values developed by the strength-temperature regression, and these values have therefore been employed in summary Figure 1. A graphical comparison of the results by this procedure with those by the two parameter procedures is provided in Figure 26, and the similarity of the various results is evident.

The parameter procedures do permit an assessment of 10,000 hour rupture strength at 1150 and 1200°F, and hence across-the-board comparisons can be made throughout the range 1000 to 1200°F. Since some of the test results extended to 10,000 hours, whereas none had extended to 100,000 hours, there should be an increased confidence in the results of the direct extrapolations, relative to the parameter extrapolations. Study of Table X reveals that when compared to the strength-temperature regression results, the Larson-Miller procedure resulted in higher values at all temperatures, except at 1150°F. Interestingly, the Manson compromise parameter, though more conservative than the Larson-Miller parameter, also gave higher values at 1000, 1050 and 1200°F.

Normalized-and-Tempered and Quenched-and-Tempered Material

Since the high room-temperature strength of these materials is achieved by employing tempering temperatures which may be as low as 1150°F for the normalized material and as low as 1050°F for quenched material, it is to be expected that the associated finer microstructure will be inherently less stable than that of annealed material or of material tempered at higher temperature. Moreover, a dependence of rupture and creep strength upon room-temperature strength, at least in the range of temperatures of practical interest (perhaps 800 to 1000°F), has been shown in published literature, and is corraborated by the present data.

Because of the dependence of rupture strength of these higher strength materials upon room temperature strength, any evaluation procedure, direct or indirect, that involves the scatter band of all data cannot be contemplated.* Furthermore, parameter methods would seem to be inappropriate, even if applied to the data from individual heats, owing to the increased probability of significant microstructural instability, associated with the finer microstructure.

Because scatter band evaluations are inappropriate, the rupture time and creep rate plots of Figs. 16 and 17 covering wrought material, mostly plate, are provided only to convey an impression of the volume of available data. No creep and rupture data were available for quenched and tempered castings; the few data for weld metal are considered in a separate section. Rupture strength and creep strength for individual lots of normalized and tempered or quenched and tempered material have been derived by individual-lot, direct, visual extrapolation or interpolation on log-log plots too numerous to include here, with weighting of the longer time results. The results are included in Tables 6-9. Although it is possible that the plots of log stress vs. log rupture time may develop curvilinearity at long times, no clear instances of such behavior were observed, and the rupture extrapolations were therefore performed on the assumption of linearity. Curvilinearity was evident in the plots of log stress vs. log secondary creep rate.

The dependence of rupture and creep strength of these higher strength materials upon tensile strength at room temperature becomes evident when the results are plotted as in Figure 27. Data for both quenched and tempered material and for normalized and tempered material (relatively few), distinguished by symbol, are included in the plots, since they appear to belong to the same family. Also, all of the data available for quenched and tempered material are included in the plots, even though some of the lots have a room temperature tensile strength less than or greater than permitted by current ASTM specifications. Examination of the plots of Fig. 27 a-d reveals that creep and rupture strengths increase approximately linearly with tensile strength at 800, 850 and 900°F, the dependence decreasing with increasing test temperature; at 1000°F the dependence has essentially disappeared. The data for the individual temperatures have been evaluated by the method of least squares, with tensile strength as the independent variable, assuming a linear relation between the variables; the resulting lines of best fit have been superimposed upon the plots, and values corresponding to specified minimum tensile strengths of a number of specifications of current interest have been included in Tables X-XII.**

*In principle, it would be possible, though hardly practicable, to develop scatter bands for restricted ranges of room temperature strength.

**A few apparent inconsistencies are evident (e.g. the same stress for a secondary creep rate of 0.1 percent per hour for 95 ksi material at 800 and 850°F); these are presumably to be attributed to uncertainties in the positions and slopes of the regression lines.

Comparison of the average 100,000 hour rupture strength for quenched and tempered material at 1000°F, where it is essentially independent of room temperature strength, Fig. 27c, with the average 100,000 hour rupture strength of annealed material at 1000°F, Fig. 22 reveals an interesting and surprising gap (approximately 21 ksi vs. 12 ksi). Significant differences may also be noted in the stresses for rupture in 10,000 hours and for secondary creep rates of 0.1 and 0.01 percent per 1000 hours. One possible reason for the differences may be the generally higher carbon content of the quenched and tempered or normalized and tempered material compared to the annealed material (see Tables I and II). It is also possible, of course, that the log-log relation at 1000°F curves downward beyond the limit of the available data, and, if so, the difference in 100,000 hour rupture strength relative to the annealed material may be less than now indicated.

Rupture Ductility

The elongation and reduction of area at rupture of the annealed material, Figures 15 a-e, exhibited extensive scatter, especially for tests at 1100°F. At no temperature was there evident in the scatter band a well-defined trend with increasing time-for-rupture, although it is possible to discern in some of the plots, e.g. at 1100 and 1200°F, some tendency for reduced ductility at longer times. It is possible that changes in fracture mode from transgranular to intergranular with increasing time for rupture, as well as environmental effects, may contribute to the scatter, but information that would permit consideration in such terms is lacking.

For the normalized-and-tempered and quenched-and-tempered materials, Fig. 18 a-e, rupture ductility exhibited somewhat less scatter, but the number of data was substantially less. Elongation was generally low at 800°F, a reasonable expectation for high strength material, and exhibited no trend with time for rupture, nor any evident difference amongst the three categories distinguished in the plots. At 850°F, the few data exhibited a suggestion of decreased ductility at longer time. At 900°F the average trend of elongation remained essentially unchanged, but with scatter increasing beyond 1000 hours. At 1000°F, a number of low elongation values (less than 10 percent) may be noted for rupture times beyond 1000 hours, with a few specimens fracturing at gage punch marks, all suggesting a tendency for notch sensitivity. The low elongation values have their reflection in reductions of area less than 10%.

Creep and Rupture of Weld Metal

Unfortunately, it has not been possible to identify adequately many of the lots of weld metal for which creep and rupture test results are available, and the relatively few data are therefore considered separately. As with yield and tensile strength, data for weldments have not been considered. The creep and rupture data for weld metal may be divided into two categories. The data for lots numbered W 16 and higher were generated at temperatures of 800 to 900°F, and represent quenched and tempered or tempered material. Data for lots having lower code numbers were generated at temperatures of 1000°F and higher and may be compared with the annealed category of wrought and cast material.

The time-for-rupture, secondary creep rate, and ductility data for the two foregoing categories are plotted in Figs. 19 and 20, and where possible, estimated 10,000 hour and 100,000 hour rupture strengths, and .1 and .01 percent per 1000 hour creep strengths have been developed and are included in Tables VI to IX. Because of the character of the data, no attempt has been made to develop trend curves for weld metal. However, it is of interest to compare by inspection the weld metal results with those developed earlier in this report. Comparing first the strengths for Codes numbered W 15 or lower with the scatter bands of Fig. 22, it may be seen that with respect to creep strength, three of the four lots of weld metal fall within the scatter band, and one lot (at 1000°F) falls slightly below. With respect to 100,000 hour rupture strength, five data for weld metal fall essentially within the scatter band, and two lie significantly below.

Comparing the results for lots numbered W 16 and higher with the 100,000 hour rupture strength data of Fig. 27c, the four data at 800°F fall slightly below the scatter band; four of the data at 850°F fall within the scatter band, and the remaining point falls only slightly below the scatter band; at 900°F, two data fall within the scatter band, and the remaining three fall only slightly below the band. Thus, these limited data indicate weld metal rupture strengths trending less than those for base metal. There are no data for creep strength (0.01 percent per 1000 hours).

The rupture ductility of weld metal tended to fall on the low side of the scatter band, and in some cases below the scatter band, observed for corresponding categories considered earlier in this report.

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Table I P

Identification of 2-1/4 Cr-1 Mo Plate Steels

Code No.	Spec. No.	Deoxid. Pract.	Heat (1) Treatment	ASTM (2) Grain Size	Prod. (3) Size (in.)	Data (4) Source	Source Code No.
P-1	-	-	N1675, T1250+	7-8	13x13x7-1/4	DS6-S1	7-65
P-2	-	-	" " +	"	"	"	7-66
P-3	-	-	N1675, T1350	7-8	13x13x4.6	"	7-67
P-4	-	-	" "	"	13x13x4.7	"	7-68
P-5	-	-	N1700, N1700, T1300+	"	13x13x5.4	"	7-69
P-6	-	-	" " +	"	13x13x5.2	"	7-70
P-7a	-	-	" " +	"	13x13x5.2	"	7-71a
P-7b	-	-	N1675, T1350+	"	13x13x4.8	"	7-71b
P-8a	A387D	-	N1765, T1300	-	6-1/4	Ref. 3	-
P-8b	A542	-	Q1765, T1160	-	6-1/4	"	-
P-9a	A387D	-	N1725, T1250	-	1(1/2T)	Ref. 4	-
P-9b	A387D	-	N1725, T1300	-	"	"	-
P-10a	A387D	-	N1725, T1250	-	2	"	-
P-10b	"	-	N1725, T1300	-	"	"	-
P-10c	A542	-	Q1725, T1200	-	"	"	-
P-10d	"	-	Q1725, T1150	-	"	"	-
P-11	A387D	-	N1700, T1325, T1275	-	4-1/8	"	-
P-12	"	-	" "	-	4-1/8	"	-
P-13	"	-	" "	-	4-1/8	"	-
P-14a	A542	-	Q1725, T1150	-	4	"	-
P-14b	"	-	Q1725, T1200	-	4	"	-
P-15a	"	-	Q1725, T1150	-	6-1/4	"	-
P-15b	A542	-	Q1700, Q1150	-	6-1/2	Ref. 16	-
P-15c	"	-	" "	-	"	"	-
P-15d	"	-	Q1725, A1275	-	"	"	-
P-15e	"	-	Q1750, A1325	-	4	"	-
P-16	"	-	Q1725, T1125	-	7-1/2	Ref. 4	
P-17	"	-	Q1725, T1125	-	7-1/2(1/2T)	"	-
P-18	A542	-	Q1750, T1125	-	2	Ref. 5	E
P-19	"	-	" "	-	2	"	F
P-20	"	-	" "	-	2	"	G
P-21	"	-	Q1675, T1150	-	4(1/2T)	"	H,B1
P-22	"	-	Q1800, T1150	-	6(1/2T)	"	I
P-23	"	-	Q1775, T1125	-	-(1/2T)	"	B1
P-24a	"	-	Q1775, T1075	-	7-1/2	"	B2

(1) HR-Hot Rolled; T-Tempered; N-Normalized; A-Annealed; CD-Cold Drawn; Q-Quenched
(2) Actual grain size except when identified as M for McQuaid-Ehn
(3) Specimens from 1/4 thickness position unless otherwise noted
(4) DS6-ASTM Spec. Tech. Pub. No. 151 (1953): DS6-S1-ASTM Data Series Supplement (1966)
\+ Plus several stress relief cycles--refer to DS6-S1

Cont. Table I P

Code No.	Spec. No.	Deoxid. Pract.	Heat(1) Treatment	ASTM(2) Grain Size	Prod.(3) Size (in.)	Data(4) Source	Source Code No.
P-24b	A542	-	Q1775, T1100	-	7-1/2	Ref. 5	B3
P-25	A387D	-	N1750, T1300	-	6	Ref. 17	-
P-26	"	-	N1650, T1350	-	1-1/4	"	-
P-27	"	-	N1700, T1300	-	6-1/4	"	-
P-28	"	-	N1750, T1300, T1230	-	6-1/4	"	-
P-29	"	-	" "	-	"	"	-
P-30a	"	-	N1750, T1325, T1250	-	1-1/4	"	-
P-30b	"	-	" "	-	2	"	-
P-31a	"	-	N1750, T1360	-	6-1/4	"	-
P-31b	"	-	N1750, T1420	-	6-1/4	"	-
P-32a	A387D	-	A1650	-	1	Ref. 18	-
P-32b	"	-	N1650, T1400	-	1	"	-
P-33	A542	-	Q1750, T1125	-	7-13/16	Ref. 16	-
P-34	A542	-	Q1700, T1150	-	1	Ref. 7	-
P-35	A542	-	Q1775, T1075	-	7-1/2	Ref. 8	-
P-36a	A542	-	Q1725, T1125	-	6	"	-
P-36b	"	-	" "	-	4	"	-
P-36c	"	-	" "	-	2	"	-
P-37	"	-	Q1750, T1100	-	4-7/16	"	-
P-38	A542	-	Q+T at mill; T975, T1080	-	7-1/4	Ref. 9	-
P-39	A542	-	Q1750, T1150, T975, T1085	-	7-1/4	Ref. 9	-
P-40	A542	-	Q1775, T1060, T1125(6h)	-	4-5/8	Ref. 10	-
P-41	"	-	Q1775, T1060, T1150(10h)	-	"	"	-
P-42	"	-	Q1775, T1060, T1275(15h)	-	"	"	-
P-43	A387	F.G.	Q1750, T1050	-	7-1/2*	Ref. 11	-
P-44	"	"	Q1750, T1200	-	"	"	-
P-45	"	"	Q1750, T1350	-	"	"	-
P-46	A387	F.G.	Q1750, T1100	-	3-1/4**	Ref. 11	-
P-47	"	"	Q1750, T1150	-	"	"	-
P-48	"	"	Q1750, T1200	-	"	"	-
P-49	A542	-	Q1650, T1250	-	-	Ref. 12	-
P-50	"	-	Q1750, T1250	-	-	"	-
P-51	"	-	Q1750, T1300	-	-	"	-
P-52a	A542	-	Q1725, T1125,		7-5/8	Ref. 30	-
P-52b	"	-	Q1725, T1125,T1150		"	"	-
P-52c	"	-	Q1725, T1125,T1250		"	"	-

*Samples heat treated in 1" thick slabs removed from plate.
**Samples heat treated in 3/4" round to simulate cooling rate at center of 10" thick plate.

Table I T

Identification of 2-1/4 Cr-1 Mo Pipe and Tube Steels

Code No.	Spec. No.	Deoxid. Pract.	Heat(1) Treatment	ASTM(2) Grain Size	Prod.(3) Size (in.)	Data Source	Source Code No.
T-1	A213	-	A1600/1675	4-6	1(bar)	DS 6	2
T-2	A213	-	N1650, T1300	6-8M	"	"	3
T-3	A213	-	A1650	6 M	Sch. 160	"	5
T-4a	-	Al(1/2 lb)	N1725, T1250	2-5 M	15ODx8ID	"	17A
T-4b	-	"	N1725, T1250, A1500	"	"	"	17B
T-5	-	"	N1725, T1250	"	"	"	18
T-6	-	"	A1575	-	18ODx18ID	"	19
T-7	-	-	A1650	-	7.5ODx1.71W	DS 6 S1	7-72
T-8	-	-	CD, T1375	-	2-1/4OD x .48W	"	7-74
T-9	-	-	CD, A1650	-	"	"	7-75
T-10	-	-	CD, T1375	-	2-1/8OD x .53W	"	7-76
T-11	-	-	CD, A1650	-	2-1/8OD x .375W	"	7-77
T-12a	-	-	CD, A1650	-	2.6OD x .59W	"	7-78a
T-12b	-	-	"	-	"	"	7-78b
T-13a	-	-	A1650	-	2.81OD x .66W	"	7-79a
T-13b	-	-	"	-	5-3/4OD x .855W	"	7-79b
T-13c	-	-	"	-	"	"	7-79c
T-14	A335	-	A(as per spec.)	-	10.5OD x 1.75W	"	7-80
T-15	A335	-	"	-	"	"	7-81
T-16	A335	-	"	-	"	"	7-82
T-17	A335	-	"	-	"	"	7-83
T-18	A213	-	"	-	4-1/2OD x .5W	"	7-84a
T-19	A335	-	"	-	6ODx.5W	"	7-84b
T-20	A213	-	"	-	3/4 bar	"	7-85a
T-21	"	-	NT(as per spec.)	-	"	"	7-85b
T-22a	A213	-	A(as per spec.)	-	-	DS 6 S1	7-86a
T-22b	"	-	"	-	-	"	7-86b
T-22c	"	-	NT(as per spec.)	-	-	"	7-86c
T-22d	"	-	"	-	-	"	7-86d

(1) HR-Hot Rolled; T-Tempered; N-Normalized; A-Annealed; CD-Cold Drawn; Q-Quenched
(2) Actual grain size except when identified as M for McQuaid-Ehn
(3) Specimens from 1/4 thickness position unless otherwise noted

Cont. Table I T

Code No.	Spec. No.	Deoxid. Pract.	Heat[1] Treatment	ASTM[2] Grain Size	Prod.[3] Size (in.)	Data Source	Source Code No.
T-23	A199	-	Subcrit. Anneal	-	4.87x.454	DS6-S1	7-87
T-24a	A213	-	A(as per spec.)	-	2x.358	"	7-88a
T-24b	"	-	"	-	2x.460	"	7-88b
T-25	-	-	CD, A1650	-	2-1/8 x .428	Ref. 19	-
T-26	-	-	"	-	2.26x.59	"	-
T-27	-	-	"	-	2.26x.59	"	-
T-28	-	-	"	-	2-1/8 x .342	"	-
T-29	-	-	"	-	"	"	-
T-30	-	-	"	-	"	"	-
T-31	-	-	"	-	"	"	-
T-32	-	-	"	-	"	"	-
T-33	-	-	A1550	-	2-1/2 x .523	Ref. 12	-
T-34	-	-	CD, A1650	-	5.75x.855	Ref. 19	-
T-35	-	-	"	-	"	"	-
T-36	-	-	"	-	2.5x.48	"	-
T-37	-	-	A1750	-	Hollow Forging	Ref. 12	-
T-38	-	-	"	-	"	"	-
T-39	-	-	"	-	"	"	-
T-40	-	-	"	-	"	"	-
T-41	-	-	"	-	"	"	-
T-42	-	-	"	-	"	"	-
T-43	-	-	"	-	"	"	-
T-44	-	-	A1650	-	8.x.16	Ref. 20	-
T-45	-	-	A1650	-	8.x.16	Ref. 20	-
T-46	-	-	N1600, T1325	-	18x1-5/16	Ref. 17	-
T-47	-	-	N1675, T1275	-	"	"	-
T-48	A213	-	N1650, T1400	-	13.5OD x .358W	"	-
T-49	"	-	N1650, T1400	-	1.315x.787	"	-
T-50	"	-	A1600*	-	2.x.388	"	-
T-51	"	-	"	-	"	"	-
T-52	"	-	"	-	"	"	-
T-53	"	-	A1600**	-	2x.36	"	-
T-54	"	-	"	-	"	"	-
T-55	"	-	"	-	"	"	-
T-56	"	-	"	-	"	"	-
T-57	"	-	"	-	"	"	-
T-58	"	-	"	-	"	"	-
T-59	-	-	Q1775, T1100	-	5-7/8 wall	Ref. 5	A
T-60	-	-	" "	-	"	"	B
T-61	-	-	" "	-	"	"	C
T-62	-	-	Q1750, T1125	-	7 wall	"	D

* Continuous anneal in zone furnace: 1600, 1300, 1375°F
** Continuous anneal in zone furnace: 1600, 1200°F

Cont. Table I T

Code No.	Spec. No.	Deoxid. Pract.	Heat[1] Treatment	ASTM[2] Grain Size	Prod.[3] Size (in.)	Data Source	Source Code No.
T-63	A213	-	A1650	-	2.125OD x .375W	Ref. 6	-
T-64	"	-	"	-	"	"	-
T-65	"	-	"	-	2.125x.360	"	-
T-66	"	-	"	-	"	"	
T-67	"	-	"	-	"	"	-
T-68	"	-	"	-	"	"	-
T-69	A213	-	A1650	-	2.125x.360	"	-
T-70	"	-	"	-	2.00x.165	"	-
T-71	"	-	"	-	"	"	-
T-72	"	-	"	-	2.125x.360	"	-
T-73	"	-	"	-	"	"	-
T-74	"	-	"	-	2.00x.480	"	-
T-75	"	-	"	-	"	"	-
T-76	"	-	"	-	2.125x.300	"	-
T-77	"	-	"	-	"	"	-
T-78	"	-	"	-	2.125x.340	"	-
T-79	"	-	"	-	2.125x.300	"	-
T-80	"	-	"	-	2.125x.333	"	-
T-81	"	-	"	-	2.00x.400	"	-
T-82	"	-	"	-	2.125x.378	"	-
T-83	"	-	"	-	2.00x.444	"	-
T-84	"	-	"	-	2.00x.444	"	-
T-85	"	-	"	-	"	"	-
T-86	"	-	"	-	"	"	-
T-87	"	-	"	-	2.00x.511	"	-
T-88	"	-	"	-	2.00x.400	"	-
T-89	"	-	"	-	2.00x.400	"	-
T-90	"	-	"	-	2.00x.355	"	-
T-91	"	-	"	-	2.00x.320	"	-
T-92	"	-	"	-	2.125x.375	"	-
T-93	"	-	"	-	2.00x.40	"	-
T-94	"	-	"	-	2.50x.20	"	-
T-95	"	-	"	-	"	"	-
T-96	"	-	"	-	2.00x.300	"	-
T-97	"	-	"	-	2.125x.375	"	-
T-98	"	-	"	-	"	"	-
T-99	"	-	"	-	2.500x.148	"	-
T-100	"	-	"	-	1.875x.378	"	-
T-101	"	-	"	-	2.50x.18	"	-
T-102	"	-	"	-	2.50x.203	"	-
T-103	"	-	"	-	2.125x.320	"	-
T-104	"	-	"	-	2.50x.203	"	-
T-105	"	-	"	-	1.875x.375	"	-
T-106	"	-	"	-	"	"	-
T-107	"	-	"	-	2.50x.203	"	-
T-108	"	-	"	-	2.50x.148	"	-
T-109	A335	-	A1700	7-8	10x1.97W	Ref. 15	-

Table I - B

Identification of 2-1/4 Cr-1 Mo Bar Steels

Code No.	Spec. No.	Deoxid. Pract.	Heat[(1)] Treatment	ASTM[(2)] Grain Size	Product[(3)] Size	Data Source	Source Code No.
B-1	-	Si-Al (1-1/4)	A1550	8	1	DS6	1
B-2	-	Si-Al(1)	N1650, T1300F	4-6M	-	"	4
B-3	-	Si-Al(1)	N1650, T1380	9	-	"	15
B-4	-	-	N1675, T1100	-	3/4	Ref. 12	-
B-5a	-	-	N1700, T1290	-	"	"	-
B-5b	-	-	N1920, T1290	-	"	"	-
B-6	-	-	CD, A1350	-	3/4	"	-

Table I - F

Identification of 2-1/4 Cr-1 Mo Steels - Forgings*

F-1	A182-F22	-	N1640, T1250, T1225	7 M	31-1/2OD x 12-1/2ID x 22 Wide	Ref. 21	-
F-2	"	-	N1640, T1240	-	13ODx15ID x 12 Wide	"	-
F-3	"	-	N1700, T1150	6-7	56Dx10t	"	-
F-4	A182-F22	Fine-Grain	Q1750, T1275, T1225, T1075, T1290	7-8	11 x 11	Ref. 22	
F-5	"	"	N1730, T1225, T1075, T1250	"	13 x 13	"	
F-6	"	"	N1730, T1315, T1250	"	"	"	-
F-7	"	"	Q1750, T1275	"	12 x 12	"	-
F-8	"	"	Q1775, T1225, T1225, T1075	6-7	-	"	-

*Electric furnace, vacuum degassed. Specimens were taken from extra metal on forgins.

(1) HR-Hot Rolled; T-Tempered; N-Normalized; A-Annealed; CD-Cold Drawn; Q-Quenched.

(2) Actual grain size except when identified as M for McQuaid-Ehn

(3) Specimens from 1/4 thickness position unless otherwise noted.

(4) DS6-ASTM Spec. Tech. Pub. No. 151 (1953): DS6-S1-ASTM Data Series Supplement (1966).

Table I - C

Identification of 2-1/4 Cr-1 Mo Cast Steels

Code No.	Spec. No.	Deoxid. Pract.	Heat Treatment(1)	ASTM Grain Size	Prod.(2) Size	Data Source	Source Code No.
C-1	A217	Si-Al(2.7)	N1650, T1300	-	-	DS6	(6)
C-2	"	-	N1825, T1250	7	7x1x1	"	(8)
C-3	"	-	N1800, N1700, T1300	7	-	"	(9)
C-4	-	Al(2)	N1750, N1675, T1300	-	-	"	(20)
C-5	-	Al(2)	N1800, N1630, T1250	-	-	"	(21)
C-6	-	Al(2-1/2)	N1775, N1700, T1300	-	-	"	(22)
C-7	-	-	N1700, T1300	-	-	DS6-S1	7-73
C-8 N	A487-8N	-	N1700, T1340	-	-	Ref. 23	
C-8 Q	A487-8Q	-	Q1700, T1225	-	-	"	
C-9 N	A487-8N	-	N1700, T1340	-	-	"	
C-9 Q	A487-8Q	-	Q1700, T1225	-	-	"	
C-10N	A487-8N	-	N1700, T1340	-	-	"	
C-10Q	A487-8Q	-	Q1700, T1225	-	-	"	
C-11	A356-10	-	Q1700, T1300	-	6x9x9	"	
C-12	A356-10	-	" "	-	8x9x9	"	
C-13	A356-10	-	" "	-	12x36x36	"	
C-14	A356-10	Al(2)	N1700, T1350	-	-	Ref. 24	
C-15	"	Al(1/2)	N1700, T1350	-	-	"	

(1) HR-Hot Rolled; T-Tempered; N-Normalized; A-Annealed; CD-Cold Drawn; Q-Quenched
(2) Actual grain size except when identified as M for McQuaid-Ehn

Table I - W

Identification of 2-1/4 Cr-1 Mo Weld Metal

Code No.	Process	Preheat Temp.°F	Post Heat[1] Treatment	Electrode Size	Electrode Type	Data Source	Source Code No.
W-1a	Met. Arc	350	None	5/32"	-	Ref. 13	1
W-1b	"	"	1350F, AC	"	-	"	1
W-2	"	-	None	"	-	"	2
W-3a	"	-	None	"	-	"	3
W-3b	"	-	1350F, AC	"	-	"	3
W-4	"	-	None	"	-	"	4
W-5	"	350	1350F, AC	"	-	"	5
W-6	"	400	None	"	-	"	6
W-7	"	300	None	"	E9015	"	7
W-8	"	450	1350F, FC	3/16	E10016	"	8
W-9	"	400	1350F, FC	1/8	-	"	9
W-10	"	600	1325F	5/32	-	"	10
W-11	-	600	1325F	5/32	-	"	11
W-12a	-	-	1350F	-	-	"	12
W-12b	-	-	N1725, T1350	-	-	"	12
W-12c	-	-	A1575	-	-	"	12
W-13	Met. Arc	-	1350F	5/32	-	"	13
W-14	"	300	1350F	5/32	E9015	"	15
W-15	"	-	A1675	-	-	"	19
W-16	Elect. Slag	-	Q1750, T1125	1/8	-	Ref. 4	-
W-17	Met. Arc	300	975, 1080F, FC	-	-	Ref. 9	-
W-18	Sub. Arc	300	Q1750, 1150, 1075, FC	-	-	"	-
W-19	Met. Arc	300	" "	-	-	"	-
W-20	Elect. Slag	-	" "	-	-	"	-
W-21	Sub. Arc	-	1075F, FC	-	-	Ref. 5,14	W1
W-22	"	-	Q1675, T1100	-	-	"	W2
W-23	Elect. Slag	-	T1050F, FC	-	-	"	W3
W-24	Sub. Arc	-	T1075F	-	-	Ref. 14	1216
W-25	Elect. Slag	-	Q1675, T1135, T1075	-	-	"	1237

(1) HR-Hot Rolled; T-Tempered; N-Normalized; A-Annealed; CD-Cold Drawn; Q-Quenched

Table II-P

Chemical Composition of 2-1/4 Cr-1 Mo Plate Steels

Code No.	C	Mn	P	S	Si	Cr	Mo	Ni	Cu	Al	N
P-8a,b	.14	.40	.010	.019	.37	2.38	1.06			.007	.012
P-9a,b	.13	.57	.010	.020	.19	2.42	.90				
P-10abcd	.14	.41	.010	.022	.24	2.48	.98				
P-11	.12	.41	.010	.017	.21	2.18	.95				
P-12	.13	.42	.017	.020	.27	2.29	.91				
P-13	.15	.52	.018	.024	.28	2.28	.95				
P-14a,b	.15	.42	.009	.018	.21	1.99	.98				
P-15a-e	.15	.40	.013	.020	.32	2.39	.96	.23	.25	.018	
P-16	.11	.44	.013	.019	.29	2.20	.97				
P-17	.11	.44	.012	.019	.29	2.25	.98				
P-18	.10	.46	.017	.013	.41	2.12	.98				
P-19	.09	.46	.015	.016	.37	2.37	1.02				
P-20	.11	.46	.018	.020	.32	2.17	1.02				
P-21	.14	.44	.009	.024	.26	2.09	.88				
P-22	.13	.34	.010	.016	.20	2.23	.90				
P-23	.12	.49	.017	.017	.40	2.29	1.03				
P-24a,b	.14	.46	.020	.010	.28	2.35	.99				
P-25	.14	.47	.007	.015	.40	2.40	1.02				
P-26	.09	.45	.008	.013	.28	2.35	1.00	.14	.05		
P-27	.13	.43	.008	.015	.34	2.38	1.08	.22			
P-28	.12	.45	-	-	.40	2.25	1.00				
P-29	.15	.58	-	-	.47	2.45	1.08	.23			
P-30a,b	.14	.48	-	-	.40	2.33	1.06	.23			
											V
P-31a,b	.14	.54	-	-	.42	2.44	1.02	.23			
P-32a,b	.12	.50	.010	.018	.21	2.16	.97	.08	.19		.026
P-33	.14	.46	.010	.020	.28	2.35	.99				
P-34	.11	.37	.010	.010	.26	2.20	.96				
P-35	.14	.46	.020	.010	.28	2.35	.99				
P-36abc	.08	.47	.016	.023	.33	2.15	1.02				
P-37	.12	.45	.010	.015	.25	2.12	.97	.11	.11		
P-38	.11	.47	.016	.030	.19	2.23	1.00				
										Sn	
P-39	.12	.47	.013	.026	.32	2.24	.93				
P-40	.13	.43	.015	.024	.20	2.14	.94	.14	.20	.013	.01
P-41,	.13	.47	.012	.018	.21	2.10	.93	.20	.23	.013	.01
P-42											
P-43-	.12	.43	.010	.018	.26	2.34	.98	.20			
P-45											
P-46-	.14	.51	.013	.016	.27	2.27	.96				
P-48											
P-49	.15	.38	.012	.014	.20	2.16	.95				
P-50,	.14	.42	.010	.022	.15	2.21	.92				
P-51										Al	
P-52a,b,c	.11	.44	.012	.019	.29	2.23	.98	.20	.15	.056	

Table II - T

Chemical Composition of 2-1/4 Cr-1 Mo Pipe-Tube Steels

Code No.	C	Mn	P	S	Si	Cr	Mo	Ni	Cu	Al	N
T-25	.08	.42	.011	.020	.29	2.34	.95	.19	.13		
T-26	.10	.41	.011	.020	.26	2.18	.97	.15	.14		
T-27	.10	.43	.010	.018	.34	2.29	.98	.12	.11		
T-28	.11	.37	.011	.014	.33	2.21	.95	.25	.11		
T-29	.09	.43	.012	.014	.29	2.24	.97	.16	.11		
T-30	.09	.43	.009	.016	.35	2.35	1.03	.17	.12		
T-31	.09	.50	.016	.025	.27	2.31	1.01	.23	.13		
T-32	.09	.38	.013	.022	.31	2.21	.98	.12	.13		
T-33	.08	.44	.025	.020	.29	2.12	.97	.10	-		
T-34	.09	.43	.009	.016	.35	2.35	1.03	.17	-		
T-35	.10	.41	.008	.013	.34	2.28	.98	.18	-		
T-36	.09	.40	.010	.012	.34	2.27	1.00	.10	-		
T-37	.12	.45	.031	.017	.33	2.35	1.04	.14	.11		
T-38	.08	.41	.027	.017	.26	2.15	.93	.17	.10		
T-39	.11	.41	.025	.016	.48	2.25	1.04	.14	.11		
T-40	.09	.48	.029	.017	.34	2.10	1.04	.14	.11		
T-41	.10	.57	.021	.017	.27	2.30	.92	.12	.17		
T-42	.11	.47	.023	.021	.37	2.09	.94	.16	.15		
T-43	.10	.44	.016	.024	.31	2.18	.96	.16	.10		
T-44	.09	.62	.005	.026	.09	2.22	.97	-	-		
T-45	.13	.57	.020	.020	.34	2.00	1.03	-	-		
T-46	.09	.44	.017	.026	.27	2.34	.96	-	-		
T-47	.08	.43	.013	.015	.29	2.18	1.02	-	-		
T-48	.09	.38	.013	.018	.26	2.25	.99	-	-		
T-49	.08	.47	.016	.019	.21	2.23	.94	-	-		
T-50	.08	.41	.011	.021	.23	2.20	.96	-	-		
T-51	.09	.45	.015	.027	.25	2.25	.97	-	-		
T-52	.08	,42	.018	.017	.23	2,19	.98	-	-		
T-53	.10	.40	.012	.019	.26	2.21	.95	.10	-	.037	
T-54	.09	.40	.012	.017	.27	2.20	.95	.068	-	.036	
T-55	.12	.41	.013	.016	.30	2.24	.92	.11	-	.038	
T-56	.12	.41	.013	.017	.24	2.33	1.02	.089	-	.045	
T-57	.09	.40	.010	.016	.28	2.20	-	.067	-	.036	
T-58	.11	.43	.011	.016	.34	2.16	.95	.087	-	.049	
T-59	.11	.47	.019	.014	.41	2.25	1.00	-	-		
T-60	.11	.42	.019	.013	.33	2.24	.96	-	-		
T-61	.10	.46	.021	.012	.36	2.40	1.03	-	-		
T-62	.12	.47	.029	.022	.45	2.43	1.02	-	-		
T-63	.09	.38	.010	.015	.41	2.31	.99	.14	-		
T-64	.10	.42	.011	.021	.37	2.25	.98	.15	-		
T-65	.12	.39	.010	.015	.38	2.19	.97	.19	-		
T-66	.09	.38	.010	.015	.41	2.31	.99	.14	-		
T-67	.10	.41	.009	.015	.36	2.18	.90	.12	-		
T-68	.10	.42	.011	.021	.37	2.25	.98	.15	-		
T-69	.10	.41	.008	.014	.41	2.24	.96	.14	-		
T-70	.10	.37	.010	.014	.39	2.32	.99	.11	-		
T-71	.10	.41	.009	.015	.36	2.18	.90	.12	-		
T-72	.10	.34	.011	.014	.40	2.50	.96	.13	-		
T-73	.12	.47	.009	.014	.39	2.31	.97	.23	-		

Cont. Table II - T

Code No.	C	Mn	P	S	Si	Cr	Mo	Ni	Cu	Al	N
T-74	.12	.39	.009	.015	.38	2.21	.95	.24			
T-75	.09	.38	.010	.015	.41	2.31	.99	.14			
T-76	.11	.50	.011	.020	.37	2.45	1.00	.16			
T-77	.12	.41	.009	.015	.37	2.24	1.00	.15			
T-78	.11	.50	.011	.020	.37	2.45	1.00	.16			
T-79	.11	.41	.011	.016	.43	2.34	1.00	.15			
T-80	.08	.38	.010	.015	.40	2.36	.97	.14			
T-81	.09	.38	.010	.015	.41	2.31	.99	.14			
T-82	.09	.40	.010	.013	.38	2.37	.98	.20			
T-83	.10	.42	.011	.021	.37	2.25	.98	.15			
T-84	.09	.38	.010	.015	.41	2.31	.99	.14			
T-85	.10	.50	.011	.012	.28	2.20	.97	.16			
T-86	.11	.41	.011	.016	.43	2.34	1.00	.15			
T-87	.10	.40	.011	.020	.39	2.34	1.00	.22			
T-88	.10	.42	.011	.021	.37	2.25	.98	.15			
T-89	.10	.41	.008	.014	.41	2.24	.96	.14			
T-90	.10	.42	.011	.021	.37	2.25	.98	.15			
T-91	.10	.43	.010	.022	.38	2.33	.97	.16			
T-92	.09	.43	.010	.024	.36	2.25	.99	.17			
T-93	.08	.50	.009	.020	.32	2.37	1.02	.14			
T-94	.09	.41	.015	.015	.31	2.19	.99	.10			
T-95	.09	.39	.011	.018	.39	2.20	.97	.15			
T-96	.09	.43	.010	.024	.36	2.25	.99	.17			
T-97	.10	.43	.010	.022	.38	2.33	.97	.16			
T-98	.10	.40	.011	.020	.39	2.34	1.00	.22			
T-98	.10	.36	.009	.019	.38	2.21	.98	.16			
T-100	.09	.40	.008	.014	.42	2.39	1.00	.13			
T-101	.09	.39	.011	.018	.39	2.20	.97	.15			
T-102	.09	.39	.011	.021	.39	2.25	.98	.20			
T-103	.09	.41	.009	.015	.42	2.34	.98	.14			
T-104	.10	.36	.009	.019	.38	2.21	.98	.16			
T-105	.09	.39	.011	.021	.39	2.25	.98	.20			
T-106	.12	.44	.008	.016	.39	2.23	.98	.10			
T-107	.09	.41	.015	.015	.31	2.19	.99	.10			
T-108	.12	.41	.010	.012	.42	2.21	.96	.21			
T-109	.14	.52	.013		.40	2.17	.94		.30	.007	

Table II - B

Chemical Composition of 2-1/4 Cr-1 Mo Bar Steels

Code No.	C	Mn	P	S	Si	Cr	Mo	Ni	Cu	Al	N
B-4	.12	.45	.008	.013	.37	2.36	.99				
B-5 a,b	.11	.39	.017	.022	.28	2.17	.87	.17	.16		
B-6	.12	.47	.016	.018	.35	2.20	.98	.15	.12		

Table II - F

Chemical Composition of 2-1/4 Cr-1 Mo Forging Steels

Code No.	C	Mn	P	S	Si	Cr	Mo	Ni	V	Cu
F-1	.10	.40	.013	.017	.27	2.14	.96			
F-2	.09	.42	.011	.013	.25	2.26	1.02			
F-3	.13	.47	.013	.018	.28	2.20	1.00			
F-4	.11	.49	.016	.012	.21	2.24	.98	.13	.04	.07
F-5	.12	.52	.012	.011	.22	2.40	1.01		.01	.10
F-6	.12	.59	.015	.007	.19	2.44	.98	.05	.05	.10
F-7	.13	.56	.008	.010	.28	2.15	.96	.17	.05	.08
F-8	.122	.53	.010	.012	.24	2.14	.92	.05	.03	.06

Table II - C

Chemical Composition of 2-1/4 Cr-1 Mo Cast Steels

Code No.	C	Mn	S	P	Si	Cr	Mo	Ni	Cu	Al
C-8 N,Q	.16	.63	.014	.015	.47	2.42	1.04	.04		
C-9 N,Q	.17	.57	.011	.014	.46	2.19	1.00	.20		
C-10 N,Q	.16	.59	.010	.011	.48	2.19	1.03	.10		
C-11	.21	.59	.018	.010	.57	2.43	1.19			
C-12	.15	.67	.010	.007	.43	2.18	1.06			
C-13	.15	.43	.016	.011	.31	2.11	1.00			
C-14	.17	.55	.015	.013	.36	2.25	.96			.023
C-15	.18	.60	.013	.014	.36	2.32	.94			.011

Table II - W

Chemical Composition of 2-1/4 Cr-1 Mo Weld Metal

Code No.	C	Mn	P	S	Si	Cr	Mo	Ni	Cu
W-16	.09	.55	.008	.018	.22	2.40	.95		
W-17	.07	1.06	.017	.022	.33	2.16	1.00		
W-18	.095	.98	.021	.018	.38	2.23	1.02		
W-19	.10	.94	.019	.020	.34	2.27	1.05		
W-20	.14	.71	.019	.022	.19	2.38	1.00		
W-21	.073	.90	.019	.011	.53	2.20	1.00	.13	.27
W-22	.11	.96	.016	.020	.41	2.23	1.00	.08	.33
W-23	.14	.68	.021	.017	.20	2.39	1.02	.14	.28
W-24	.08	.81	.026	.012	.43	2.16	1.00	.19	.47
W-25	.15	.74	.023	.019	.17	2.23	.99	.13	.25

Table III - P

Short-Time Tensile Properties of 2-1/4 Cr-1 Mo Steel - Plate

Code No.	Test Temp.°F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
P-8a	80	74.	95.	23.	72.
	500	66.	81.	21.	70.
	700	64.	79.	18.	62.
	800	62.	76.	18.	60.
	900	59.	70.	21.	71.
	1000	55.	65.	22.	79.
P-8b	80	102.	119.	20.	68.
	500	90.	106.	18.	68.
	700	88.	103.	19.	68.
	800	86.	100.	17.	67.
	900	82.	94.	19.	69.
	1000	78.	88.	20.	77.
P-9a	75	74.8	89.9	28.	72.
	750	56.1	68.5	21.	73.
	850	50.7	68.6	22.	71.
	950	47.5	57.4	26.	76.
P-9b	75	67.3	86.6	29.	72.
	750	46.6	68.8	23.	68.
	850	48.1	70.1	24.	71.
	950	44.5	53.8	30.	76.
P-10a	75	83.5	95.9	25.	72.
	750	63.7	82.7	20.	65.
	850	61.0	75.5	18.	66.
	950	53.6	59.4	22.	79.
P-10b	75	72.9	82.7	27.	73.
	750	52.5	75.4	22.	69.
	850	51.7	71.0	20.	65.
	950	48.5	55.3	25.	78.
P-10c	75	105.8	119.2	22.	71.
	750	80.8	94.7	18.	67.
	850	78.7	92.2	19.	69.
	950	73.1	80.6	23.	74.
P-10d	75	122.1	132.2	20.	68.
	750	93.2	106.4	18.	65.
	850	91.6	104.7	19.	64.
	950	87.4	97.5	21.	69.

Cont. Table III - P

Code No.	Test Temp. °F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
P-11	75	49.8	75.9	30.	75.
	300	41.3	65.0	28.	79.
	500	35.8	62.0	29.	78.
	650	34.9	61.5	25.	74.
	750	-	63.3	24.	69.
	800	35.2	63.3	24.	70.
	850	39.2	60.3	25.	71.
	900	32.7	56.5	26.	76.
	950	33.2	54.3	29.	79.
P-12	75	67.0	85.0	30.	75.
	300	55.9	73.9	24.	72.
	500	54.8	72.0	22.	65.
	650	54.4	71.5	22.	69.
	750	50.6	68.5	22.	69.
	800	52.3	68.0	22.	69.
	850	52.0	66.5	22.	71.
	900	49.8	62.5	23.	73.
	950	48.7	60.2	24.	74.
P-13	75	79.8	94.2	24.	69.
	300	64.3	82.5	22.	67.
	500	61.7	78.7	20.	62.
	650	63.1	78.5	20.	63.
	750	62.0	78.7	20.	59.
	800	60.5	76.0	20.	63.
	850	58.2	74.0	21.	67.
	900	-	70.	20.	63.
	950	55.2	67.5	23.	67.
P-14a	75	114.6	123.7	21.	64.
	750	83.5	100.5	20.	65.
	850	79.8	94.3	21.	66.
	950	75.0	89.1	21.	67.
P-14b	75	101.2	111.3	22.	69.
	750	77.0	93.9	19.	57.
	850	73.0	86.5	22.	68.
	950	70.2	82.8	20.	70.
P-15a	75	102.0	120.0	19.	60.
	200	96.5	113.0	19.	66.
	400	90.6	108.0	17.	64.
	600	86.6	104.2	16.	56.
	800	78.5	95.2	19.	68.
	850	79.8	90.3	18.	70.
	900	78.5	88.3	20.	68.

Cont. Table III - P

Code No.	Test Temp.°F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
P-15b	80	108.3	123.3	21.	64.
	900	85.2	93.2	18.	64.
	1000	78.7	83.7	23.	70.
	1100	73.3	75.3	22.	76.
P-15c	80	104.2	122.2	22.	72.
	900	80.3	86.5	19.	72.
	1000	75.2	80.2	22.	77.
	1100	64.7	66.7	24.	81.
P-15d	80	83.5	103.9	22.	68.
	900	65.1	82.2	22.	65.
	1000	60.2	68.1	25.	72.
	1100	54.0	57.0	21.	77.
P-15e	80	65.0	87.3	29.	71.
	850	52.3	75.4	23.	63.
	900	49.4	70.3	23.	65.
	1000	46.5	61.8	25.	70.
P-16	75	109.0	126.6	19.	64.
	500	108.0	122.3	17.	57.
	650	105.7	127.0	16.	59.
	725	102.0	122.8	17.	61.
	800	89.3	110.8	17.	63.
	850	89.4	107.0	19.	65.
	925	88.7	102.3	17.	64.
	975	87.7	101.5	18.	66.
P-17	75	113.8	130.8	19.	57.
	500	104.0	125.1	16.	56.
	650	102.2	124.9	16.	54.
	725	103.5	122.6	15.	55.
	800	97.3	113.3	16.	57.
	850	88.8	107.2	18.	56.
	925	83.8	101.3	18.	61.
P-18	75	119.3	132.6	18.	70.
	200	119.5	130.5	15.	68.
	400	111.9	124.2	16.	67.
	600	109.9	121.8	13.	63.
	700	106.8	118.3	15.	68.

Cont. Table III - P

Code No.	Test Temp. °F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
P-19	75	123.6	138.5	19.	70.
	200	115.6	128.8	17.	68.
	400	110.6	122.6	17.	68.
	600	106.9	119.1	13.	67.
	700	103.9	115.9	14.	68.
P-20	75	115.8	131.7	20.	67.
	200	112.4	125.7	17.	68.
	400	104.0	117.7	17.	67.
	700	100.6	113.6	17.	65.
P-21	75	98.5	114.5	22.	70.
	250	96.8	110.5	19.	74.
	650	90.0	102.0	19.	67.
	750	89.3	100.3	19.	68.
	850	84.5	94.0	17.	71.
	900	84.8	93.5	19.	72.
P-22	75	104.0	118.5	20.	68.
	200	102.5	116.5	20.	66.
	400	97.0	111.3	19.	67.
	600	91.5	105.5	19.	66.
	750	91.5	103.5	17.	64.
	800	88.0	102.5	17.	69.
	850	86.5	98.5	17.	66.
	900	-	96.4	17.	61.
	950	82.5	93.6	19.	67.
P-23	75	128.0	142.0	14.	45.
P-24a	75	130.5	149.5	21.	62.
P-24b	75	117.0	130.5	18.5	66.
P-25	70	68.7	89.9	26.	65.
	700	60.0	78.1	18.	57.
	800	58.7	73.4	15.	48.
P-26	80	54.0	76.8	29.	-
	600	44.3	68.1	23.	73.
	700	45.1	71.3	-	72.
	800	39.7	68.1	24.	72.
	900	43.3	65.9	24.	76.

Cont. Table III - P

Code	No. Test Temp.°F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
P-27	300	67.7	86.1	22.	70.
	400	65.8	83.9	21.	71.
	450	65.3	83.0	20.	70.
	500	63.8	82.0	21.	69.
	550	63.8	82.0	21.	68.
	600	62.4	80.7	21.	71.
	650	62.9	82.0	20.	66.
	700	63.9	83.4	20.	66.
	750	62.2	81.7	20.	66.
	800	60.5	79.0	21.	68.
	850	60.5	77.4	21.	64.
	900	59.3	72.4	23.	72.
	950	57.1	70.5	23.	75.
	1000	57.6	67.0	24.	76.
P-28	80	63.0	78.0	26.	73.
	700	45.2	67.8	21.	70.
P-29	80	69.6	90.8	26.	67.
	700	58.8	78.0	18.	63.
P-30a	80	78.6	98.4	25.	72.
	700	69.1	88.5	20.	66.
P-30b	80	71.1	97.0	24.	71.
	700	66.4	85.3	19.	64.
P-31a	80	63.7	84.4	26.	72.
	500	50.3	72.2	25.	70.
	700	51.5	74.5	22.	65.
	800	50.0	71.4	23.	65.
	860	47.0	66.2	23.	71.
	900	35.0	65.7	24.	71.
P-31b	80	57.4	80.6	29.	72.
	500	46.4	69.2	27.	71.
	700	45.0	71.5	26.	65.
	800	42.7	68.7	23.	62.
	860	41.6	66.3	26.	66.
	900	40.0	64.0	25.	70.
P-32a	75	40.3	78.5	27.	55.
	200	36.4	72.1	26.	55.
	300	36.5	70.0	25.	54.
	400	35.4	68.8	23.	50.
	500	39.1	69.6	20.	50.
	600	39.4	72.8	17.	44.
	700	39.7	75.2	17.	44.

Cont. Table III - P

Code No.	Test Temp. °F	1000 psi Yield Strength	1000 psi Tensile Strength	Per Cent Elong.	Per Cent Red. Area
P-32a	800	37.8	75.6	19.	49.
	900	36.6	72.8	19.	51.
	1000	36.3	68.0	19.	55.
	1100	35.8	56.3	23.	65.
P-32b	75	71.1	87.9	25.	63.
	200	66.8	82.8	23.	63.
	300	64.6	80.5	21.	60.
	400	62.8	79.3	21.	59.
	500	61.9	79.0	21.	60.
	600	63.6	80.8	18.	57.
	700	60.6	82.0	20.	56.
	800	60.6	80.0	18.	53.
	900	57.2	74.6	17.	58.
	1000	53.6	68.1	18.	59.
	1100	50.9	57.9	19.	69.
P-33	75	96.7	115.2	21. *	65.
	900	78.6	88.8	18.6*	67.
P-34	75	119.0	137.0	25.	70.
P-35	75	130.0	149.2	20.	63.
	750	109.7	131.5	16.	58.
	850	105.2	129.5	17.5	59.
	950	98.5	117.5	18.2	58
P-36a	80	-	122.8	21.	63.
	400	-	115.0	19.5	64.
	600	-	114.8	18.5	59.
	800	-	111.5	17.5	59.
	1000	-	102.4	17.	65.
P-36b	80	-	101.0	24.	76.
	400	-	91.6	20.	74.
	600	-	88.7	19.5	73.
	800	-	87.5	17.5	70.
	1000	-	77.2	20.5	74.
P-36c	80	-	108.0	25.	75.
	400	-	101.0	18.	72.
	600	-	99.5	18.	69.
	800	-	97.8	19.	70.
	1000	-	86.5	20.	73.

*1" gage length

Cont. Table III - P

Code No.	Test Temp. °F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
P-37	70	120.1	134.0	17.5	63.
	600	93.8	108.3	18.5	66.
	700	93.2	108.4	19.5	67.
	800	93.2	106.8	18.	67.
	900	92.2	103.1	18.	68.
	1000	87.0	95.3	21.	69.
P-38	75	101.5	116.5	20.	66.
	750	95.1	101.1	17.	64.
	800	93.1	99.4	16.	61.
P-39	75	105.7	120.1	20.	65.
	750	99.0	108.5	15.	55.
	800	93.5	105.0	13.	58.
P-40*	75	103.7	120.5	20.	66.
	800	79.2	91.8	18.	59.
	1000	73.0	78.9	22.	65.
P-41	75	94.5	111.5	22.	65.
	200	92.5	107.5	17.8	56.
	300	88.5	102.7	17.5	58.
	400	85.3	99.7	17.5	59.
	500	85.2	100.2	15.7	51.
	600	84.0	97.4	17.2	63.
	700	82.0	95.4	17.2	60.
	800	79.1	91.5	19.	62.
	900	74.8	84.1	20.5	64.
	1000	69.5	75.5	23.	67.
P-42	75	71.0	89.2	24.	66.
	800	57.8	69.9	19.5	65.
	1000	53.2	56.4	22.5	65.
P-43	75	160.0	167.0	16.	61.
	200	146.0	161.6	19.	64.
	400	141.6	155.2	15.	55.
	600	144.0	158.8	15.	53.
	700	133.0	149.0	16.	61.
	800	115.6	145.6	16.	56.
	900	115.1	140.8	15.	59.
	1000	108.0	131.2	14.	58.

*Specimens from mid-thickness position

Cont. Table III - P

Code No.	Test Temp. °F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
P-44	75	102.0	115.0	21.	75.
	200	99.2	110.4	21.	76.
	400	93.6	103.2	18.	72.
	600	88.8	99.4	21.	68.
	700	84.0	99.6	18.	67.
	800	80.4	94.2	19.	69.
	900	75.2	88.6	22.	70.
	1000	-	82.8	25.	73.
P-45	75	72.0	90.0	29.	76.
	200	67.6	84.4	29.	78.
	400	65.8	80.6	25.	75.
	600	63.6	81.2	22.	72.
	700	59.2	81.0	23.	69.
	800	56.4	77.0	23.	72.
	900	55.2	73.2	24.	73.
	1000	48.0	63.6	28.	76.
P-46	75	101.5	122.5	20.	66.
	650	95.5	113.5	16.	60.
	800	99.0	113.7	16.	64.
	900	94.5	108.0	16.	65.
	1000	84.0	101.0	15.	66.
P-47	75	92.0	110.0	23.	70.
	650	75.5	91.0	19.	67.
	800	75.0	85.5	19.5	68.
	900	69.0	79.0	18.	73.
	1000	66.0	72.0	18.	76.
P-48	75	85.5	102.5	22.	71.
	650	76.0	90.5	20.	65.
	800	70.5	83.0	19.	70.
	900	67.3	81.5	18.	73.
	1000	65.5	71.0	20.	76.
P-49	75	74.2	93.0	26.	74.
	300	67.5	83.7	22.	75.
	500	64.5	79.7	22.	75.
	700	63.7	78.2	20.	69.
	900	59.0	71.2	23.	74.
P-50	75	75.2	94.7	23.	68.
	200	-	88.8	-	-
	400	69.0	83.9	20.	68.
	600	68.2	81.2	19.	67.
	700	67.0	80.3	18.	63.

Cont. Table III - P

Code No.	Test Temp. °F	Yield Strength	Tensile Strength	Elong.	Red. Area
		1000 psi		Per Cent	
P-50	800	59.5	77.4	21.	63.
	900	62.0	74.4	21.	69.
	1000	58.2	68.0	20.	72.
P-51	75	60.7	82.0	28.	72.
	200	-	75.8	-	-
	400	54.4	70.1	23.	71.
	600	53.5	66.7	21.	69.
	700	52.5	67.0	21.	66.
	800	50.7	65.8	21.	68.
	900	49.2	62.0	21.	69.
	1000	47.0	57.4	24.	72.
P-52a	75		131.0		
P-52b	75		111.0		
P-52c	75		97.0		

Table III - T

Short-Time Tensile Properties of 2-1/4 Cr-1 Mo Steels - Pipe and Tube

Code No.	Test Temp.°F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
T-34	75	42.0	72.8	34.	76.
	300	33.0	65.0	30.	75.
	500	36.4	67.5	26.	70.
	700	34.5	73.6	24.	66.
	900	31.5	67.1	23.	74.
	1000	25.6	58.0	26.0	82.
	1100	26.0	45.5	37.	90.
T-35	75	42.6	71.6	34.	76.
	300	35.4	62.9	33.	77.
	500	37.9	64.1	28.	79.
	700	34.2	67.8	26.	74.
	900	35.0	59.9	26.	76.
	1000	28.5	51.9	31.	81.
	1100	25.3	41.1	40.	90.
T-36	75	41.2	70.0	31.	75.
	300	35.4	60.2	36.	76.
	500	36.6	62.0	26.	72.
	700	34.5	66.2	26.	69.
	900	30.0	56.6	28.	64.
	1000	25.2	47.7	32.	71.
	1100	23.5	38.2	55.	88.
T-46	75	32.6	66.3	40.	76.
	900	21.9	51.8	34.	78.
	1050	20.4	36.3	50.	89.
	1200	16.8	23.3	66.	95.
T-47*	75	41.8	87.8	33.	62.
	900	40.8	100.0	23.	76.
	1050	40.5	77.5	33.	69.
	1200	26.1	36.2	45.	89.

*Data appear unreasonable, and have been excluded from the evaluations.

Code No.	Test Temp.°F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
T-48	70	44.2	72.3	33.	78.
	300	38.7	63.7	31.	79.
	500	37.3	63.0	27.	78.
	700	31.8	67.3	24.	73.
	900	30.3	60.8	29.	78.
	1100	28.3	46.2	29.	83.
	1200	22.9	37.5	54.	89.
	1300	17.8	21.8	74.	95.

Cont. Table III - T

Code No.	Test Temp.°F	1000 psi Yield Strength	1000 psi Tensile Strength	Per Cent Elong.	Per Cent Red. Area
T-49	70	44.1	63.5	38.	80.
	300	37.2	55.0	35.	81.
	500	34.4	55.7	29.	79.
	700	33.8	60.8	27.	75.
	900	26.8	54.6	31.	77.
	1100	21.7	36.4	30.	83.
	1200	17.8	27.4	63.	90.
	1300	14.7	18.4	97.	95.
T-50	70	44.4	75.8	34.	80.
	300	40.7	66.6	32.	76.
	500	44.1	70.2	27.	76.
	700	42.7	79.6	25.	66.
	900	41.2	73.9	25.	70.
	1100	31.9	47.8	45.	83.
	1200	20.6	34.5	54.	87.
	1300	15.5	21.4	44.	91.
T-51	70	50.1	70.4	35.	79.
	300	42.2	63.7	31.	80.
	500	44.4	69.4	26.	75.
	700	38.7	74.2	25.	71.
	900	32.7	68.1	27.	77.
	1100	25.5	45.5	43.	85.
	1200	20.6	32.5	52.	90.
	1300	16.6	22.1	61.	91.
T-52	70	40.8	72.6	34.	75.
	300	39.5	64.7	32.	77.
	500	44.2	69.8	26.	72.
	700	43.6	78.8	24.	71.
	900	39.1	73.4	25.	76.
	1100	30.9	49.0	42.	82.
	1200	23.5	35.0	61.	88.
	1300	16.0	21.8	80.	90.
T-53	70	30.4	70.2	37.	72.
	200	28.2	64.9	35.	72.
	400	28.0	61.7	31.	68.
	600	29.6	69.6	23.	66.
	800	29.3	77.1	23.	66.
	1000	27.2	66.2	21.	63.
	1050	27.3	62.9	33..	73.
	1100	25.8	52.2	38.	78.

Cont. Table III - T

Code No.	Test Temp.°F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
T-54	70	30.8	71.0	36.	72.
	200	28.8	65.4	35.	72.
	400	27.6	61.6	32.	72.
	600	30.6	70.5	25.	67.
	800	28.9	78.2	26.	68.
	1000	26.9	65.3	25.	71.
	1050	27.0	60.4	36.	76.
	1100	24.6	49.8	42.	80.
T-55	70	31.2	77.8	34.	76.
	200	27.3	71.4	32.	66.
	400	28.7	67.2	30.	68.
	600	30.8	76.6	22.	61.
	800	29.7	84.2	23.	66.
	1000	28.2	69.6	--	64.
	1050	28.1	63.8	34.	70.
	1100	25.4	54.6	41.	75.
T-56	70	32.1	76.3	34.	67.
	200	30.1	71.3	34.	65.
	400	29.7	67.1	31.	67.
	600	32.3	74.5	23.	64.
	800	30.1	84.6	24.	63.
	1000	29.7	73.9	24.	61.
	1050	28.6	66.6	35.	74.
	1100	26.9	52.9	42.	80.
T-57	70	27.6	71.1	37.	68.
	200	25.5	65.0	34.	72.
	400	25.4	61.8	31.	70.
	600	27.1	69.3	25.	68.
	800	28.9	79.9	25.	65.
	1000	26.0	70.3	24.	65.
	1050	24.1	63.1	35.	75.
	1100	24.3	52.0	41.	80.
T-58	70	33.8	78.2	33.	66.
	200	33.9	71.8	33.	66.
	400	28.9	68.2	31.	65.
	600	31.4	76.1	23.	60.
	800	29.9	85.5	23.	65.
	1000	30.5	73.9	31.	70.
	1050	28.1	63.9	37.	73.
	1100	27.7	57.1	26.	72.

Cont. Table III - T

Code No.	Test Temp. °F	1000 psi Yield Strength	1000 psi Tensile Strength	Per Cent Elong.	Per Cent Red. Area
T-59	75	106.5	132.0	20.	66.
	800	98.5	116.0	18.5	65.
	850	91.5	116.7	17.	67.
	900	97.5	111.5	18.5	67.
T-60	75	110.5	130.5	22.	69.
	800	105.0	118.0	18.5	69.
	850	-	111.2	22.	70.
	900	90.7	107.7	18.5	69.
T-61	75	106.0	125.5	21.	67.
	800	97.5	117.0	19.	69.
	850	-	108.5	19.	70.
	900	-	113.3	20.	70.
T-62	75	128.6	145.7	20.	62.
	200	124.8	139.5	19.5	61.
	300	117.9	136.3	18.	58.
	400	113.6	134.8	18.	58.
	650	-	132.5	19.	64.
T-109	75	38.0	75.0	32.7	67.2
	200	33.0	69.7	31.	67.2
	400	29.0	65.4	28.5	65.9
	600	29.3	69.7	22.	60.8
	800	27.7	66.6	27.5	66.1
	900	27.0	58.8	31.5	72.5
	950	26.0	54.2	34.	75.
	1000	25.3	48.8	37.	81.8
	1050	24.8	42.9	41.5	86.1
	1100	23.4	37.5	49.	90.7

Table III - F

Short-Time Tensile Properties of 2-1/4 Cr-1 Mo Steel - Forgings

Code No.	Test Temp. °F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
F-1	75	60.5	82.8	27.	75.
	800	41.5	65.5	23.	72.
	850	40.0	64.2	23.	72.
F-2	75	43.5	75.5	31.	77.
	750	30.0	61.0	27.	71.
F-3	75	87.5	106.5	23.	69.
	750	74.0	89.0	21.	71.
F-4	75	69.0	88.0	24.	78.
	800	58.3	69.5	21.	76.
F-5	75	54.8	81.0	27.	75.
	810	46.0	65.5	22.	71.
F-6	75	50.2	78.3	28.	75.
	810	41.9	65.3	23.	71.
F-7	75	71.0	88.0	25.	78.
	800	59.1	71.9	18.	72.
F-8	75	72.2	90.2	23.	72.
	850	60.1	71.5	21.	72.

Table III - C

Short Time Tensile Properties of 2-1/4 Cr-1 Mo Steel-Castings

Code No.	Test Temp.°F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
C-8 N	75	67.5	90.5	28.	64.
	300	60.0	88.8	24.	63.
	500	57.7	79.83	22.	62.
	700	57.6	82.3	19.5	54.
C-8 Q	75	93.0	110.0	21.	57.
	300	73.7	103.0	18.8	61.
	500	75.0	97.5	18.5	57.
	700	76.0	95.0	17.3	53.
C-9 N	75	75.0	96.0	26.	70.
	300	69.1	89.4	21.	64.
	500	67.2	88.0	23.	65.
	700	64.5	88.4	20.	59.
C-9 Q	75	103.0	121.5	22.5	69.
	300	95.5	110.0	18.8	64.
	500	89.6	105.5	20.0	66.
	700	79.6	107.2	19.8	64.
C-10 N	75	72.0	95.0	24.	68.
	300	66.7	87.5	24.	65.
	500	66.0	86.0	22.	64.
	700	63.7	88.5	22.	57.
C-10 Q	75	97.5	116.5	21.	58.
	300	92.2	106.5	19.5	64.
	500	90.7	105.5	17.5	58.
	700	88.5	103.7	20.	57.
C-11	75	72.	98.	25.	55.
	200	66.	89.5	25.	53.
	300	63.5	86.5	23.	57.
	400	60.5	84.0	20.	56.
	500	59.	84.	19.	50.
	600	60.5	86.3	18.	52.
	650	60.	85.5	16.	45.
	700	57.	84.	17.	47.
	750	54.5	82.	18.	45.
	950	48.5	64.5	27.	59.

Cont. Table III - C

Code No.	Test Temp.°F	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
C-12	75	64.5	89.5	28.	68.
	200	60.0	82.5	24.	65.
	300	57.5	79.5	27.	70.
	400	57.5	78.5	23.	67.
	500	53.3	76.5	22.	66.
	600	55.0	77.0	20.	65.
	650	54.0	76.5	18.5	62.
	700	53.0	77.0	20.	61.
	750	52.	75.	22.	59.
	850	48.5	69.0	27.	64.
	950	46.5	60.	26.	70.
C-13	75	62.0	87.5	27.	66.
	200	58.5	82.	24.	59.
	300	57.	77.5	24.	65.
	400	55.5	76.5	23.	63.
	500	54.	74.5	22.	57.
C-13	600	52.5	73.5	17.	57.
	650	52.5	74.0	18.5	48.
	700	53.0	74.	18.	56.
	750	51.	72.	18.	53.
	850	48.5	67.	25.	56.
	950	44.5	39.	27.	64.
C-14	75	58.4	85.3	26.	50.
	800	47.5	71.	25.	55.
	900	45.7	63.8	24.	45.
	1050	41.2	50.6	40.	80.
C-15	75	56.6	85.2	27.	52.
	800	46.8	69.8	24.	54.
	900	44.6	62.6	24.	48.
	1050	39.8	48.9	38.	78.

Table III - W

Short Time Tensile Properties of 2-1/4 Cr-1 Mo Steel Weld Metal

Code No.	Test Temp.°F	Test Location	Yield Strength (1000 psi)	Tensile Strength (1000 psi)	Elong. (Per Cent)	Red. Area (Per Cent)
W-16	75	S	89.8	108.2	21.*	70.
	"	1/4T	94.7	110.1	23.*	68.
	"	1/2T	89.6	106.6	23.*	71.
	850	S	75.3	85.3	18.5	65.
	"	1/2T	77.6	84.7	18.	67.
	900	S	74.5	81.6	19.8	64.
	"	1/2T	76.1	81.3	19.6	66.
W-17	75		119.5	130.5	19.	59.
	800		101.5	111.5	16.	50.
W-18	75		105.5	116.5	18.	61.
	750		93.5	108.2	15.	63.
	800		89.0	99.5	14.	50.
W-19	75		107.5	121.0	19.	60.
	800		90.5	103.0	13.5	48.
W-20	75		103.0	117.0	20.	62.
	750		91.0	101.0	16.5	59.
	850		89.0	99.2	16.	40.
W-21	75		128.0	142.0	14.	45.
W-22	75		114.0	127.7	23.	61.
W-23	75		112.7	128.0	19.5	63.
W-24	75		118.0	135.0	19.	57.
W-25	75		99.1	115.5	21.	67.

*Elongation in 1"

Table IV - P

Creep and Rupture Data for 2-1/4 Cr-1 Mo Steel--Plate

Code No.	Temp.°F	Stress, ksi	Test Duration-Hours (1)		Min. creep Rate-%/hr.	At Rupture-% Elong.	Red. Area
P-8a	800	65.9	24.5		-	23.	76.
		65.9	90.4	T	-	26.	67.
		56.5	3174.		-	12.	77.
		56.5	4446.	T	-	26.	74.
	900	56.5	44.7		-	22.	76.
		56.5	55.1	T	-	27.	74.
		51.8	212.		-	33.	80.
		51.8	260.	T	-	34.	75.
		42.0	7690.	T	-	17.	71.
		37.6	5192.		-	35.	82.
		37.6	>13,000.	T	-	-	-
	1000	47.1	18.8		-	30.	80.
		42.0	136.		-	*	73.
		37.6	718.		-	31.	79.
		32.0	4095.		-	-	56.
		28.2	10,410.		-	8.*	44.
P-8b	800	95.0	99.		-	10.	64.
		95.0	49.	T	-	15.	63.
		84.7	5093.		-	30.	70.
		84.7	7286.	T	-	26.	63.
	900	80.0	60.		-	22.	72.
		80.0	11.4	T	-	20.	67.
		75.0	159.	T	-	21	70.
		70.6	583.		-	25.	73.
		65.0	1809.	T	-	15.	70.
		61.2	1751.		-	-	75.
		55.0	5995.		-	-	68.
	1000	55.0	69.		-	22.	78.
		50.0	343.		-	12.	66.
		45.0	903.	N	-	-	-
		40.0	1226.	N	-	-	-

(1) All tests to rupture except those designated C, which were discontinued before rupture. Specimens represent longitudinal orientation unless designated T for transverse.

* Failed at punch mark.

N - Failed in notch section of combined test specimen

Cont. Table IV - P

Code No.	Temp.°F	Stress, ksi	Test[(1)] Duration-Hours		Min. Creep Rate-%/hr.	An Rupture-% Elong.	Red. Area
P-12	850	64.0	1.75		2.58	Not Reported	
		64.0	2.6		1.17	"	"
		61.0	26.4		.118	"	"
		58.0	46.		.106	"	"
		55.0	124.		.0282	"	"
		51.0	482.		.0052	"	"
		48.0	1010.		.0036	"	"
	900	55.0	.3		6.6	"	"
		50.0	10.2		.205	"	"
		45.0	64.		.121	"	"
		42.0	584.		.0083	"	"
		40.0	439.		.0047	"	"
		39.0	1464.		.0020	"	"
P-15a	850	85.0	5.1		1.03	"	"
		79.3	43.		.0096	"	"
		75.0	152.		.0126	"	"
		71.2	314.		.0095	"	"
		69.0	889.		.0023	"	"
	900	85.0	.6		6.93	"	"
		76.0	14.		.168	"	"
		70.0	64.		.0774	"	"
		65.0	240.		.0255	"	"
		62.0	484.		.0101	"	"
		60.0	688.		.0078	"	"
	950	70.0	11.		.321	-	-
		65.0	41.		.102	-	-
		60.0	146.		.0324	-	-
		55.0	421.		.0126	-	-
		50.0	1136.	C	.0034	-	-
		39.0	1000.	C	.00023	-	-
P-15b	900	70.0	96.		.030	27.	64.
		65.0	417.		.0119	22.	69.
		60.0	1130.		.00435	20.	63.
	1000	75.0	0.2		24.9	21.	71.
		68.0	3.2		1.095	21.	68.
		64.0	7.6		.537	21.	67.
		60.0	18.7		.441	22.	71.
	1100	60.0	0.9		5.19	24.	73.
		55.0	1.6		3.1	26.	74.
		50.0	9.3		.588	22.	42.
		45.0	23.		.181	9.8	22.
		45.0	24.		.195	14.	31.
		40.0	55.		.0702	9.8	14.
		35.0	119.		-	8.7*	8.0*
		30.0	242.		.0135	6.9	11.

*Failed at punch mark.

Cont. Table IV - P

Code No.	Temp. °F	Stress, ksi	Test[(1)] Duration-Hours	Min. Creep Rate-%/hr.	At Rupture-% Elong.	Red. Area
P-15c	900	78.0	24.3	.144	21.	67.
		70.0	60.9	.0729	22.	64.
		57.0	3289.	.00128	21.	44.
		55.0	3962.	.0009	19.	55.
		50.0	>13,464.	.000245	-	-
		40.0	9500. (C)	.000018	-	-
	1000	63.0	9.5	.456	27.	77.
		57.0	47.	.0792	24.	71.
		50.0	198.	.0209	17.	39.
		50.0	431.	.009	12.	20.
		40.0	2130.	.00228	7.*	7.*
		30.0	7642.	.0002	6.5*	8.6*
	1100	60.0	.43	17.4	27.	79.
		57.0	.9	5.1	25.	80.
		55.0	1.2	4.05	28.	78.
		50.0	14.	.366	25.	59.
		45.0	19.9	.276	20.	44.
		35.0	155.	.0231	9.3	13.
		20.0	2818.	.00182	15.	13.
P-15d	900	70.0	11.9	.198	21.	66.
		60.0	88.	.036	22.	71.
		55.0	289.	.003	29.	72.
		47.0	4680.	-	35.	66.
		45.0	4301.	.000126	20.	72.
	1000	50.0	20.	.249	32.	73.
		40.0	371.	.0127	26.	74.
		55.0	5.1	.855	23.	71.
		35.0	1422.	.0038	21.	45.
		33.0	3216.	.0013	16.	34.
	1100	40.0	8.6	.618	26.	75.
		35.0	113.	.0546	24.	51.
		30.0	670.	.006	15.	28.
		20.0	1751.	.0015	20.	36.
P-15e	850	70.0	14.6	.57	32.	67.
		65.0	131.	.0456	27.	69.
		55.0	847.	.00283	32.	72.
		52.8	1234.	.00117	29.	74.
		45.3	3578.	.000462	19.	75.
		60.3	819.	.0027	28.	74.

*Failed at punch mark

Cont. Table IV - P

Code No.	Temp.°F	Stress, ksi	Test[1] Duration-Hours	Min. Creep Rate-%/hr.	At Rupture-% Elong.	Red. Area
P-15e	900	60.0	50.	.028	24.	66.
		65.0	10.7	.538	33.	70.
		56.0	131.	.0218	28.	71.
		50.0	368.	.0109	33.	73.
		42.2	1576.	.00198	49.	77.
		40.0	3478.	.000985	41.	78.
P-21	800	90.0	35.	-	16.	66.
		82.0	1169.	.00247	17.0	64.
		78.0	2848.	.00077	13.0	62.
		78.0	5240.	.00058	25.	64.
		70.0	19410.	.000281	9.0	37.
	850	85.0	61.	-	20.	76.
		78.	181.	-	17.5	69.
		70.0	2345.	.00070	17.0	56.
		65.0	4289.	.00042	7.0	44.
		60.0	6853.	.00020	12.	36.
	900	65.0	690.	.00296	16.	51.
		60.0	1044.	.00201	15.	49.
		53.0	2877.	.00068	6.	10.9
		50.0	>18,000.	-	-	-
P-23	800	125.0	2460.	.00050	11.	39.
		120.	1453.	.00059	10.	42.
		115.0	6076.	.000072	1.7	29.
	850	110.0	444.	.0023	11.	55.
		105.0	1637.	.00048	10.	45.
		100.0	2127.	.0003	13.	37.
		90.0	6855.	.0001	10.	49.
		85.0	9633.	.00078	11.	49.
P-24a	800	130.0	1425.	.00121	8.	17.9
		120.0	13409.	.000028	4.	11.6
	850	110.	3688.	.00028	4.	0.0
P-24b	800	100.0	373.	.0131	17.	50.
		95.0	3658	.00054	11.	50.
		90.0	10524.	.00018	10.	52.
		82.0	21717.	.000105	13.	56.
	850	85.0	1704.	.000069	12.	57.
		80.0	3116.	.00032	15.	64.
		60.0	25860.	.000067	12.	62.

Cont. Table IV - P

Code No.	Temp. °F	Stress, ksi	Test(1) Duration-Hours	Min. Creep Rate-%/hr.	At Rupture-% Elong.	Red. Area
P-33**	900	77.0	6.8	.450	-	-
		70.0	41.	.0738	-	-
		65.0	150.	.0263	-	-
		60.0	414.	.0085	-	-
		58.0	517.	.00657	-	-
P-34+	900	102.0	3.7	-	20.*	70.
		100.0	88.	-	21.*	71.
		97.5	174.	-	18.*	63.
		95.0	199.	-	21.*	63.
		90.0	801.	-	14.*	52.
		80.0	3456.	-	12.	51.
	1000	85.0	29.6	-	17.*	66.
		85.0	0.6	-	-	72.
		80.0	8.0	-	18.*	68.
		75.0	29.3	-	16.*	65.
		70.0	105.	-	23.*	73.
		65.0	167.	-	20.*	65.
		65.0	91.	-	13.*	56.
		60.0	220.	-	24.*	70.
		55.0	128.	-	-	67.
		55.0	222.	-	23.*	72.
		49.6	26.5	-	33.*	-
		45.0	300.	-	-	71.
		40.0	19.	-	-	-
		35.0	1711.	-	26.*	54.
	1100	60.0	4.9	-	27.*	69.
		55.0	.4	-	-	-
		50.0	10.2	-	-	77.5
		50.0	1.1	-	27.*	83.
		45.0	6.1	-	22.*	80.
		40.0	15.3	-	22.*	78.
		35.0	32.2	-	28.*	71.
		30.0	71.	-	23.*	67.
		25.0	164.	-	17.*	62.
		25.0	20.6	-	34.*	-
		20.4	171.	-	35.*	-
		20.0	356.	-	-	55.
		10.0	4430.	-	-	61.
	1200	25.0	1.4	-	31.*	88.
		20.0	13.2	-	42.*	88.
		15.0	86.	-	42.*	83.
		12.0	142.	-	42.*	89.
		6.0	1319.	-	-	88.

* 1 inch gage length
** Tests from 1/2T location
\+ Data appear erratic and have been excluded from evaluations

Table IV - P

Creep and Rupture Data - Plate

Code No.	Temp. °F	Stress, ksi	Test Duration-Hours	Min. Creep Rate-%/hr.	At Rupture-% Elong.	Red. Area
P-40*	800	80.0	1405.	.0023	19.5	53.
		78.0	>5100.	.000070		
		75.0	>9600	.0000035		
	900	70.0	246.	.008	23.	60.
		65.0	1606.	.00060	19.5	58.
		60.0	2976.	.00037	22.	59.
		55.0	>6750.	.00014		
	1000	40.0	1219.	.0023	10.5	17.8
		35.0	3197.	.00085	6.5	8.6
		30.0	7195.	.00026		
P-41	800	80.0	414.	.009	23.5	63.
		75.0	3136.	.00062	22.	59.
		75.0	1682.	.0011	21.5	56.
		70.0	1822	.00135	25.	62.
		70.0	4510.	.00037	25.	63.
		65.0	7656.	.00018	21.5	62.
		60.0	5995.c	.00004	-	-
	900	60.0	705.	.0040	23.	61.
		60.0	336.	.0092	28.	76.
		55.0	1075.	.0033	24.	62.
		55.0	1189.	.0030	25.	75.
		50.0	6249.	.00053	14.5	41.
		50.0	6280.	.00051	23.	49.
		47.5	>12,300.	.00019	-	-
		45.0	4295.c	.00011	-	-
	1000	45.0	398.	.0088	17.	39.
		40.0	1460.	.0014	5.	8.9
		35.0	3248.	.00054	6.5	8.9
		30.0	8412.	.00024	4.5	5.9
P-42	800	55.0	968.	.0029	29.	72.
		50.0	5059.	.00047	28.	73.
	900	40.0	1303.	.0028	37.	74.
		35.0	5075.	.00083	35.	68.
	1000	40.0	23.2	.153	34.	75.
		35.0	115.	.036	34.	77.
		25.0	8227.	.00047	23.	48.
		19.7	2625.c	.00038	-	-

* Specimens from mid-thickness position

Cont. Table IV - P

Code No.	Temp. °F	Stress, ksi	Test Duration-Hours	Min. Creep Rate-%/hr.	At Rupture-% Elong.	Red. Area
P-43	800	144.0	>2058.*	-	-	-
	900	140.0	0.5	-	12.0	61.
		130.0	202.	-	10.0	57.
P-44	800	92.0	96.	-	19.0	69.
		90.0	181.	-	14.0	69.
		85.0	854.	-	20.0	70.
	900	86.0	2.2	-	20.0	73.
P-45	800	74.0	1.2	-	18.0	74.
		72.0	9.2	-	20.0	74.
		70.0	32.	-	20.0	72.
		60.0	1495.	-	18.0	78.
	900	55.0	41.	-	18.0	77.
P-52a	900	60.0	8919.	-	11.0	-
	1000	45.0	568.	-	10.0	-
		30.0	3009.	-	4.2	-
P-52b	850	65.0	2129.	-	20.0	-
		60.0	6400.	-	17.0	-
		55.0	16,008.	-	19.	-
	900	60.0	665.	-	29.	-
		55.0	1756.	-	17.	-
		50.0	5972.	-	13.	-
		45.0	> 8729.	-	-	-
P-52c	850	55.0	622.	-	25.	
		45.0	5626.	-	34.	
	900	45.0	813.	-	27.	-
		40.0	4239.	-	30.	-

* Test discontinued

Table IV - T

Creep and Rupture Data for 2-1/4 Cr-1 Mo Steel - Pipe and Tube

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture % Elong.	Red. Area
T-25	1000	35.0	11.	-	47.	
		28.0	80.	-	64.	
		24.0	257.	-	63.	
		20.0	1895.	-	70.	
	1100	18.0	129.	-	72.	
		16.0	387.	-	73.	
		13.0	2037.	-	51.	
T-26	1000	35.0	4.	-	51.	
		28.0	66.	-	54.	
		24.0	266.	-	81.	
		20.0	1381.	-	-	
T-27	1000	25.0	192.	-	65.	86.
		19.0	1354.	-	77.	87.
		7.8	5000. C	.000011	-	-
	1100	17.0	92.	-	89.	89.
		12.0	1009.	-	99.	93.
		5.5	5500. C	.000023	-	-
T-28	1000	34.0	101.	-	36.	-
		28.0	368.	-	53.	-
T-29	1100	20.0	61.	-	81.	-
		15.0	396.	-	56.	-
T-30	1100	16.0	556.	-	60.	-
		16.0	564.	-	59.	-
T-31	1100	19.0	117.	-	54.	-
		16.0	345.	-	58.	-
T-32	1100	19.0	71.	-	71.	-
		16.0	467.	-	59.	-
T-33	1100	15.0	121.	-	62.	-
		13.5	498.	-	80.	-
		11.5	4267.	-	85.	-
T-37	1000	21.0	4645.	-	20.	46.
	1050	15.0	10673	.00038	16.5	33.
	1100	15.0	1930.	.0018	22.5	51.
	1150	12.0	1466.	.001	21.	67.

Cont. Table IV - T

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture % Elong.	Red. Area
T-37	1200	8.0	2633.	.0008	36.	89.
	1250	6.0	1026	.0007	43.	87.
T-38	1000	18.0	1400.	.013	55.	78.
	1050	15.0	983.	.00127	62.	82.
	1100	13.5	434.	.0185	42.	81.
	1150	12.0	231.	.053	49.	84.
	1200	9.0	549.	.0127	52.	87.
	1250	7.0	446.	.013	46.	88.
T-39	1000	21.0	2590.	-	46.	65.
	1050	15.0	7470.	.00067	13.	37.
	1100	15.0	1311.	.0043	26.	62.
	1150	13.5	697.	.00583	37.	70.
	1200	9.0	1087.	.0008	26.	83.
	1250	7.0	635.	.0015	49.	86.
T-39	1000	18.0	1930.	-	49.	80.
	1050	15.0	1570.	-	52.	81.
	1100	13.5	582.	.020	47.	82.
	1150	12.0	326	.0267	60.	83.
	1200	9.0	598.	.0025	33.	86.
	1250	6.0	979.	.00107	39.	90.
T-40	1000	18.0	1781.	.00876	52.	84.
	1050	15.0	1667.	.0076	47.	80.
	1100	13.0	1371.	.0065	37.	82.
	1150	11.5	1089.	.0036	37.	81.
	1200	10.0	558.	.0095	30.	87.
	1250	8.0	312.	.0013	38.	89.
T-40	1000	18.0	3274.	.0045	36.	80.
	1050	15.0	2091.	-	49.	79.
	1100	14.0	542.	.021	47.	84.
	1150	11.5	675.	.012	41.	84.
	1200	9.5	549.	.00775	30.	88.
	1250	7.0	494.	.0038	18.5	79.
T-41	1000	18.0	5772.	.0022	22.	71.
	1050	17.0	969.	.0158	47.	77.
	1100	15.0	522.	.025	53.	78.
	1150	12.0	415.	.0258	43.	79.
	1200	10.0	346.	.0205	46.	83.
	1250	5.0	1157.	.005	48.	86.

Cont. Table IV - T

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture % Elong.	Red. Area
T-41	1000	22.0	614.	.029	57.	81.
	1050	16.5	1825.	.00848	45.	79.
	1100	15.0	478.	.0208	56.	82.
	1150	12.0	767.	.010	44.	80.
	1200	9.5	748.	.00375	32.	83.
	1250	6.5	656.	.00428	57.	90.
T-42	1000	18.0	4635.	.00303	44.	81.
	1050	16.5	1603.	.00791	45.	79.
	1100	14.0	879.	.0141	52.	82.
	1150	12.0	543.	.019	45.	85.
	1200	10.0	484.	.0125	35.	87.
	1250	8.0	216.	.032	50.	89.
T-42	1000	18.0	2710.	.0053	53.	81.
	1050	15.0	1658.	-	51.	82.
	1100	13.5	1013.	.0139	50.	82.
	1150	12.0	351.	.038	54.	86.
	1200	10.0	285.	.0315	38.	86.
	1250	8.0	239.	.035	45.	90.
T-43	1000	20.0	1149.	-	51.	80.
	1050	15.0	1634.	.008	51.	85.
	1100	11.74	4687.	.00157	39.	79.
	1150	12.0	415	.0217	36.	86.
	1200	10.0	311.	.026	42.	89.
	1250	7.0	513.	.00425	31.	90.
T-44	1000	50.0	115.	-	20.	70.
		44.0	694.	-	15.	75.
		38.0	856.	-	14.	77.
		35.0	1081.	-	13.	77.
		30.0	1669.	-	17.	83.
		26.0	3138.		17.	82.
	1100	36.0	25.	-	17.	82.
		28.0	114.	-	19.	85.
		20.0	356.	-	21.	86.
		15.0	1997.	-	21.	87.
		12.0	5260.	-	24.	79.
T-45	1000	30.0	607.	-	40.	80.
	1100	25.0	46.	-	32.	82.
	1150	20.0	113.	-	49.	83.
	1200	15.0	163.	-	38.	85.
	1300	10.0	49.	-	29.	93.

Cont. Table IV - T

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture % Elong.	Red. Area
T-46	1050	43.9	0.1	-	41.	83.
		35.0	1.9	-	55.	83.
		25.0	38.	-	70.	87.
		21.0	155.	-	83.	91.
		16.5	926.	-	60.	75.
T-47 Long.	1050	78.7	1.3	-	35.	71.
		74.4	4.5	-	34.	89.
		68.	16.	-	30.	67.
		56.	45.	-	32.	75.
		34.	344.	-	45.	83.
		28.	532.	-	44.	84.
T-47 Transv.	1050	71.	0.1	-	33.	61.
		70.5	5.6	-	31.	62.
		67.1	7.2	-	34.	64.
		56.0	17.2	-	28.	60.
		25.0	701.	-	37.	79.
T-48	1050	35.0	12.9	-	60.	-
		30.0	37.	-	68.	-
		27.0	99.	.224	55.	-
		23.0	444.	.050	55.	-
		20.0	710.	.029	50.	-
		18.0	1536.	.010	45.	-
		16.5	3386.	.00423	39.	-
	1100	30.0	7.6	-	67.	-
		27.0	19.5	-	52.	-
		20.0	137.	.161	60.	-
		15.0	982.	.144	55.	-
		12.0	3567.	.0033	46.	-
T-49	1050	35.0	1.4	-	51.	-
		27.0	19.	-	63.	-
		23.0	70.	.560	60.	-
		20.0	184.	.309	76.	-
		17.0	338.	.137	75.	-
		15.0	728.	.048	86.	-
		13.5	1444.	.020	75.	-
		12.0	3676.	.00802	77.	-
	1100	27.0	3.2	-	61.	-
		20.0	15.8	-	83.	-
		17.0	63.	.584	76.	-
		15.0	148.	.230	80.	-
		12.0	768.	.048	73.	-
		11.0	1091.	.028	84.	-
		9.0	4319.	.00653	46.	-

Cont. Table IV - T

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture Elong.	Red. Area
T-50	1050	45.0	2.2	-	40.	-
		35.0	16.8	-	55.	-
		27.0	113.	.296	54.	-
		17.0	1238.	.013	55.	-
		14.0	4475.	.0030	50.	-
	1100	27.0	17.2	-	67.	-
		20.0	100.	.578	57.	-
		15.0	494.	.037	50.	-
		12.0	1647.	.0057	50.	-
		11.0	3138.	.0023	50.	-
T-51	1050	35.0	19.7	-	50.	-
		32.0	48.	.762	41.	-
		25.0	160.	.129	55.	-
		17.0	1357.	.014	57.	-
		15.0	2477.	.0062	52.	-
		14.0	3700.	.0037	47.	-
	1100	27.0	18.5	-	50.	-
		20.0	77.	.381	55.	-
		15.0	608.	.024	49.	-
		12.0	1759.	.0062	40.	-
		11.0	2757.	.0032	40.	-
T-52	1050	45.0	4.7	-	40.	-
		35.0	28.1	-	45.	-
		27.0	79.	.491	54.	-
		25.0	221.	.165	48.	-
		17.0	1189.	.0137	45.	-
		14.0	4626.	.0028	40.	-
	1100	27.0	21.5	-	55.	-
		20.0	123.	-	56.	-
		15.0	479.	.038	57.	-
		12.0	2084.	.0053	40.	-
		11.0	3525.	.0024	45.	-
T-53	1050	30.0	177.	-	30.	-
		25.0	361.	-	31.	-
	1100	20.0	101.	-	72.	-
		18.0	145.	-	74.	-
		15.0	316.	-	75.	-
		14.0	601.	-	55.	-

Cont. Table IV - T

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture Elong.	Red. Area
T-54	1050	30.0	96.	.087	55.	-
		30.0	150.	.047	52.	-
		25.0	318.	.070	53.	-
		24.0	402.	.058	53.	-
		23.0	374.	.047	57.	-
		19.0	691.	.037	78.	-
		15.0	2068.	.012	70.	-
		13.0	3717.	.0041	45.	-
	1100	25.0	62.	.607	60.	-
		20.0	94.	.223	64.	-
		18.0	170.	.379	67.	-
		15.0	377.	.0439	53.	-
		15.0	315.	.0474	68.	-
		13.0	621.	.0300	65.	-
		10.0	3052.	.0043	58.	-
T-55	1050	30.0	127.	-	30.	-
		25.0	306.	-	36.	-
		23.0	430.	-	48.	-
	1100	20.0	106.	-	66.	-
		20.0	87.	-	46.	-
		18.0	96.	-	62.	-
		15.0	437.	-	58.	-
T-56	1050	30.0	188.	.0723	44.	-
		30.0	181.	.0654	42.	-
		23.0	370.	.0130	55.	-
		20.0	716.	.0052	49.	-
		15.0	3222.	.0047	52.	-
	1100	20.0	193.	.477	67.	-
		18.0	243.	.167	66.	-
		15.0	438.	.044	64.	-
		15.0	400.	.0506	69.	-
		13.0	1134.	.0152	56.	-
		10.0	4961.	.00178	63.	-
T-57	1050	30.0	242.	-	45.	-
		25.0	364.	-	54.	-
		23.0	451.	-	54.	-
	1100	20.0	129.	-	68.	-
		18.0	143.	-	65.	-
		15.0	417.	-	65.	-
		14.0	498.	-	69.	-

Cont. Table IV - T

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture Elong.	Red. Area
T-58	1050	45.0	53.	-	30.	-
		35.0	160.	-	35.	-
		30.0	276.	-	43.	-
		25.0	478.	-	45.	-
		25.0	465.	-	38.	-
		20.0	907.	-	55.	-
		15.0	2564.	-	41.	-
	1100	20.0	168.	-	45.	-
		18.0	253.	-	63.	-
		18.0	223.	-	78.	-
		15.0	489.	-	63.	-
		14.0	769.	-	53.	-
		10.0	5307.	-	56.	-
T-63	1100	15.5	246.			
		13.5	569.			
T-64	1100	15.5	373.			
		13.5	906.			
T-65	1100	15.5	235.			
		13.5	670.			
T-66	1100	15.5	255.			
		13.5	577.			
T-67	1100	15.5	459.			
		13.5	1236.			
T-68	1100	15.5	309.			
		13.5	806.			
T-69	1100	15.5	226.			
		13.5	439.			
T-70	1100	15.5	164.			
		13.5	435.			
T-71	1100	15.5	347.			
		13.5	778.			
T-72	1100	15.5	122			
		13.5	274.			
T-73	1100	15.3	218			
		13.5	538.			

Cont. Table IV - T

Code No.	Temp. °F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture Elong.	Red. Area
T-74	1100	15.5	243.			
		13.5	508.			
T-75	1100	15.5	124.			
		13.5	305.			
T-76	1100	15.5	199.			
		13.5	457.			
T-77	1100	15.5	303.			
		13.5	787.			
T-78	1100	15.5	239.			
		13.5	563.			
T-79	1100	15.5	104.			
		13.5	347.			
T-80	1100	15.5	119.			
		13.5	358.			
T-81	1100	15.5	129.			
		13.5	468.			
T-82	1100	15.5	198.			
		13.5	465.			
T-83	1100	15.5	184.			
		13.5	421.			
T-84	1100	15.5	163.			
		13.5	406.			
T-85	1100	15.5	485			
		13.5	1622			
T-86	1100	15.5	203			
		13.5	438.			
T-87	1100	15.5	118.			
		13.5	306.			
T-88	1100	15.5	168.			
		13.5	383.			
T-89	1100	15.5	166.			
		13.5	378.			
T-90	1100	15.5	220.			
		13.5	489.			

Cont. Table IV - T

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture Elong.	Red. Area
T-91	1100	15.5	229.			
		13.5	533.			
T-92	1100	15.5	252.			
		13.5	534.			
T-93	1100	15.5	356.			
		13.5	801.			
T-94	1100	15.5	203.			
		13.5	419.			
T-95	1100	15.5	126.			
		13.5	308.			
T-96	1100	15.5	305			
		13.5	655.			
T-97	1100	15.5	203.			
		13.5	470.			
T-98	1100	15.5	242.			
		13.5	266.			
T-99	1100	15.5	215.			
		13.5	583.			
T-100	1100	15.5	104.			
		13.5	283.			
T-101	1100	15.5	101.			
		13.5	312.			
T-102	1100	15.5	169.			
		13.5	394.			
T-103	1100	15.5	135.			
		13.5	376.			
T-104	1100	15.5	439.			
		13.5	1379.			
T-105	1100	15.5	217.			
		13.5	501.			
T-106	1100	15.5	211.			
		13.5	406.			
T-107	1100	15.5	680.			
		13.5	2852.			

Cont. Table IV - T

Code No.	Temp. °F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture Elong.	Red. Area
T-108	1100	15.5	686.			
		13.5	1819.			
T-109	950	32.	379.4	-	49.	81.
		29.5	703.7	-	58.	83.
		28.0	1151.1	-	53.	82.
		24.75	3284.5	-	53.	84.
		23.25	4902.0	-	52.	85.
	1000	40.0	2.90	-	41.	79.
		29.	87.8	-	47.	83.
		25.	445.9	-	65.	87.
		23.5	675.6	-	55.	85.
		19.125	3013.1	-	57.	87.
		17.75	7146.	-	48.	85.
	1050	21.	313.	-	56.	86.
		19.	587.	-	49.	84.
		15.25	4835.	-	54.	80.
		14.25	8014.	-	29.	73.
	1100	29.	2.2	-	47.	86.
		19.	87.	-	51.	88.
	1150	14.	329.	-	44.	85.
	1200	19.	4.2	-	51.	92.
		10.	608.	-	50.	86.

Table IV - B

Creep and Rupture Data for 2-1/4 Cr-1 Mo Steel-Bar

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture-% Elong.	Red. Area
B-4	900	40.0	32520.	-	7.5	-
B-5a	1050	30.0	432.	.0067	5.0	-
		30.0	510.	.0048	4.5	-
		25.0	1314.	.001235	4.0	-
		23.0	1692.	.0012	4.5	-
		18.5	4318.	.000345	3.0	-
B-5b	1050	30.0	168.	.0210	14.5	-
		27.0	453.	.0060	5.0	-
		22.0	1606.	.0069	3.0	-
B-6	1100	14.0	1005.	-	43.	-
		12.0	2496.	-	34.	-
		10.0	4792.	-	40.	
		8.5	11424.	-	29.	-
	1200	7.0	1392.	-	30.	-

Table IV - C

Creep and Rupture Data for 2-1/4 Cr-1 Mo - Castings

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture-% Elong.	Red. Area
C-14	950	36.	129.	.034	40.	-
		28.	1037.	.0045	47.	-
	1000	25.	561.	.010	45.	-
		21.	1648.	.0042	46.	-
	1050	18.	1157.	-	28	-
	1100	16.5	348.	.026	28.	-
		12.0	1944.	.0042	23.	-
	1150	13.5	202.	.049	42.	-
		10.0	1356.	.0065	27.	-
C-15	950	36.0	96.	.049	40.	-
		28.0	872.	.0045	49.	-
	1000	25.0	363.	.015	47.	-
		21.0	1430.	.0041	40.	-
	1050	18.0	1103.	.0034	58.	-
	1100	16.5	257.	.026	57.	-
		12.0	2149.	.0036	36.	-
	1150	13.5	212.	.041	68.	-
		10.0	1920.	.0041	30.	-

Table IV - W

Creep and Rupture Data for 2-1/4 Cr-1 Mo - Weld Metal

Code No.	Temp.°F	Stress, ksi	Test Duration Hours	Min. Creep Rate-%/hr.	At Rupture-% Elong.	Red. Area
W-16	850	80.	12.8	.195	-	-
		70.	135.	.0166	-	-
		65.	548.	.00441	-	-
		60.	2840.	.00117	-	-
	900	75.	14.6	.206	-	-
		70.	21.3	.134	-	-
		65.	56.	.055	-	-
		60.	295.	.0125	-	-
		55.	1202.	.00345	-	-
		70	31.6	-	-	-
		65.	61.	.0549	-	-
		60.	286.	.0135	-	-
		57.	672.	.00732	-	-
W-21	850	105.	91.	-	9.	41.
		95.	610.	.00264	3.4	20.
		90.	1832.	.0065	4.	2.7
		80.	4695.	.00004	-	7.3
	900	80.	443.	-	2. *	5. *
		75.	349.	.00017	1. *	2.5*
		70.	1107.	.00043	- *	4. *
		65.	2970.	.00015	7.	32.
		55.	3534.	.00078	12.	14.
		50.	3921.	.00035	15.	38.
		45.	6557.	.00021	17.	21.6
W-22	800	90.	168.	.020	13.0	60.
		80.	2517.	.00079	15.8	47.
		75.	15807.	.00008	8.7	58.
	850	100.	0.5	-	18.	56.
		90.	10.	-	15.	57.
		80.	233.	.00546	15.	61.
		70.	2318.	.00045	17.	63.
		60.	8827.	.00014	20.	51.
	900	60.	1078.	.00172	19.0	56.
		55.	2460.	.00101	18.	40.
		50.	7150	.00036	13.	15.7
		45.	11218.	.00018	5.	8.8
W-23	800	90.	140.	-	19.	57.
		80.	2150.	.00141	14.	59.
		75.	6053.	.00050	12.	45.

*Specimens broke in fillet, outside the gage length.

Cont. Table IV - W

Code No.	Temp.°F	Stress, ksi	Test[1] Duration Hours	Min. Creep Rate%/hr.	At Rupture-% Elong.	At Rupture-% Red. Area
W-23	850	85.0	57.	-	16.	59.
		80.0	236.	.0156	17.	49.
		73.0	895.	.00382	14.	56.
		65.	4868.	.00338	9.	23.6
	900	70.0	170.	-	16.	60.
		65.0	502	.0075	15.	50.
		62.5	1115.	.00328	12.	34.
		60.0	1335.	.00289	13.	22.
		55.0	3541.	.000664	6.	7.5
		50.0	7802.	.000194	5.	6.
		45.0	14356.	.00013	5.	6.
W-24	800	110.0	8.	-	16.	56.
		106.0	3068.	.00017	4.	6.
		103.0	9299.	.00026	2.	7.5
		95.0	16946.	.00005	3.	11.6
		90.0	18341.	.00006	3.	8.
	850	90.0	2794.	.00047	4.	14.6
		85.0	4163.	.00042	3.	12.4
		80.0	8263.	.00007	4.	10.1
	900	65.0	2650.	.00038	3.	11.1
		60.0	2862.	.00034	3.	11.9
		55.0	4001.	.00019	4.	21.
		50.0	6764.	.00056	5.	6.
W-25	800	80.0	397.	.00807	14.	57.
		80.0	1014.	.00472	19.	62.
		75.0	4830.	.000460	17.	63.
		70.0	7899.	.000038	14.	56.
		65.0	>15312.	-	-	-
	850	84.0	12.	-	15.	60.
		75.0	181.	-	26.	62.
		67.0	1273.	.00208	17.	61.
		50.0	>8136.	-	-	-
	900	75.0	19.	-	17.	56.
		65.0	174.	-	18.	66.
		55.0	1730.	.00231	11.	35.
		55.0	2697	.00117	12.	46.
		45.0	>9096.	-	-	-

Table V

Ratio of Elevated Temperature Yield and Tensile Strength to Strengths at Room Temperature*

Yield Strength Ratio

Temp. °F	Ann.	NT TS>75 ksi	QT TS<115 ksi	QT TS>115 ksi	QT All data	Castings All data	All data except Ann
75	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	.980	.978	.990	.985	.987	.980	.982
200	.926	.917	.965	.957	.960	.924	.935
300	.902	.870	.941	.934	.937	.895	.902
400	.895	.850	.920	.917	.918	.877	.881
500	.899	.826	.900	.903	.902	.861	.866
600	.905	.810	.877	.887	.885	.843	.852
700	.905	.790	.851	.866	.864	.823	.832
800	.891	.762	.821	.835	.835	.796	.803
900	.856	.722	.785	.790	.795	.757	.757
1000	.790	.660	.740	.729	.741	.691	.689
1100	.688	.577	-	-	-	.575	.594
1200	.540	-	-	-	-	.371	.467
1300	.338	-	-	-	-	-	-

Tensile Strength Ratio

Temp. °F	Ann.	NT TS>75 ksi	QT TS<115 ksi	QT TS>115 ksi	QT All data	Castings All data	All data except Ann
75	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	.980	.980	.985	.988	.986	.980	.985
200	.920	.921	.949	.958	.953	.941	.935
300	.882	.889	.923	.938	.930	.899	.908
400	.882	.875	.905	.925	.912	.877	.896
500	.915	.870	.891	.914	.905	.873	.889
600	.962	.864	.876	.901	.892	.873	.881
700	1.000	.851	.855	.881	.874	.860	.865
800	1.001	.820	.825	.850	.844	.817	.832
900	.947	.764	.779	.802	.798	.737	.774
1000	.828	.673	.715	.734	.731	.625	.685
1100	.653	.539	-	-	-	.503	.556
1200	.454	-	-	-	-	.423	.380
1300	.293	-	-	-	-	-	-

*Ann. - Annealed; NT-normalized and tempered; QT-quenched and tempered.
Note: Ann - includes NT data for lots in which TS<75 ksi.

Table VI

Summary of 10,000-Hour Rupture Strengths (ksi)

	Temperature °F								
Code No.	800	850	900	950	1000	1050	1100	1150	1200
PART A - Annealed									
Pipe-Tube									
T-1					16.8		9.7		4.5
T-3					16.7		11.0		
T-7					16.1		11.1		
T-8					16.4	12.3	7.9		
T-9					14.5	10.9	8.4		
T-10					16.7	13.0	10.3		
T-11					18.1		10.3		
T-13a					15.0		10.4		
T-13b							11.2		
T-13c							12.0		
T-14					17.0		11.0		4.4
T-15					15.2		9.8		4.6
T-16					14.9		8.6		4.4
T-17					18.6		11.2		4.2
T-18					14.0		8.9		4.2
T-19							9.3		
T-20							10.8		
T-21							10.0		
T-22a							7.7		
T-22b							11.0		
T-22c							10.2		
T-22d							10.1		
T-23					14.0		8.1		3.7
T-24a					14.9		8.9		
T-24b					16.1		9.7		
T-25					16.2		10.8		
T-26					15.5				
T-33							10.6		
T-44					20.0		10.8		
T-46						12.2			
T-48						14.1	10.2		
T-49						10.1	8.0		
T-50						12.0	9.0		
T-51						11.4	8.6		
T-52						12.0	9.1		
T-54						10.0	7.8		
T-56						11.3	8.8		
T-58						10.5	8.9		
T-109				21.2	17.1	13.9			

Table VI - Cont.

Code No.	Temperature °F 800	850	900	950	1000	1050	1100	1150	1200
Bar									
B-2			37.0			16.9			4.0
B-5a						16.1			
B-5b						16.2			
B-6							8.8		
Castings									
C-1						9.8			
C-2					19.0				
C-3					14.0		8.2		
C-14				21.0	15.9		9.7	7.3	
C-15				20.9	16.7		9.7	8.0	
PART B - Normalized and Tempered or Quenched and Tempered									
T-2				39.5			11.5		
P-8a	54.0		39.0		29.0				
P-8b	83.0		52.0						
P-12		41.0	35.0						
P-15a		61.0	49.0						
P-15b			52.0						
P-15c			53.0		29.0		15.8		
P-15d			43.0		30.0				
P-15e		40.0	35.0						
P-21	74.0	59.0	50.0						
P-23	113.0	85.0							
P-24a	120.0								
P-24b	88.0	67.0							
P-33			48.0						
P-40	74.0		51.0		29.0				
P-41	66.0		48.0		28.0				
P-42	47.0		33.0		24.0				
P-45	55.0								
P-52b		57.0	47.0						
P-52c		43.0	37.0						
PART C - Weld Metal									
W-5							5.9		
W-9					19.0		12.0		
W-12a					16.0				
W-12b					15.2				
W-12c					15.8				
W-14							7.7		
W-15							10.8	7.1	3.4
W-16		56.0	48.0						
W-21		73.0	45.0						
W-22	76.0	59.0	47.0						
W-23	74.0	61.0	47.0						
W-24	97.0	77.0	46.0						
W-25	68.0	60.0	50.0						

Table VII

Summary of Creep Strengths (0.1% per 1000 hours) ksi

Code No.	800	850	900	950	1000	1050	1100	1150	1200
					Temperature °F				
PART A - Annealed									
Pipe-Tube									
T-1			36.0		16.0		10.8		
T-3					12.5		9.5		
T-4a						11.0	7.8		
T-4b					13.5		8.7		
T-5						11.4	8.4		3.1
T-6					15.8	13.7	9.3		
T-18					10.2		6.0		3.2
T-22c							10.1		
T-24a					13.9		7.1		
T-24b					12.2		9.1		
Bar									
B-3					12.6		5.6		
B-5a						14.4			
Castings									
C-1						9.0	8.0		
C-2					12.0		8.8		
C-3							6.1		
C-4					14.0		6.3		
C-5					9.6		6.0		
C-6					9.8				
C-7					16.5				
PART B - Normalized and Tempered or Quenched and Tempered									
T-2				33.0		8.9			
P-12		39.0	34.0						
P-15a		63.0		37.0					
P-15b			45.0						
P-15c			45.0		27.0		11.0		
P-15d			33.0		27.0				
P-15e		42.0	30.0						
P-21	65.0	55.0	41.0						
P-23	114.0	88.0							
P-24a	122.0								
P-24b	86.0	64.0							
P-40	76.0		52.0		26.0				
P-41	63.0		44.0		26.5				
P-42	45.0		28.0						

Table VII - Cont.

Temperature °F

Code No.	800	850	900	950	1000	1050	1100	1150	1200
W-9					10.0		7.0		
W-10						10.4			
W-11						12.5			
W-16		51.0							
W-21		83.0							
W-22	75.0	57.0	41.0						
W-23	69.0		46.0						
W-24	99.0	81.0	47.0						
W-25	71.0								

Table VIII

Summary of 100,000-Hours Rupture Strengths (ksi)

Code No.	Temperature °F 800	850	900	950	1000	1050	1100	1150	1200
Part A - Annealed									
Pipe Tube									
T-1					13.4		6.8		2.8
T-3					12.5				
T-7					12.4				
T-8					11.8	8.7	4.9		
T-9					11.0	8.1	6.0		
T-10						9.2	7.5		
T-11					13.9		7.6		
T-13a					11.1		8.1		
T-13b							8.4		
T-13c							9.2		
T-14					13.1		8.0		2.1
T-15					11.0		7.4		2.5
T-16					12.0		6.4		2.7
T-17					13.3		8.7		2.1
T-18					10.0		6.5		2.4
T-19							6.0		
T-20							7.9		
T-21							5.2		
T-22a							5.3		
T-22b							7.7		
T-22c							5.8		
T-22d							7.3		
T-23					10.1		5.7		1.9
T-24a					9.6		5.6		
T-24b					11.7		7.1		
T-25					12.8		8.2		
T-26					12.2				
T-33							9.1		
T-44					12.0		6.8		
T-46						9.1			
T-48						10.1	7.2		
T-49						7.0	5.8		
T-50						8.1	6.1		
T-51						7.5	5.6		
T-52						7.9	6.0		
T-54						5.9	4.8		
T-56						6.8	5.9		
T-58						5.5	5.7		
T-109				16.0	13.0	10.4			
Bar									
B-2			31.0*			11.7			2.1
B-5a						10.0			
B-5b						11.3			
B-6							5.3		

*Longest test less than 1000 hours.

Table VIII - Cont.

Code No.	800	850	900	950	1000	1050	1100	1150	1200
					Temperature °F				
Castings									
C-1						6.1			
C-2					14.1				
C-3					9.8		5.6		
C-14				16.0					
C-15									
PART B - Normalized and Tempered or Quenched and Tempered									
T-2				34.0			7.4		
P-8a	50.0		33.0		24.0				
P-8b	78.0		40.0						
P-12		35.0	31.0						
P-15a		55.0							
P-15b			44.0						
P-15c			46.0		20.0		10.2		
P-15d			37.0		24.0				
P-15e		31.5	27.5						
P-21	65.0	49.0	41.0						
P-23	100.0	68.0							
P-24a	110.0								
P-24b	78.0	50.0							
P-40	67.0		39.0		20.0				
P-41	57.0		40.0		20.5				
P-42	40.0		26.5		20.0				
P-45	50.0								
P-52b		48.0	37.5						
P-52c		35.0	30.5						
PART C - Weld Metal									
W-5							3.3		
W-12A					12.0				
W-12b					11.4				
W-14							4.6		
W-15							6.7	4.0	1.42
W-16		50.0	41.0						
W-21		56.0	28.0						
W-22	70.0	45.0	36.0						
W-23	66.0	52.0	33.0						
W-24	80.0	59.0							
W-25	54.0		41.0						

Table IX

Summary of Creep Strengths (0.01% per 1000 hours)-ksi

Code No.	Temperature °F 800	850	900	950	1000	1050	1100	1150	1200
PART A - Annealed									
Pipe and Tube									
T-1			22.0		8.0		5.4		2.5
T-3					7.2		5.5		
T-4a						7.8	4.6		
T-4b					8.4		5.7		
T-5						8.0	6.5		
T-6					10.5	8.8	5.0		
T-12a					7.5		5.0		
T-12b					8.2		5.2		
T-18					7.2		3.5		
T-27					7.7				
Bar									
B-3					—				
Castings									
C-1						6.1	4.6		
C-2					7.1		5.7		
C-3							4.1		
C-4					7.9				
C-6					6.0				
C-7					10.1				2.9
PART B - Normalized and Tempered or Quenched and Tempered									
T-2						3.8			
P-15a				30.0					
P-15c			37.5		21.0				
P-15d			26.0						
P-21	54.0	41.0							
P-23	105.0	68.0							
P-24a	118.0								
P-24b	79.0	44.0							
P-40	72.0		40.0		19.0				
P-41	54.0		38.0		18.0				

Table IX - Cont.

Code No.	800	850	900	950	1000	1050	1100	1150	1200
					Temperature °F				
PART C - Weld Metal									
W-9					6.4		3.2		
W-10						6.6			
W-11						7.7			
W-21		76.0							
W-22	69.0	45.0	30.5						
W-23			37.0						
W-24	81.0	71.0							
W-25	66.0								

Table X a

Summary - Stress for Rupture in 10,000 Hours (ksi)
Annealed Material

Temp. °F	Average: Arith. Mean of Indiv. Extrap.	Average: Linear Ext. of Isotherm. Regress. Line	Average: Strength-Temp. Regress. Individ. Extrap.	Parameter Scatter Band: Larson-Miller (C=20)	Parameter Scatter Band: Manson Compromise
900				27.3	28.4
950				21.7	21.8
1000	16.2	16.19	16.33	16.8	16.5
1050	12.42	12.0	12.12	12.8	12.4
1100	9.71	9.9	9.47	9.6	9.3
1150		(7.8)	7.55	7.0	6.9
1200	4.25	4.58*	4.18	5.1	5.15

*Isothermal may be better viewed as quadratic; if so, strength is 4.2 ksi
( ) value not well established.

Minimum - 90% Confidence

Temp. °F	Arith. Mean of Indiv. Extrap.	Linear Ext. of Isotherm. Regress. Line	Strength-Temp. Regress. Individ. Extrap.	Larson-Miller (C=20)	Manson Compromise
900				21.6	22.7
950				17.0	17.3
1000	13.52		13.12	13.1	13.1
1050	8.67		9.92	10.0	9.8
1100	7.80		7.75	7.5	7.3
1150			6.18	5.5	5.4
1200	3.77		3.42	4.0	4.05

Table X b

Average Stress for Rupture in 10,000 Hours (ksi)
Normalized and Tempered or Quenched and Tempered Material
(Adjusted to selected levels of specified minimum tensile strength)

Temp. °F	Specified Minimum Tensile Strength (ksi): 95	105	115
800	53.0	64.5	76.0
850	44.5	52.0	59.5
900	38.0	43.5	48.5
1000	27.0	28.0	29.0

Table XI a

Stress for Rupture in 100,000 Hours (ksi)
Annealed Material

Average

Temp. °F	Arith. Mean of Indiv. Extrap.	Linear Ext. of Isotherm. Regress. Line	Strength-Temp. Regress. Individ. Extrap.	Parameter Scatter Band Larson-Miller (C=20)	Parameter Scatter Band Manson Compromise
900				21.0	20.8
950				16.1	15.4
1000	11.89	12.1	11.82	12.2	11.2
1050	8.31	7.67	8.12	8.9	8.1
1100	6.77	7.36	6.66	6.4	5.85
1150	-	(5.5)	4.84		
1200	2.32	2.7*	2.31		

*Isothermal may be better viewed as quadratic; if so, strength is 1.85 ksi
( ) Value not well established.

Minimum - 90% Confidence

Temp. °F	Arith. Mean of Indiv. Extrap.	Linear Ext. of Isotherm. Regress. Line	Strength-Temp. Regress. Individ. Extrap.	Larson-Miller (C=20)	Manson Compromise
900				16.4	16.5
950				12.6	12.2
1000	9.65	-	8.87	9.4	8.8
1050	5.25	-	6.10	7.0	6.4
1100	4.76	-	5.00	5.0	4.6
1150			3.6		
1200	1.79	-	1.73		

Table XI b

Average Stress for Rupture in 100,000 Hours (ksi)
Normalized and Tempered or Quenched and Tempered Material
(Adusted to selected levels of specified minimum tensile strength)

Specified Minimum Tensile Strength (ksi)

Temp. °F	95	105	115
800	47.5	57.5	68.0
850	37.0	43.0	48.5
900	31.5	36.0	40.0
1000	22.0	21.5	21.0

Table XII

Summary of Average Creep Strengths (ksi)

PART A: Annealed Material

Temp. °F	0.1% per 1000 hrs.	0.01% per 1000 hrs.
1000	13.0	8.0
1050	10.1	6.4
1100	8.0	5.1
1150	5.0	3.6
1200	3.1	2.7

PART B: Normalized and Tempered or Quenched and Tempered Material - adjusted to selected levels of specified minimum tensile strength

0.1 per cent per 1000 hours

	Specified minimum tensile strength (ksi)		
Temp. °F	95	105	115
800	45.0	58.0	71.5
850	45.0	52.5	60.0
900	34.0	38.5	43.0
1000	27.0	27.0	26.5

0.01 per cent per 1000 hours

Temp. °F	95	105	115
800		40.5	57.5
850		-	38.0
900		29.0	35.5
1000		-	18.5

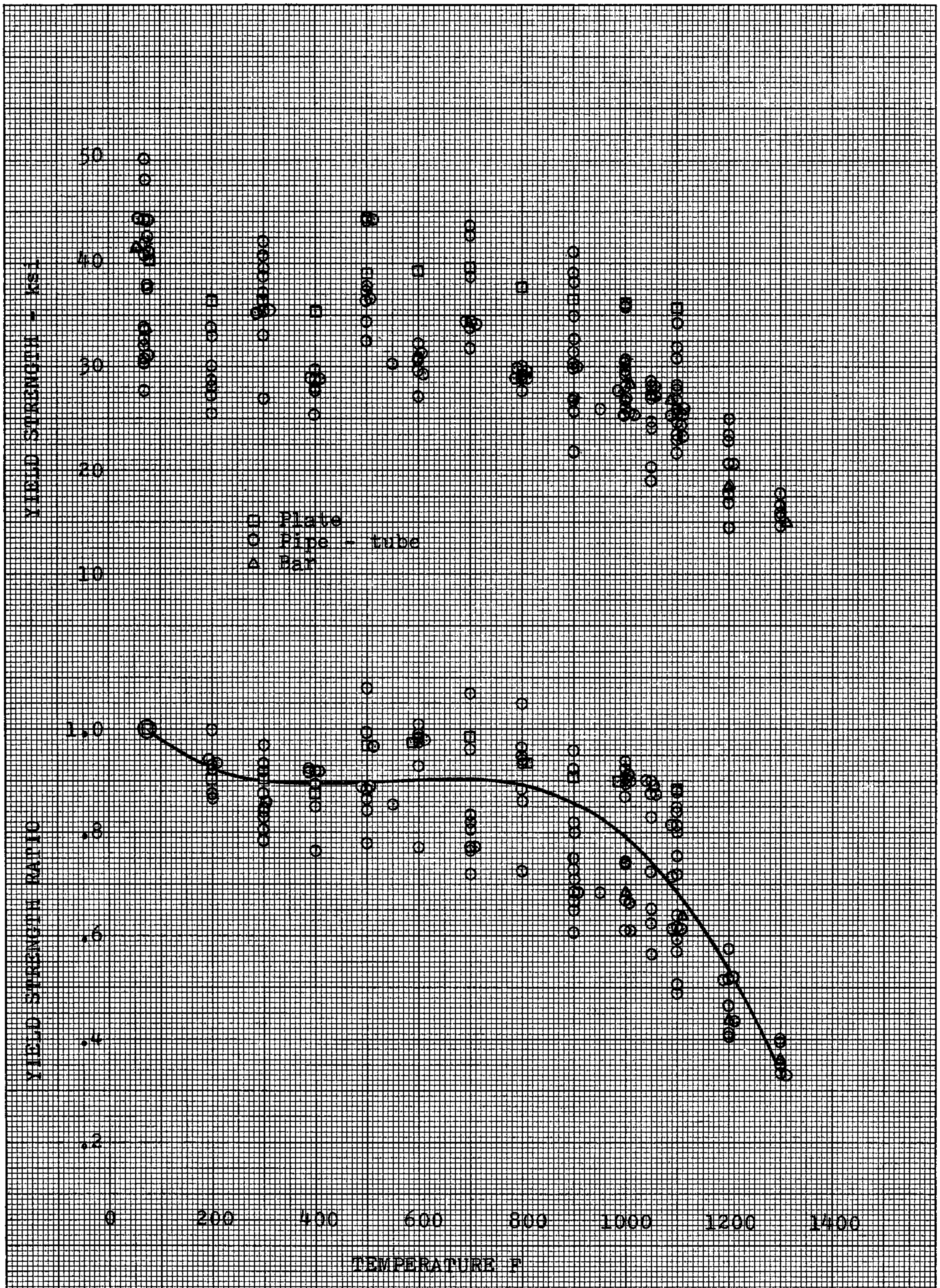

Fig. 7a Variation of yield strength of annealed material with temperature.

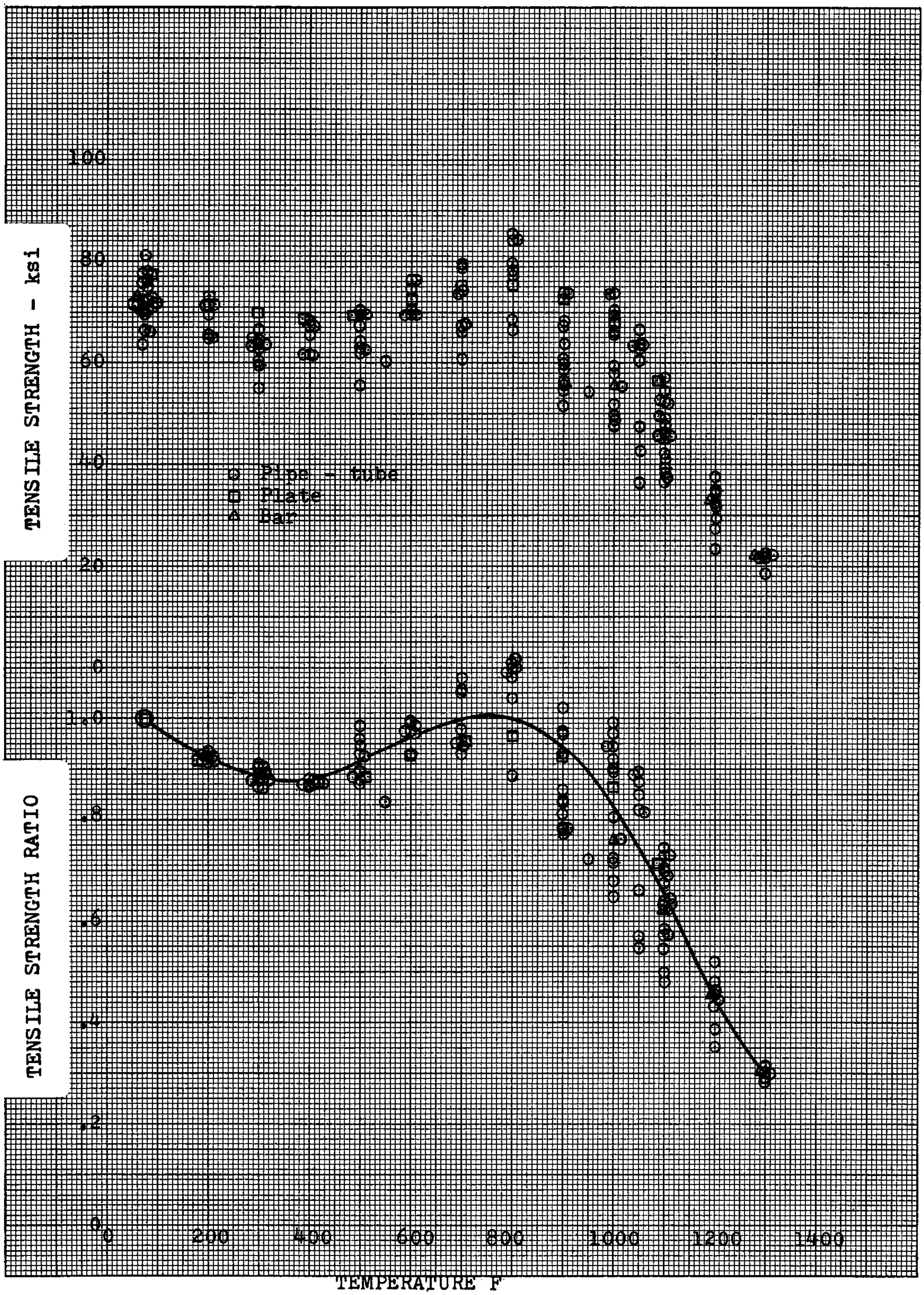

Fig. 7b - Variation of tensile strength of annealed material with temperature.

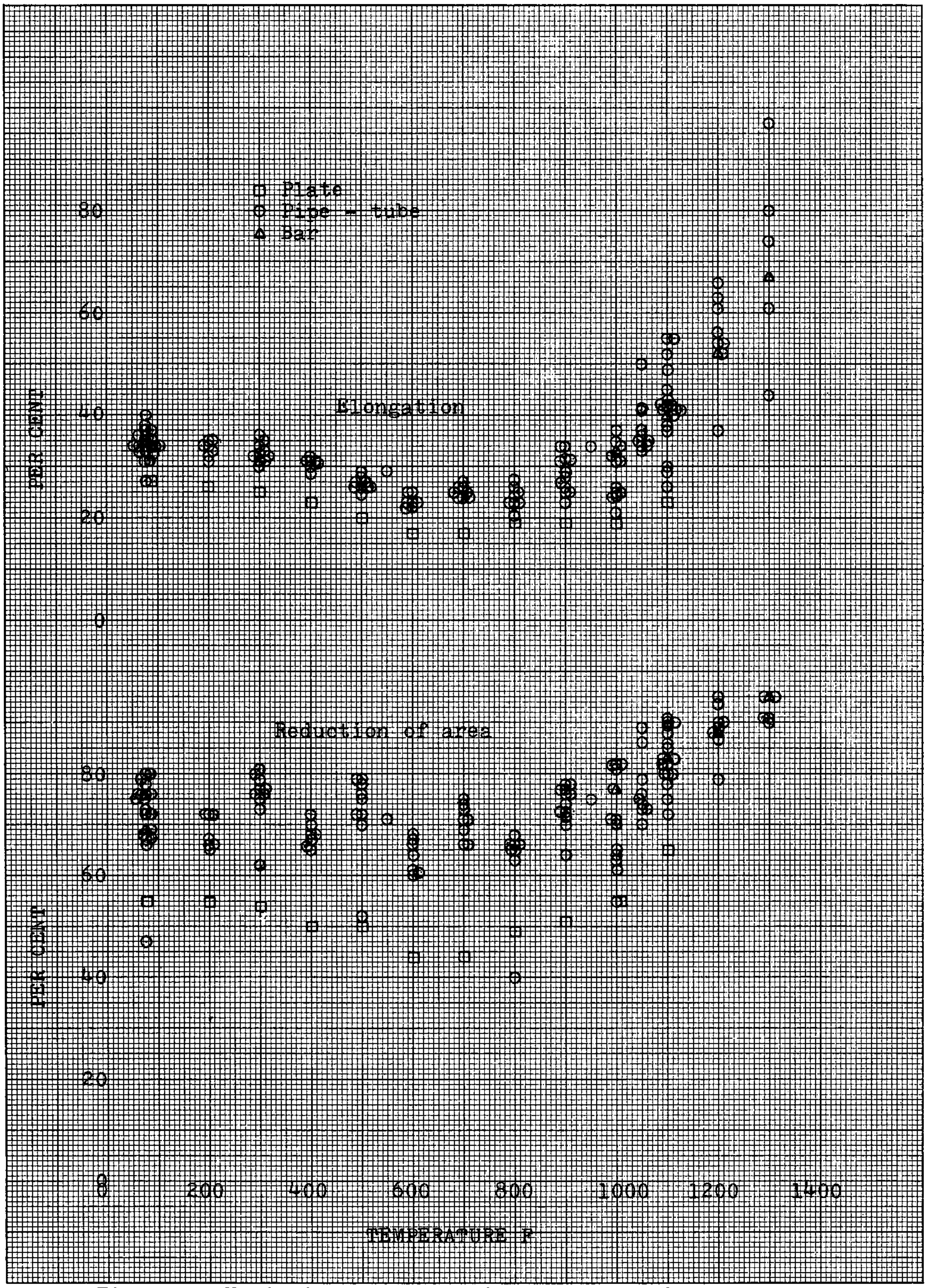

Fig. 7c - Variation of elongation and reduction of area of annealed material with temperature.

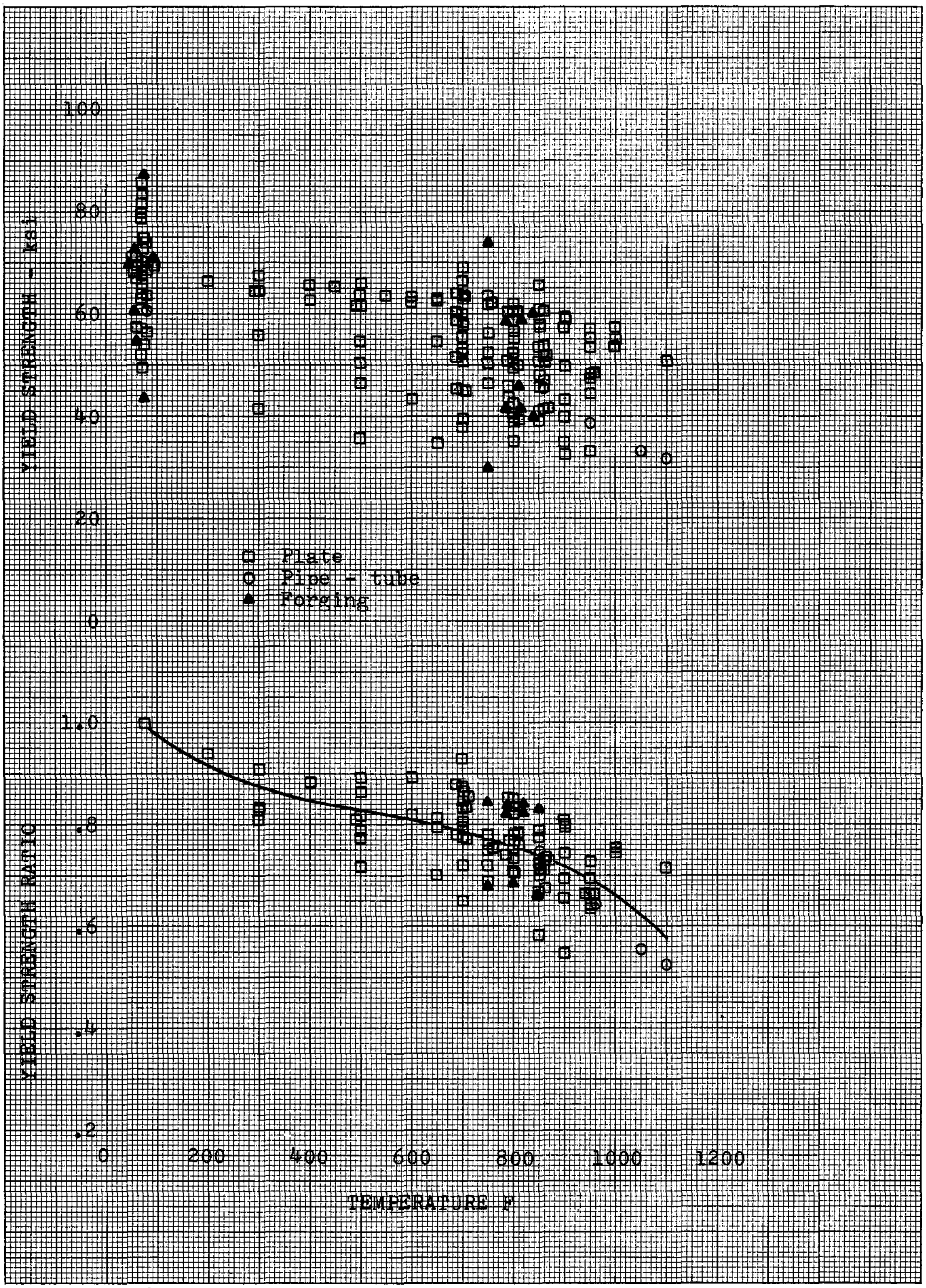

Fig. 8a - Variation of yield strength of normalized and tempered material with temperature.

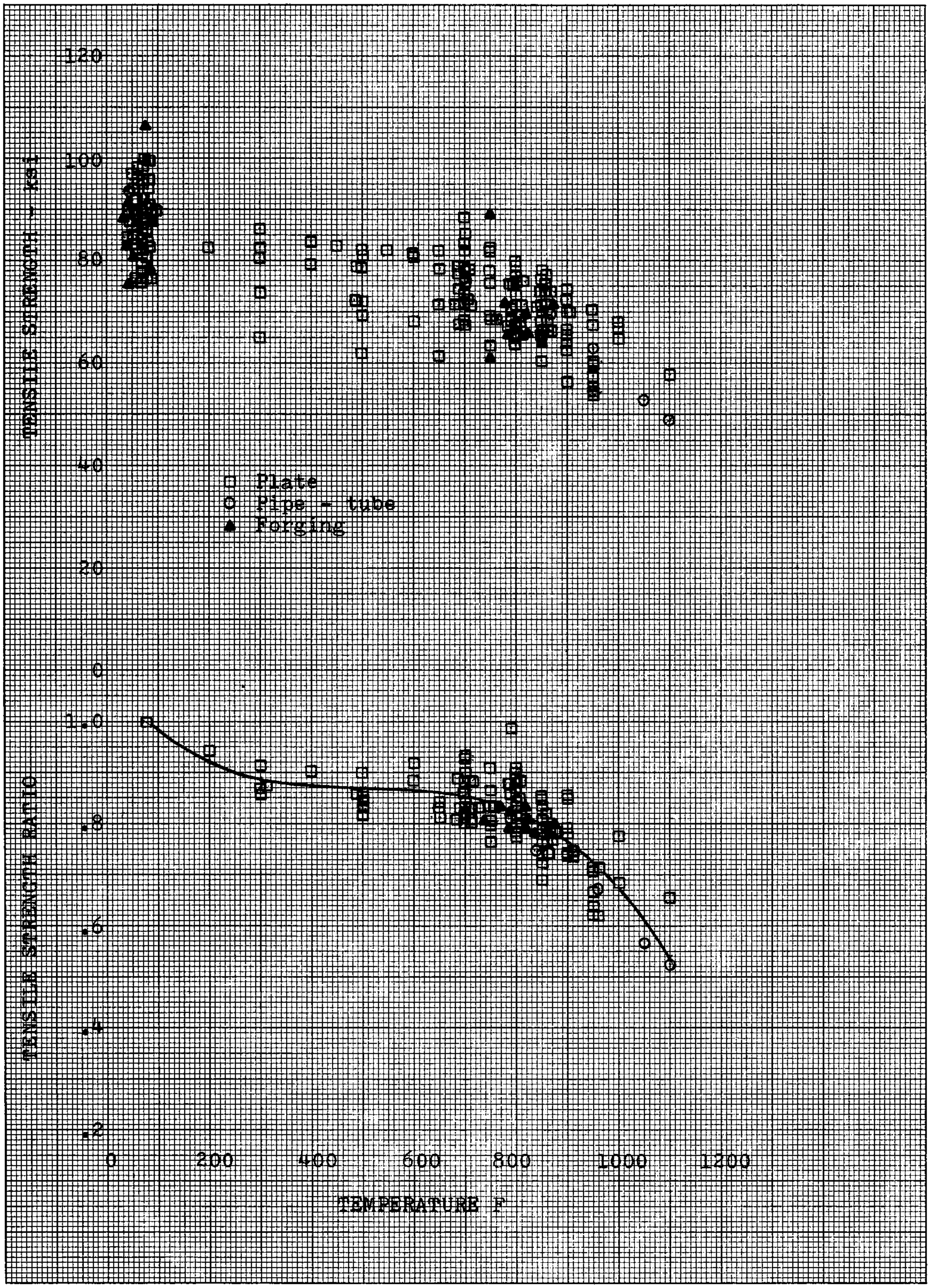

Fig. 8b - Variation of tensile strength of normalized and tempered material with temperature.

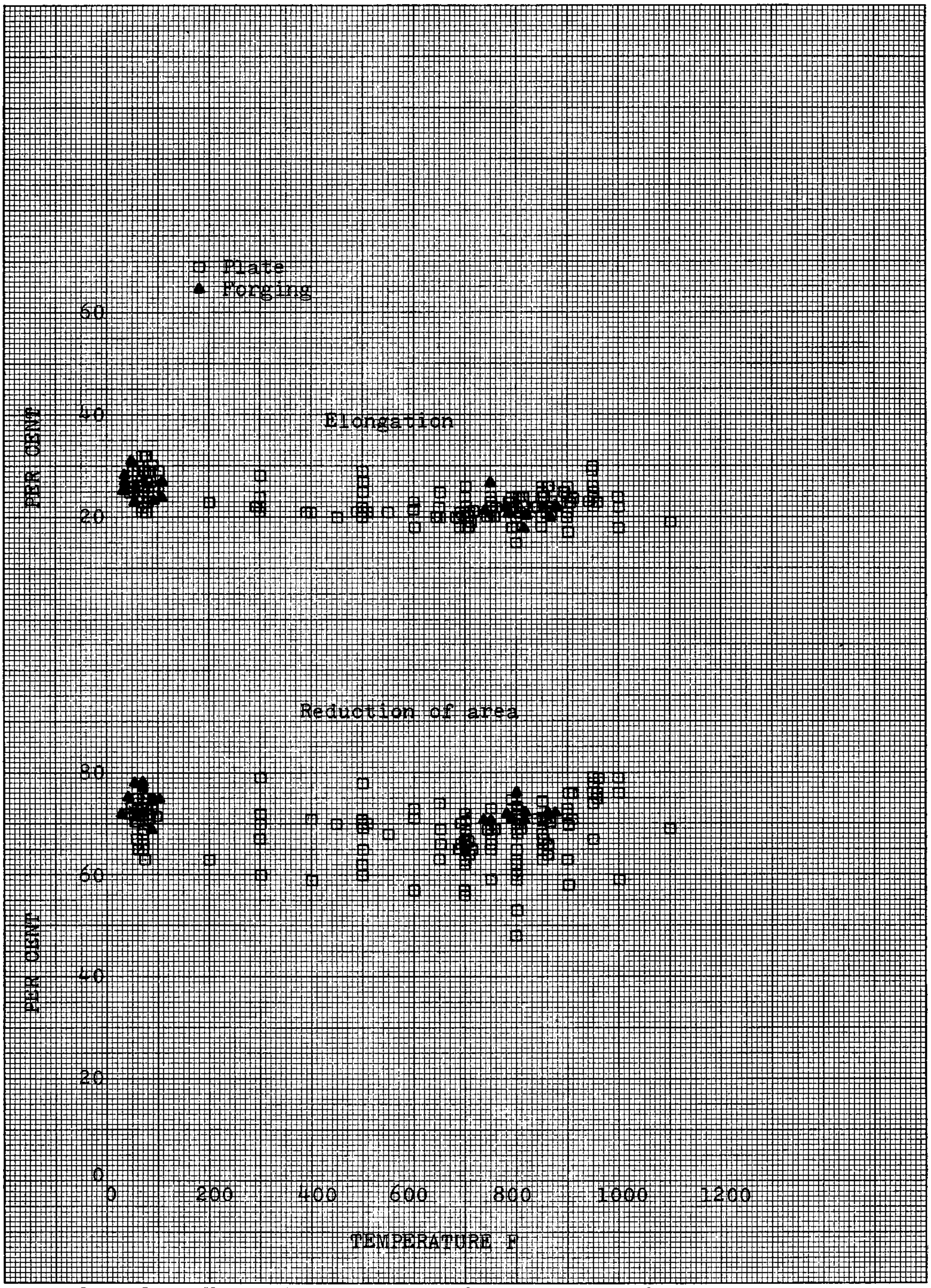

Fig. 8c - Variation of elongation and reduction of area of normalized and tempered material with temperature.

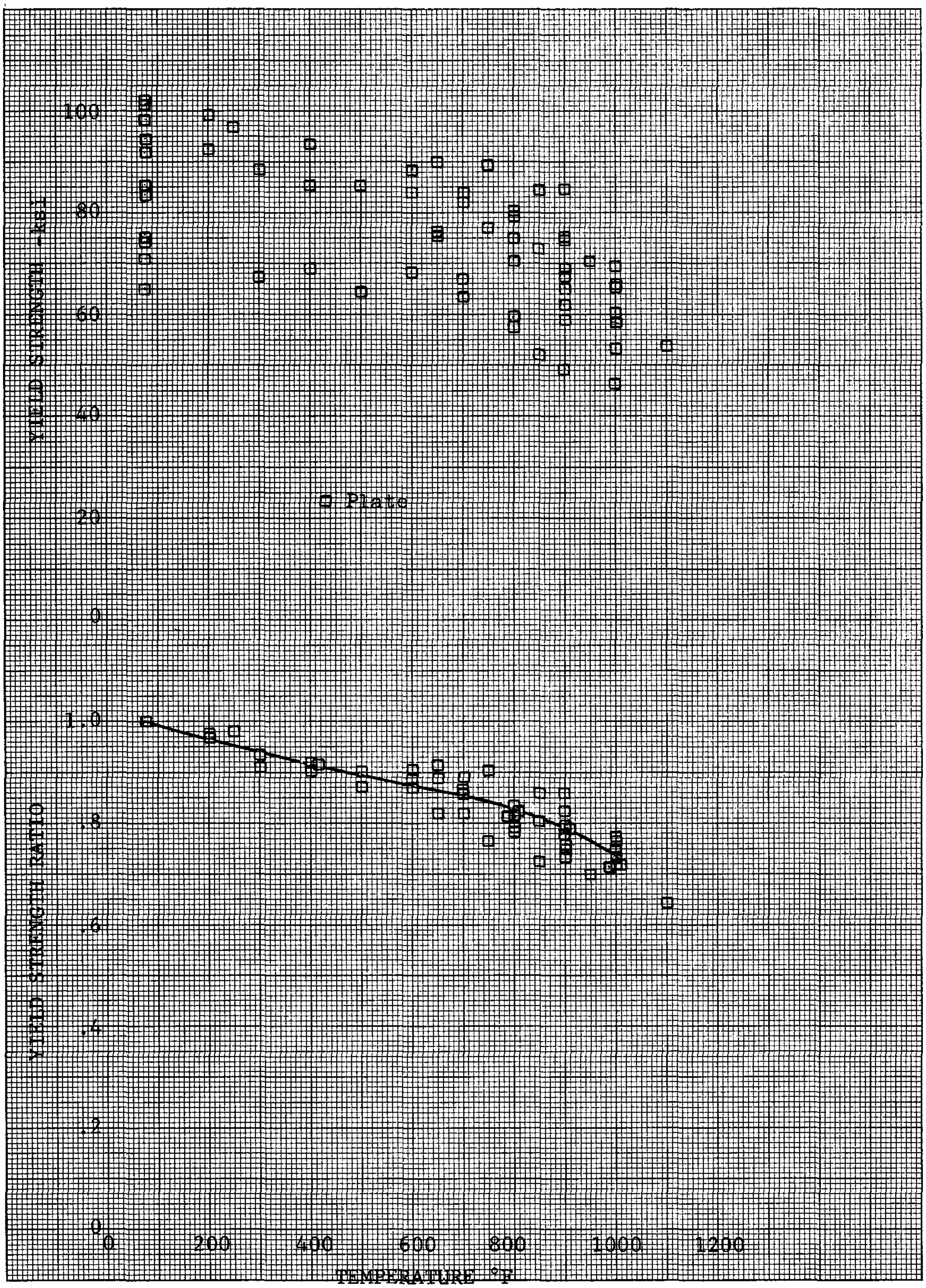

Fig. 9a - Variation of yield strength of quenched and tempered material (TS < 115 ksi) with temperature.

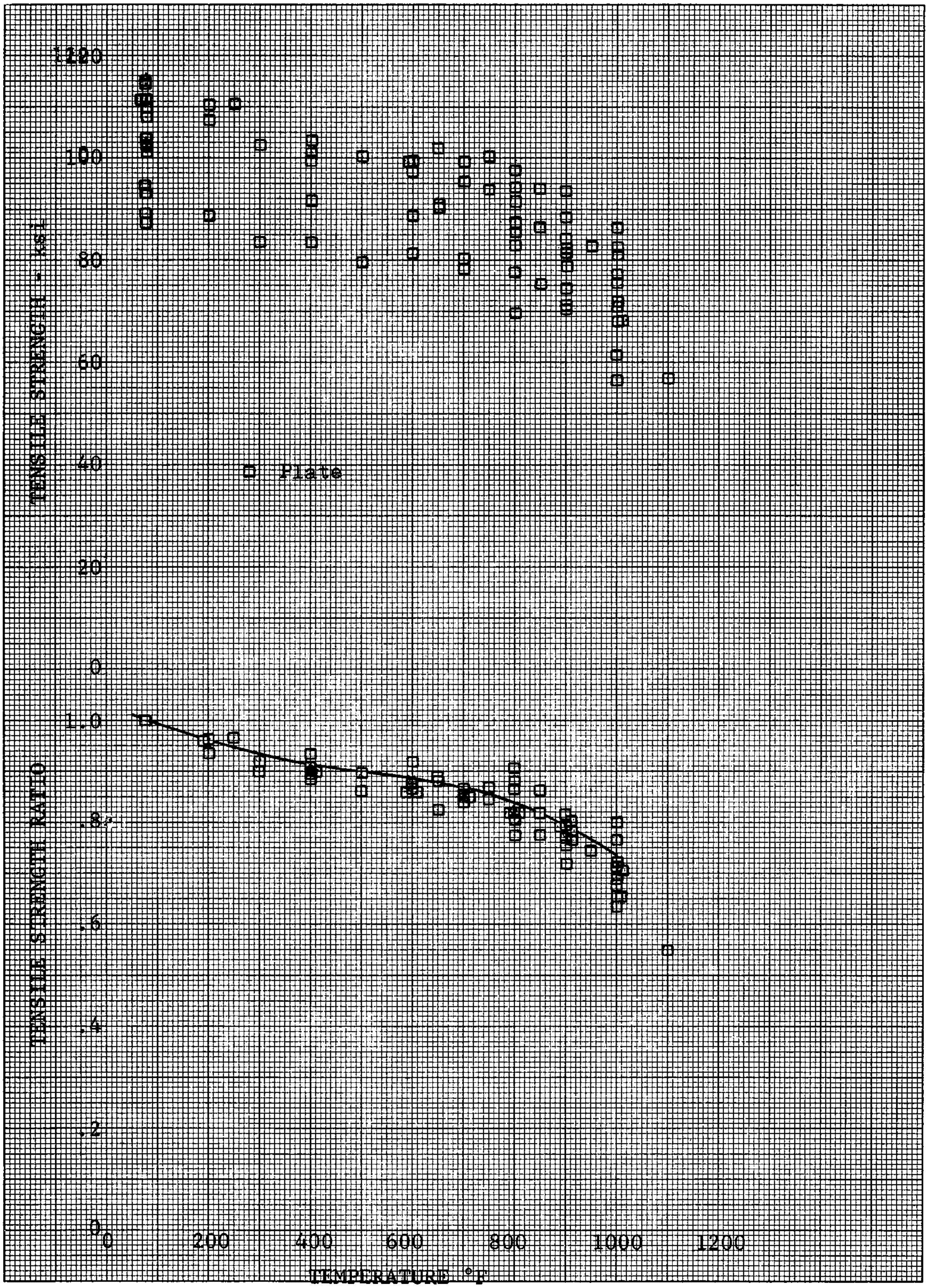

Fig. 9b - Variation of tensile strength of quenched and tempered material (TS < 115 ksi) with temperature.

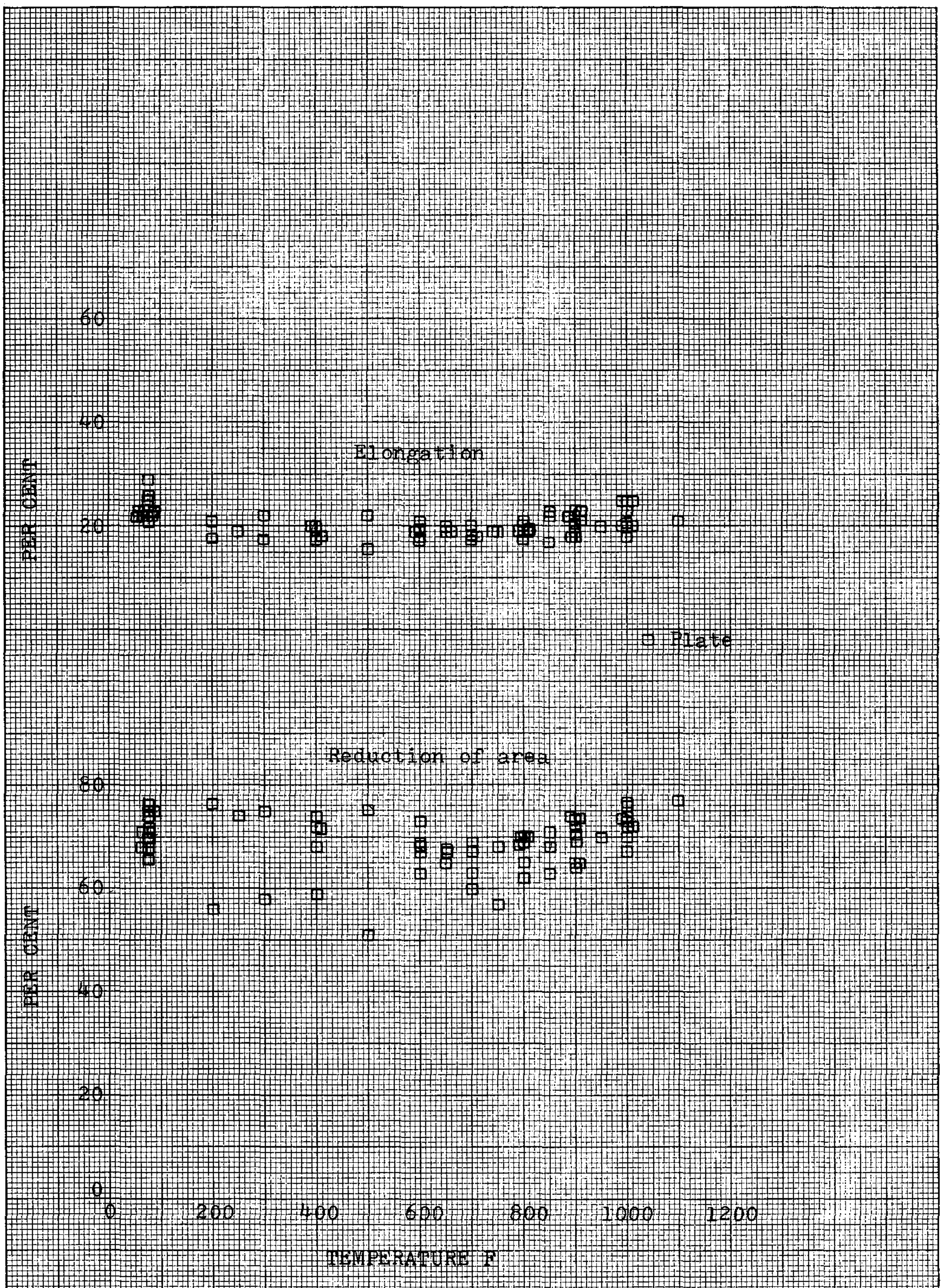

Fig. 9c - Variation of elongation and reduction of area of quenched and tempered material (TS< 115 ksi) with temperature.

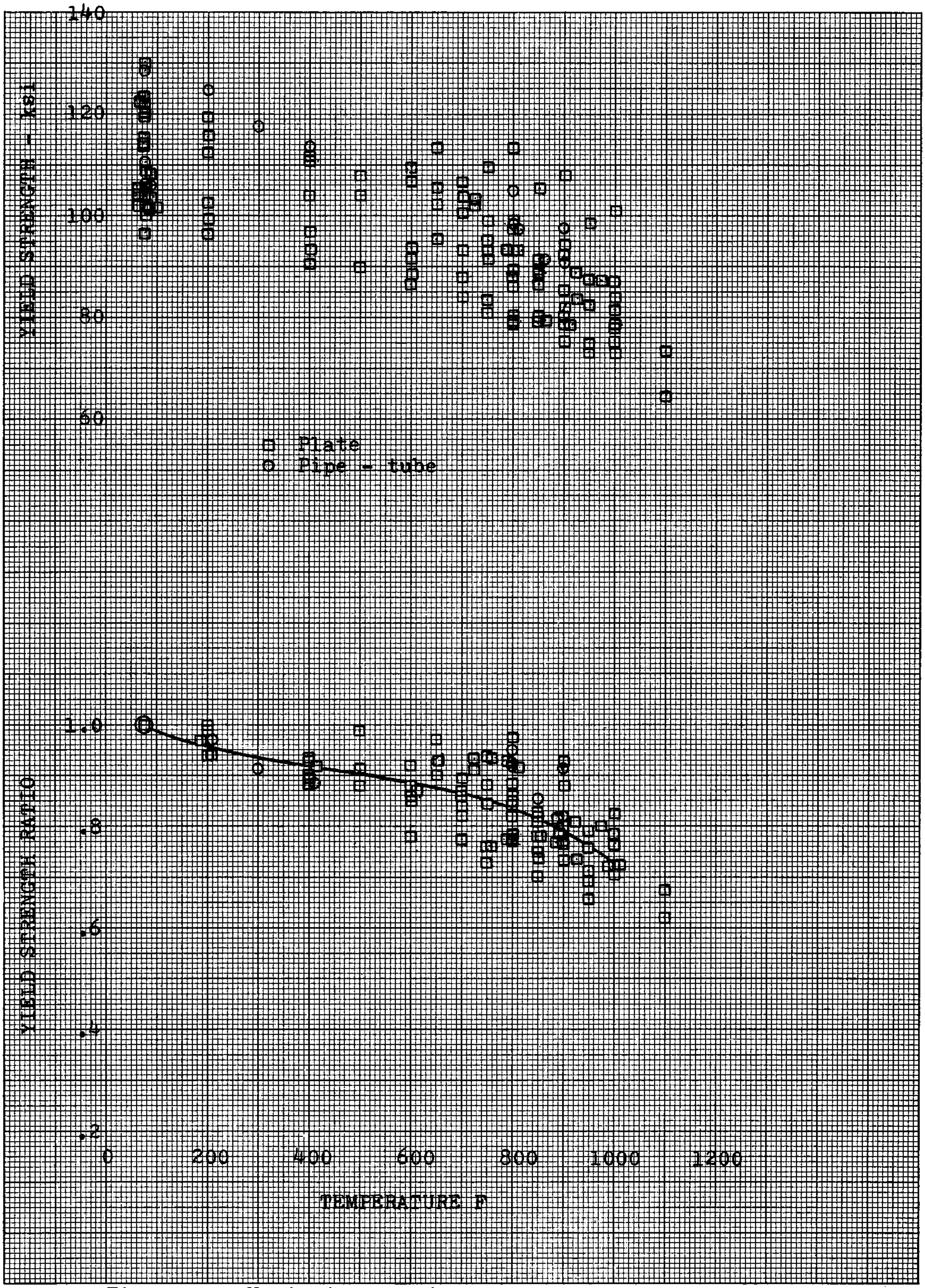

Fig. 10a - Variation of yield strength of quenched and tempered material (TS >115 ksi) with temperature.

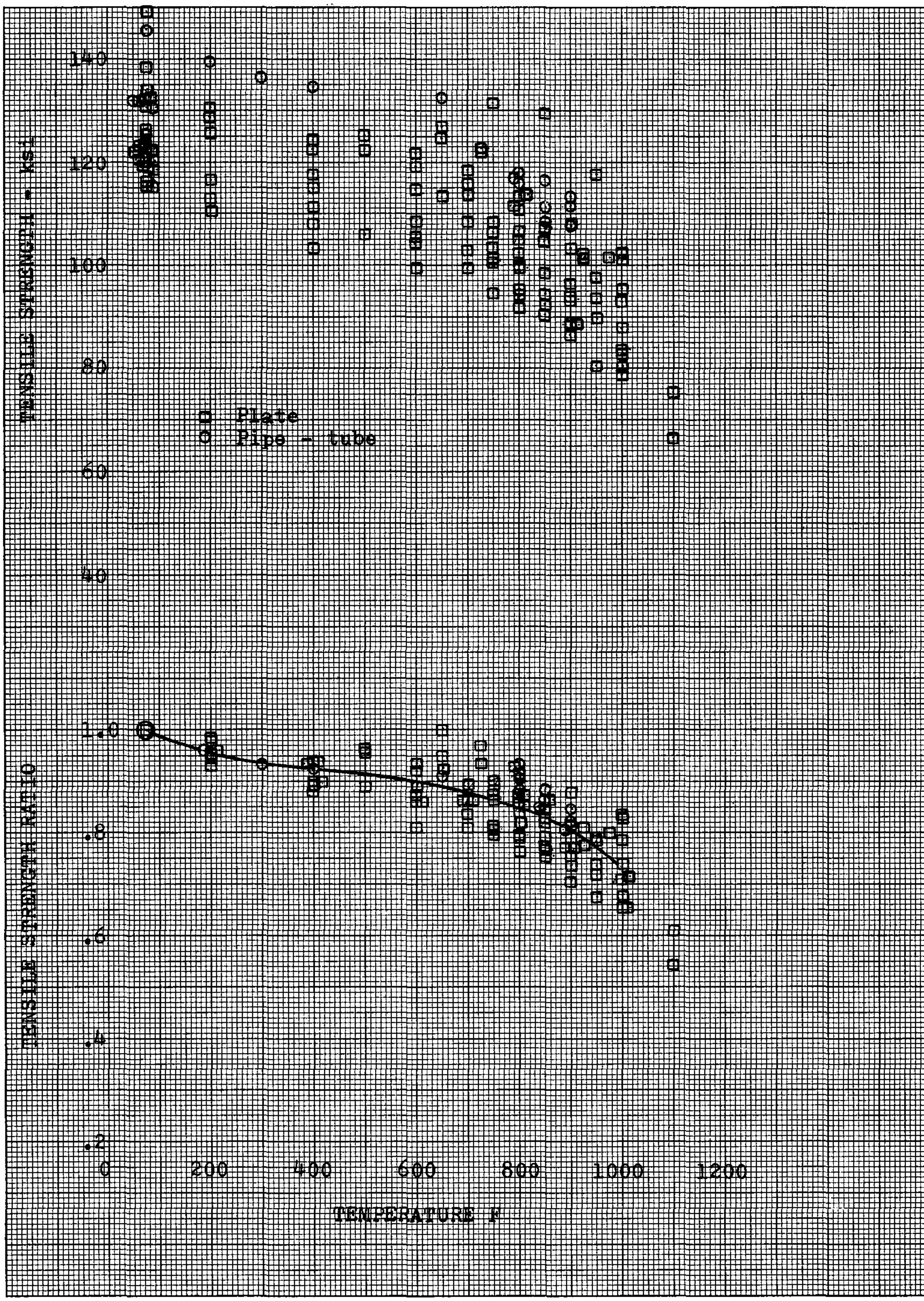

Fig 10b - Variation of tensile strength of quenched and tempered material (TS > 115 ksi) with temperature.

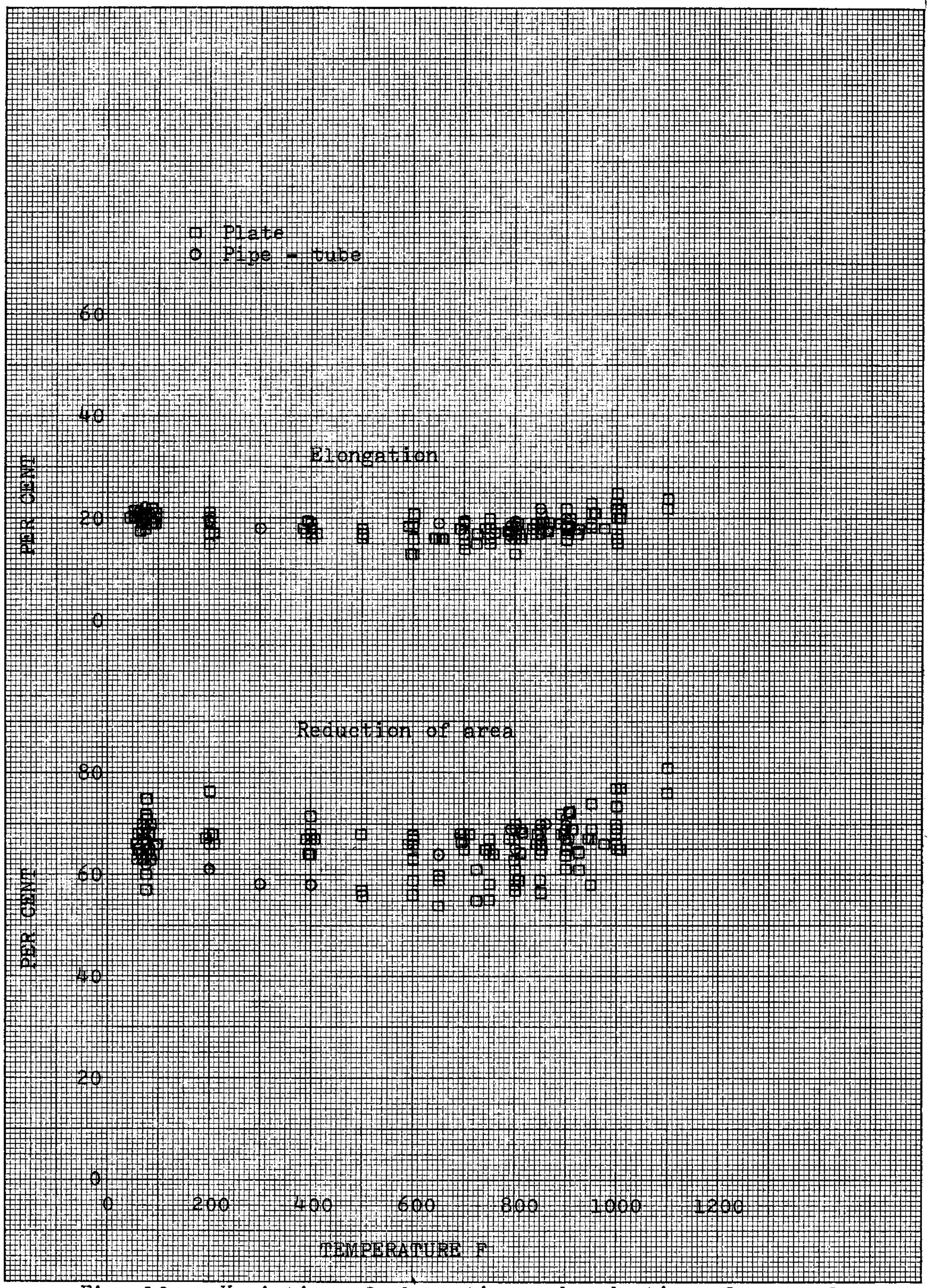

Fig. 10c - Variation of elongation and reduction of area of quenched and tempered material (TS > 115 ksi) with temperature.

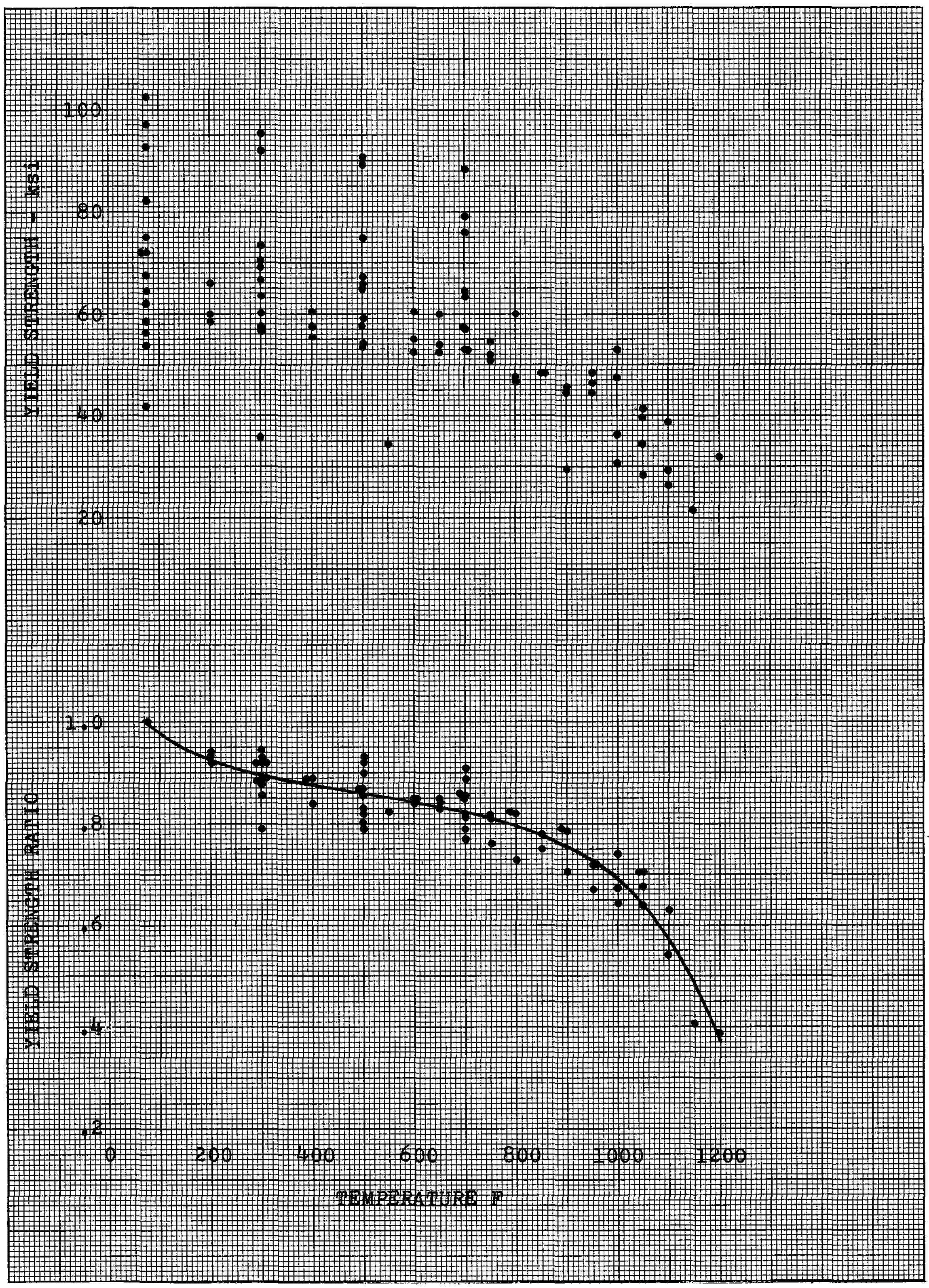

Fig. 11a - Variation of yield strength of normalized-and-tempered and quenched-and-tempered cast material with temperature.

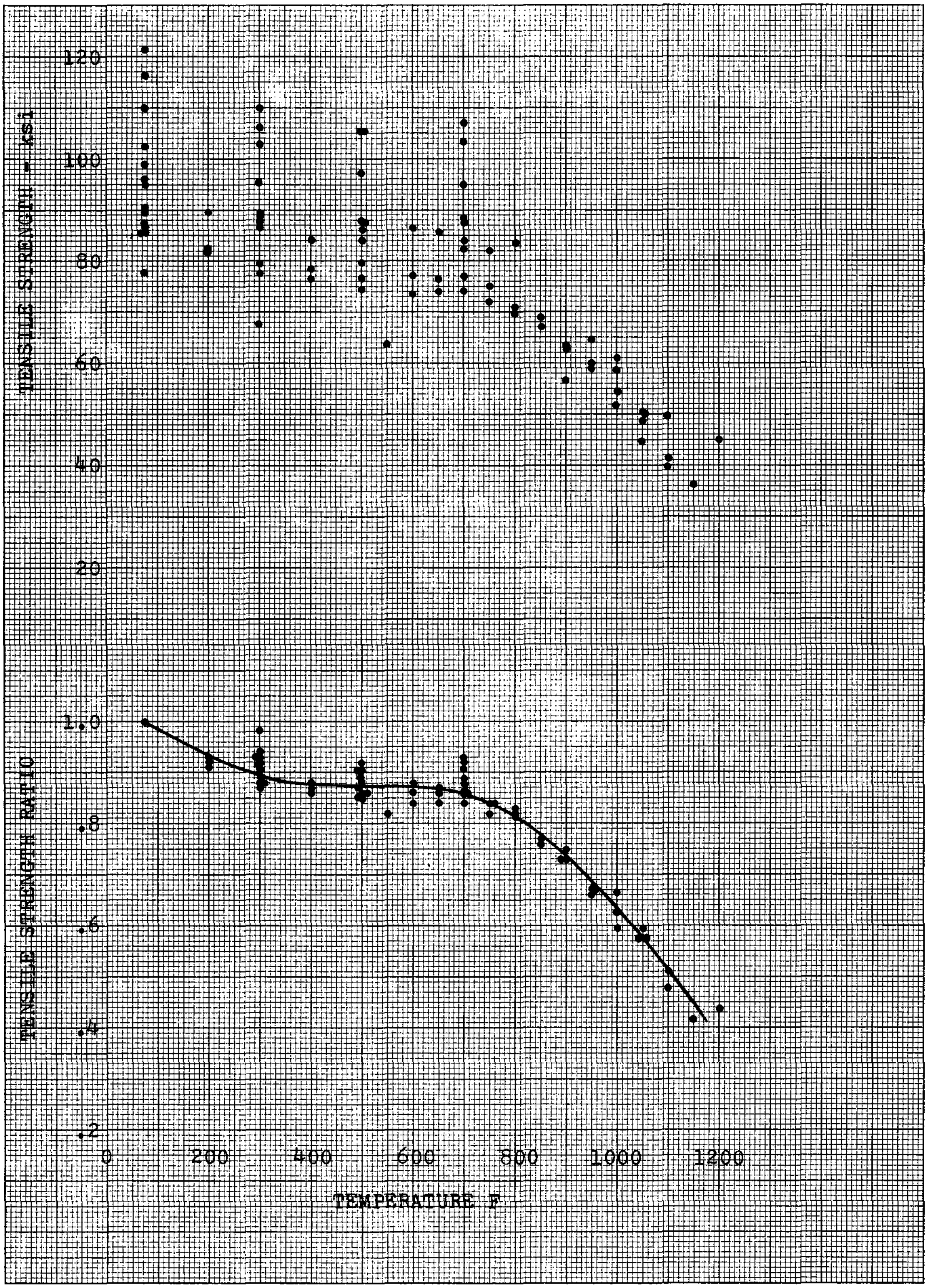

Fig. 11b - Variation of tensile strength of normalized-and-tempered and quenched-and-tempered cast material with temperature.

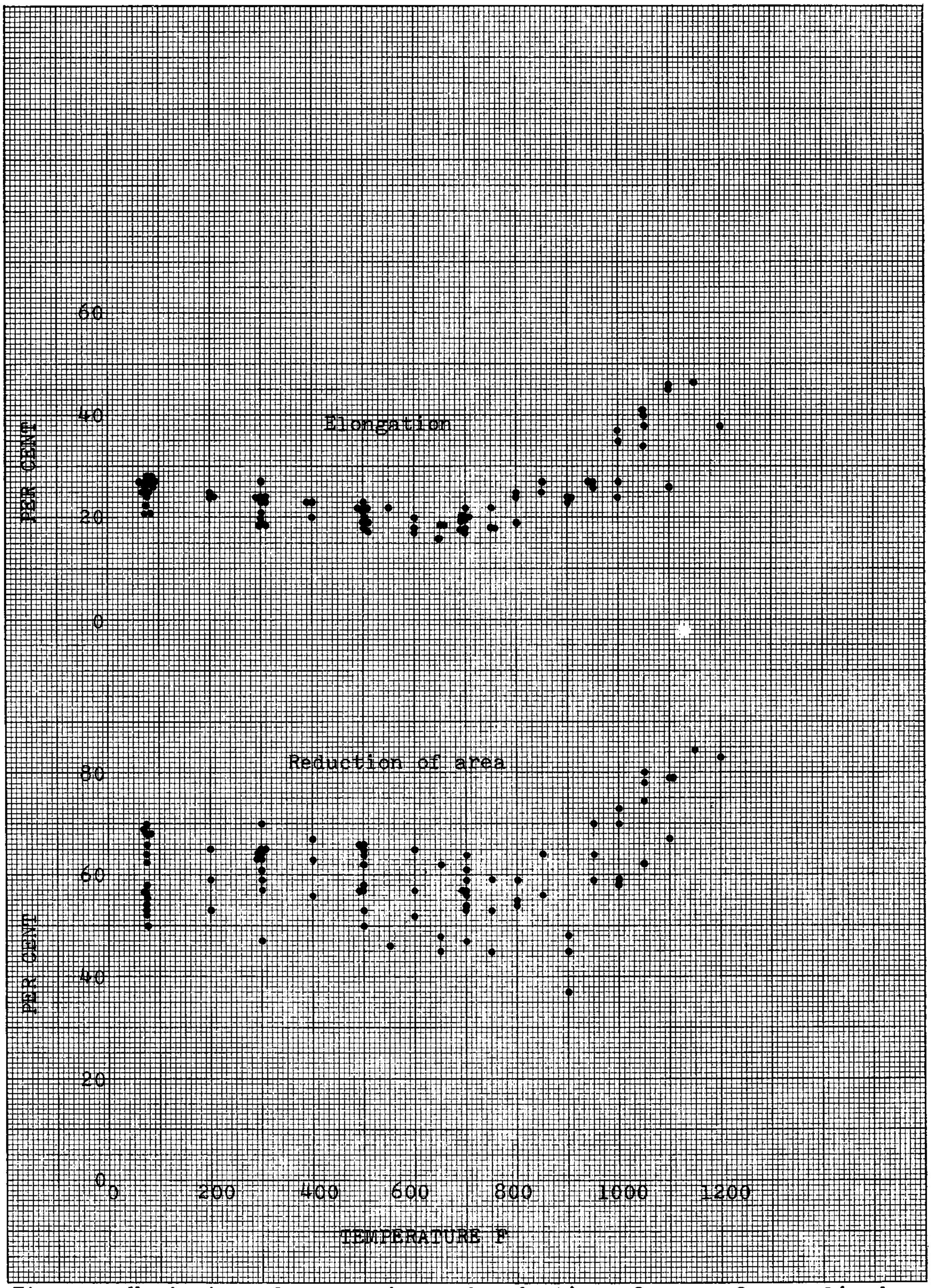

Fig. 11c Variation of elongation and reduction of area of normalized-and-tempered and quenched-and-tempered cast material with temperature.

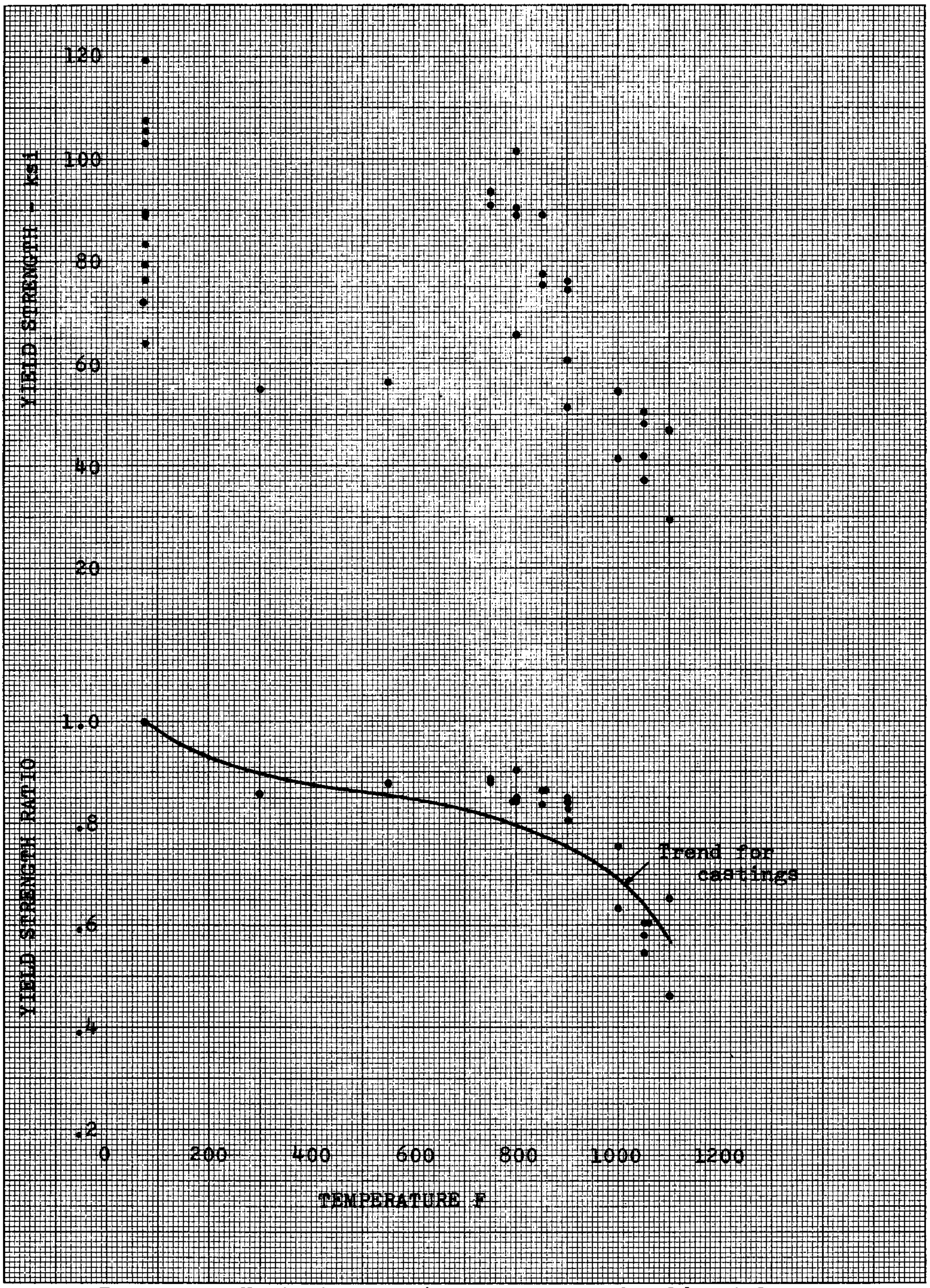

Fig. 12a - Variation of yield strength of weld metal with temperature

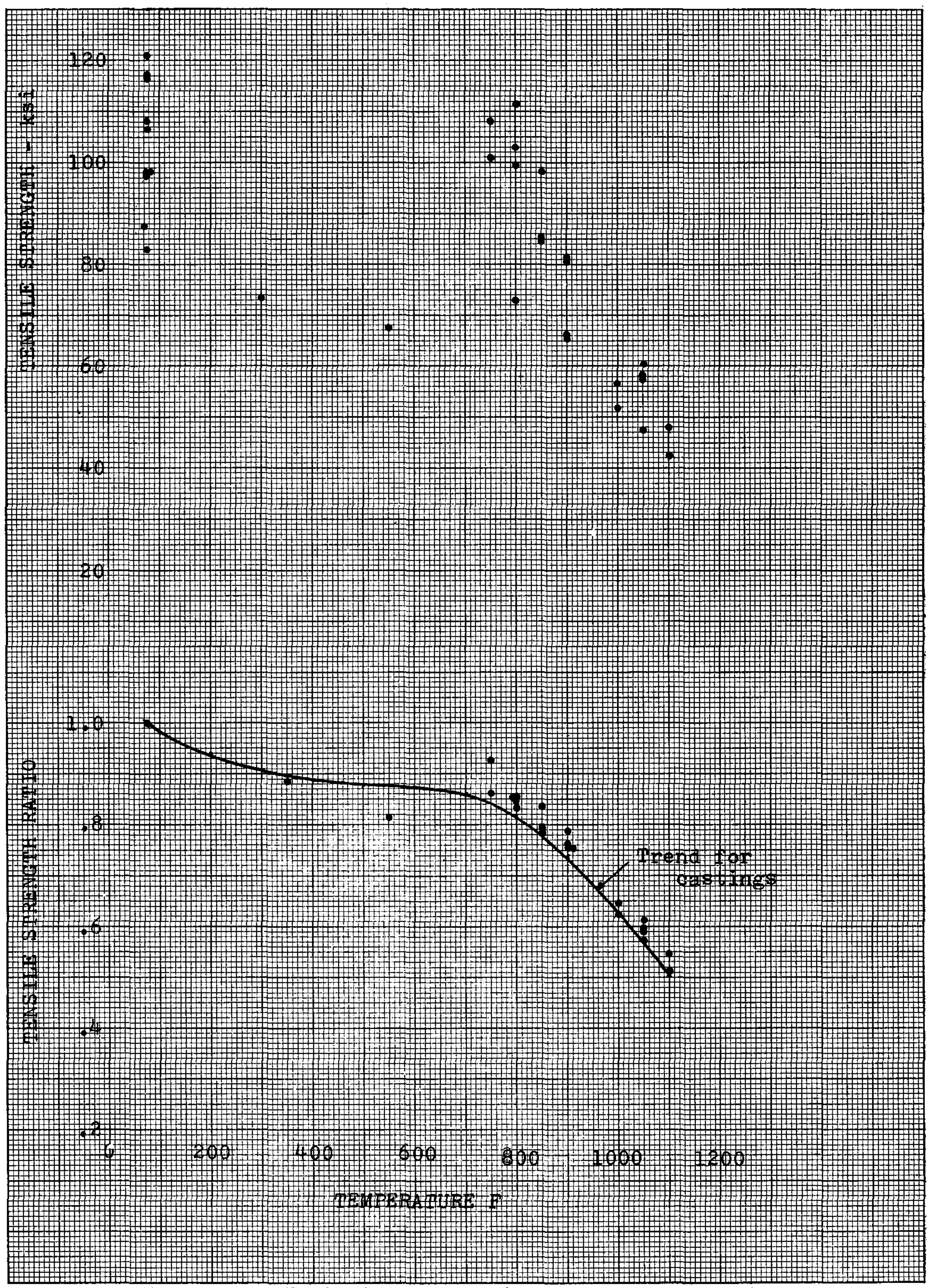

Fig. 12b - Variation of tensile strength of weld metal with temperature.

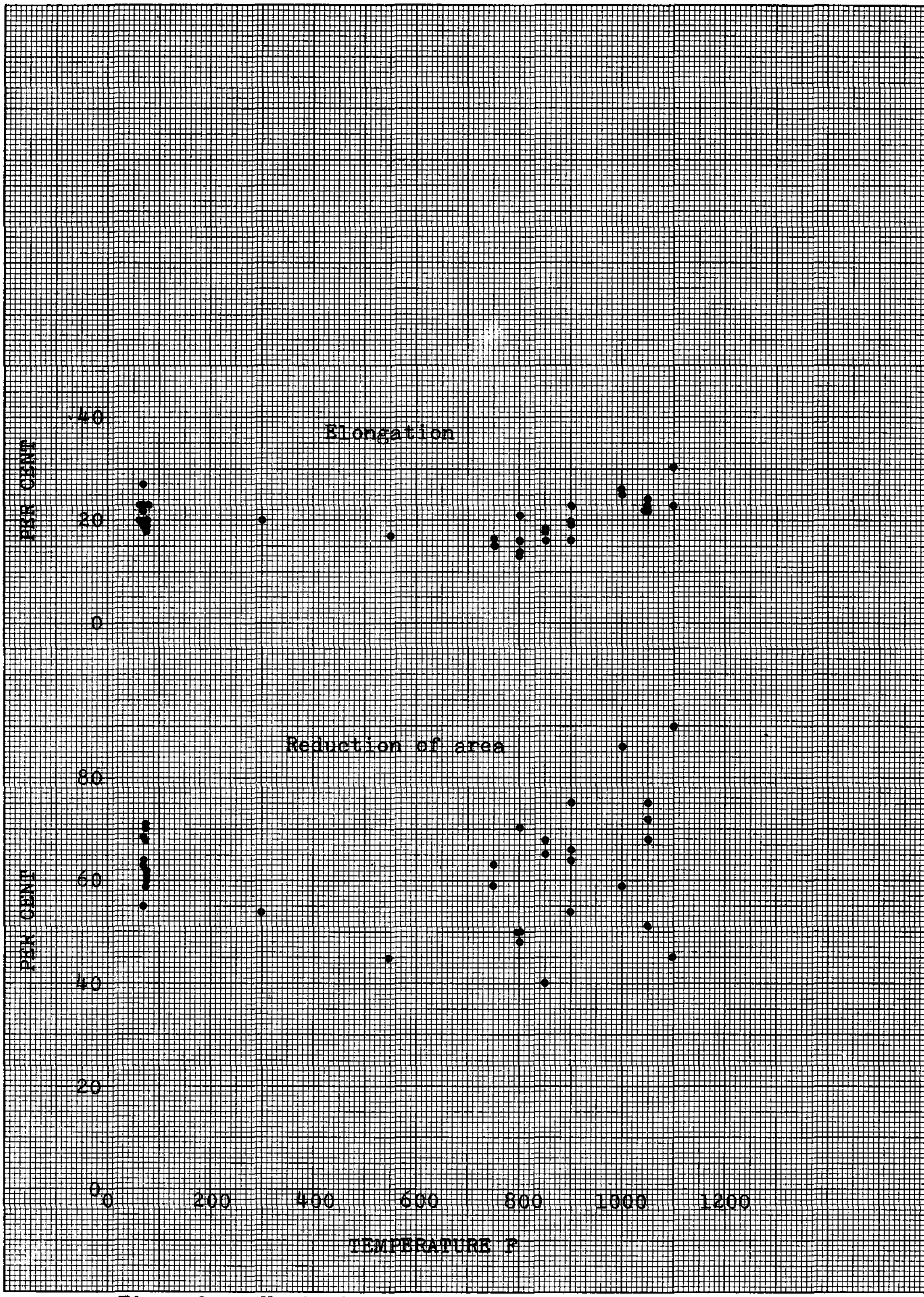

Fig. 12c - Variation of elongation and reduction of area of weld metal with temperature.

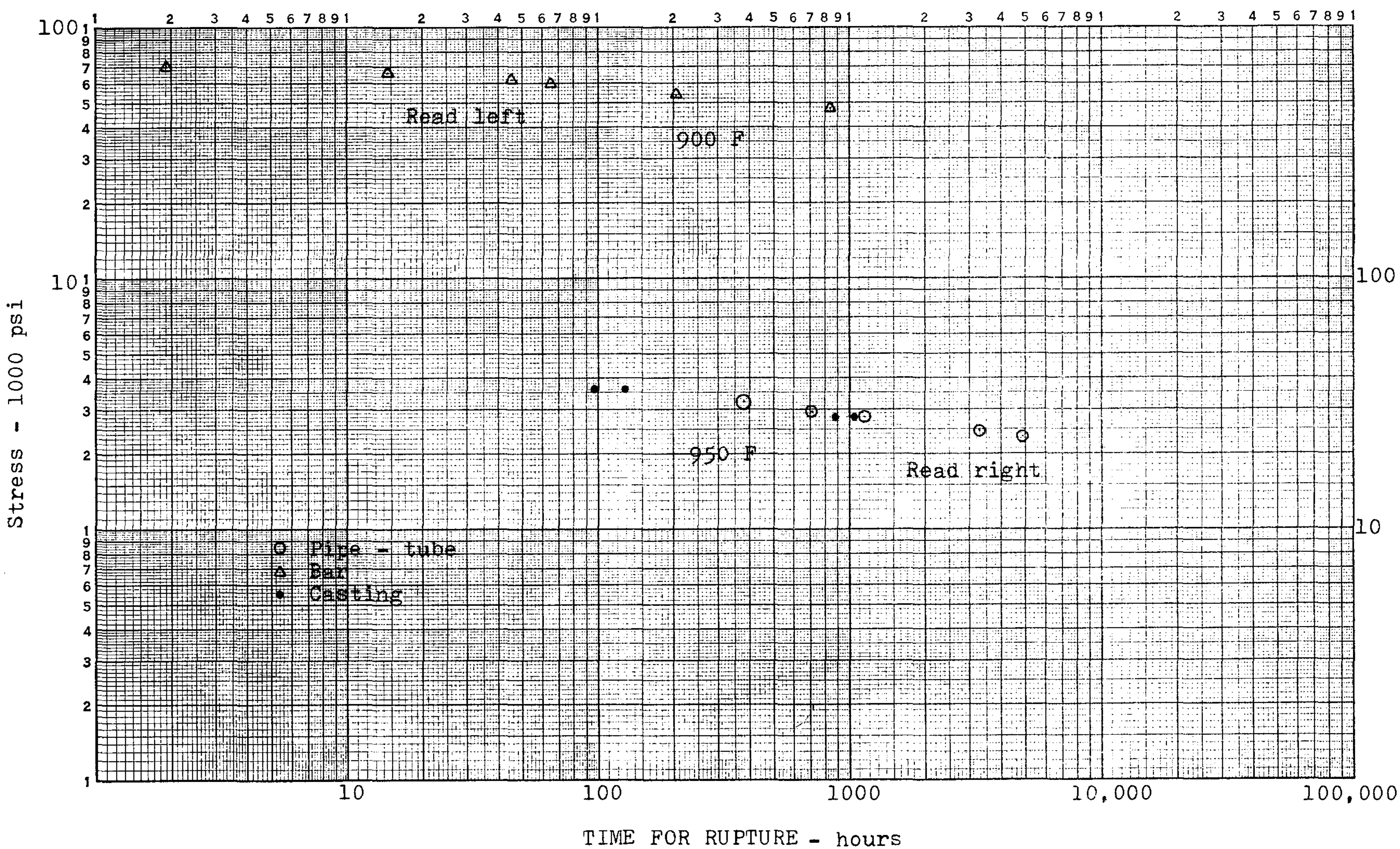

Fig. 13a - Stress vs time for rupture for annealed material.

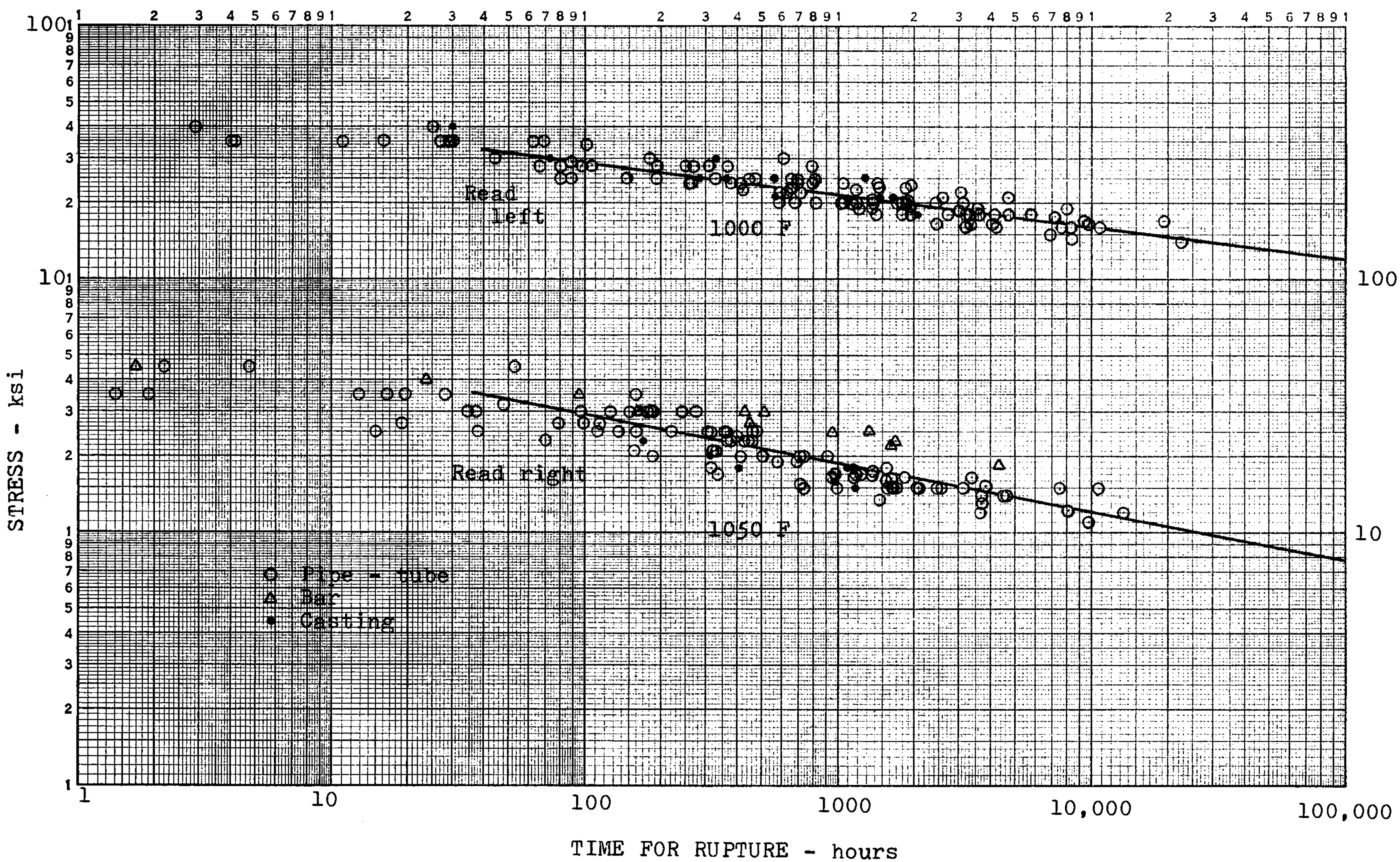

Fig. 13b - Stress vs time for rupture for annealed material.

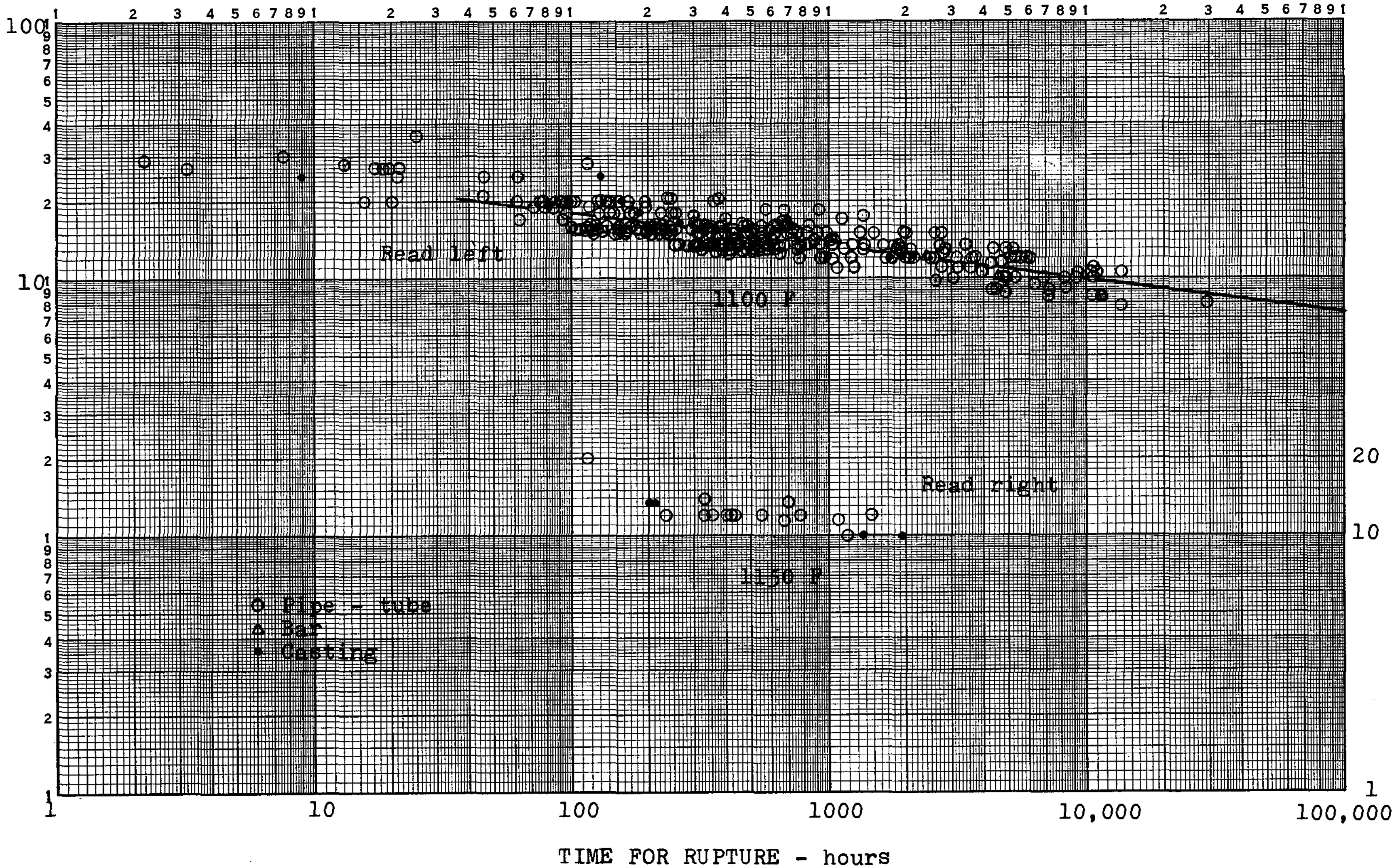

Fig. 13c - Stress vs time for rupture for annealed material.

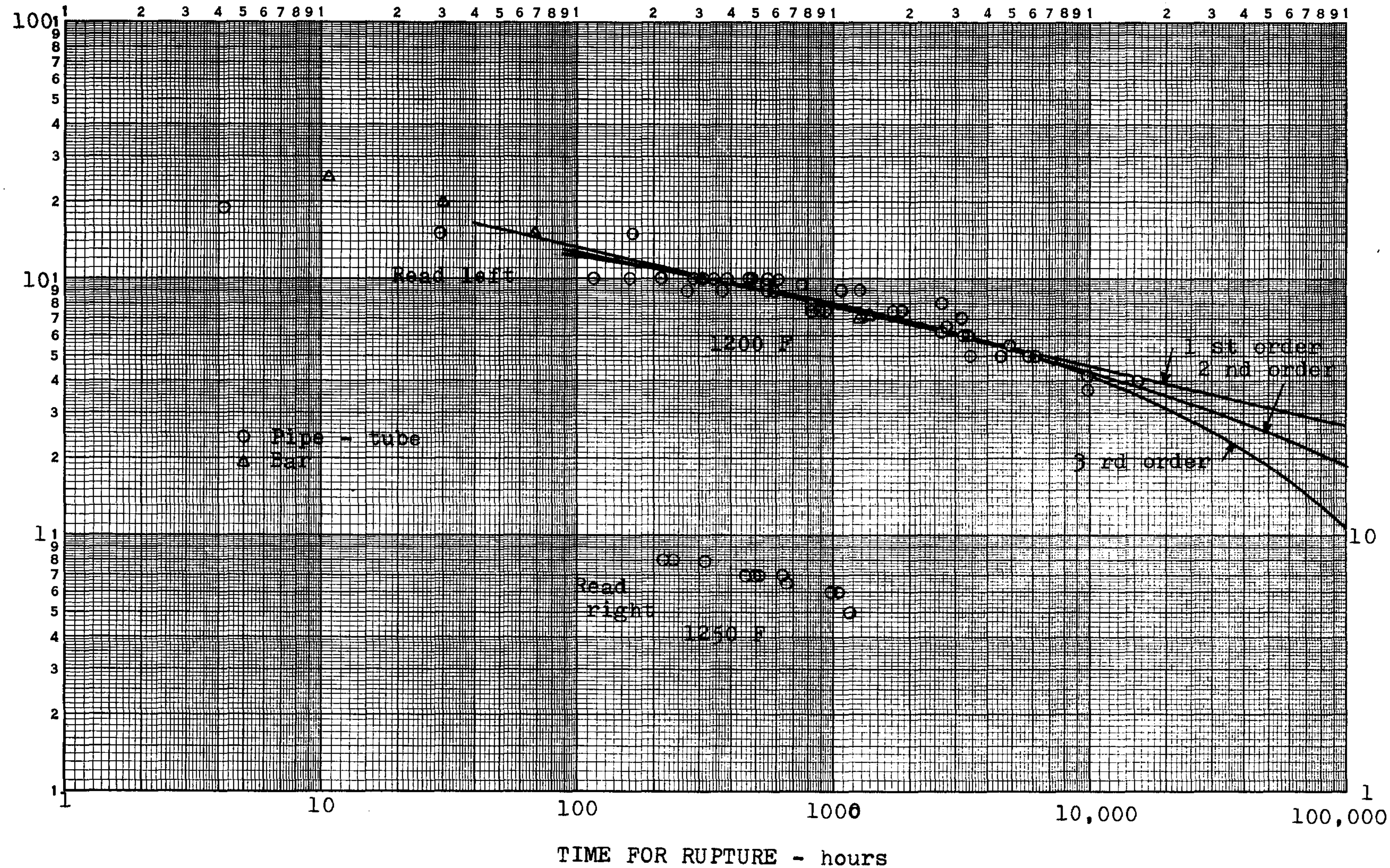

Fig. 13d - Stress vs time for rupture for annealed material.

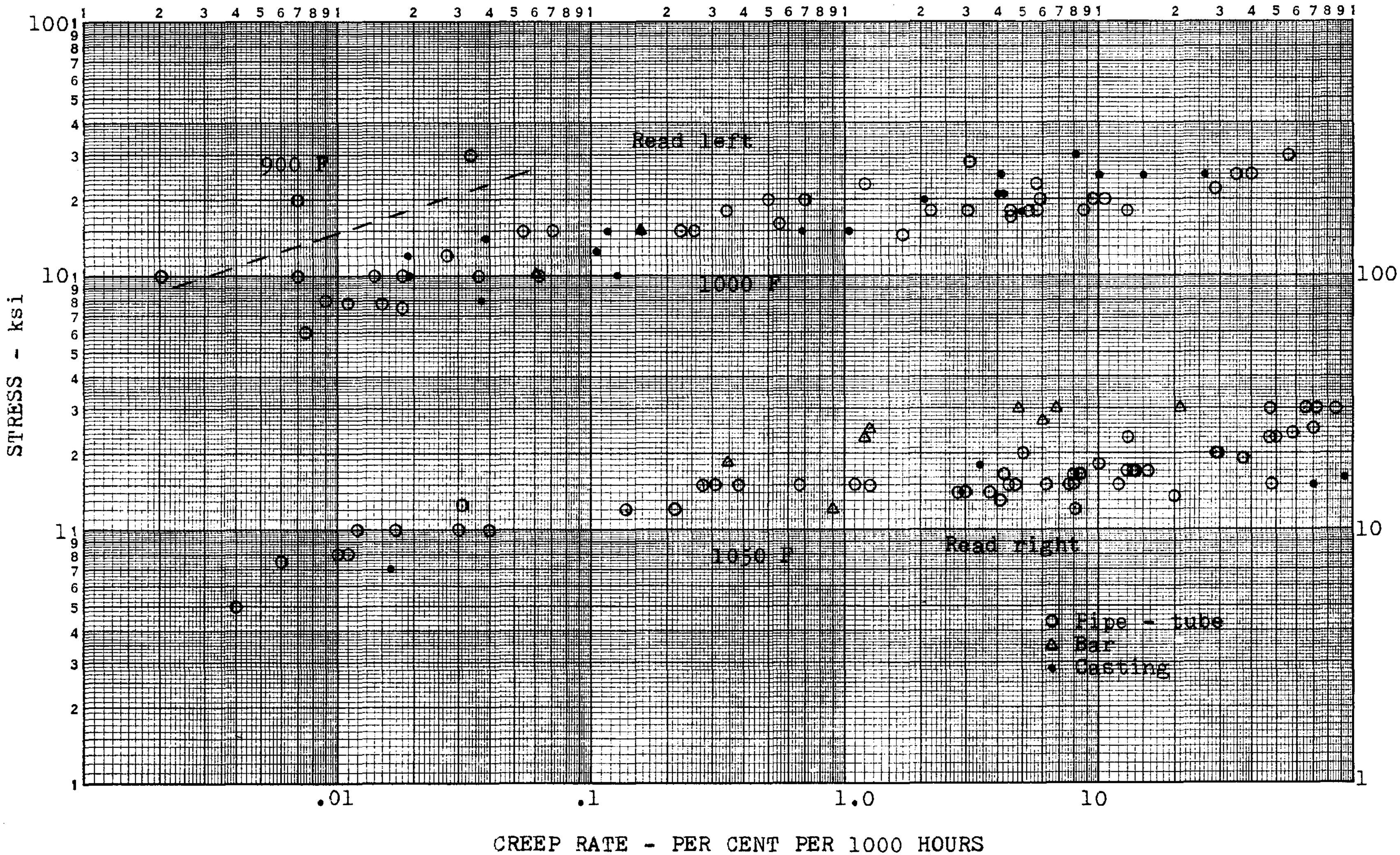

Fig. 14a - Stress vs secondary creep rate for annealed material.

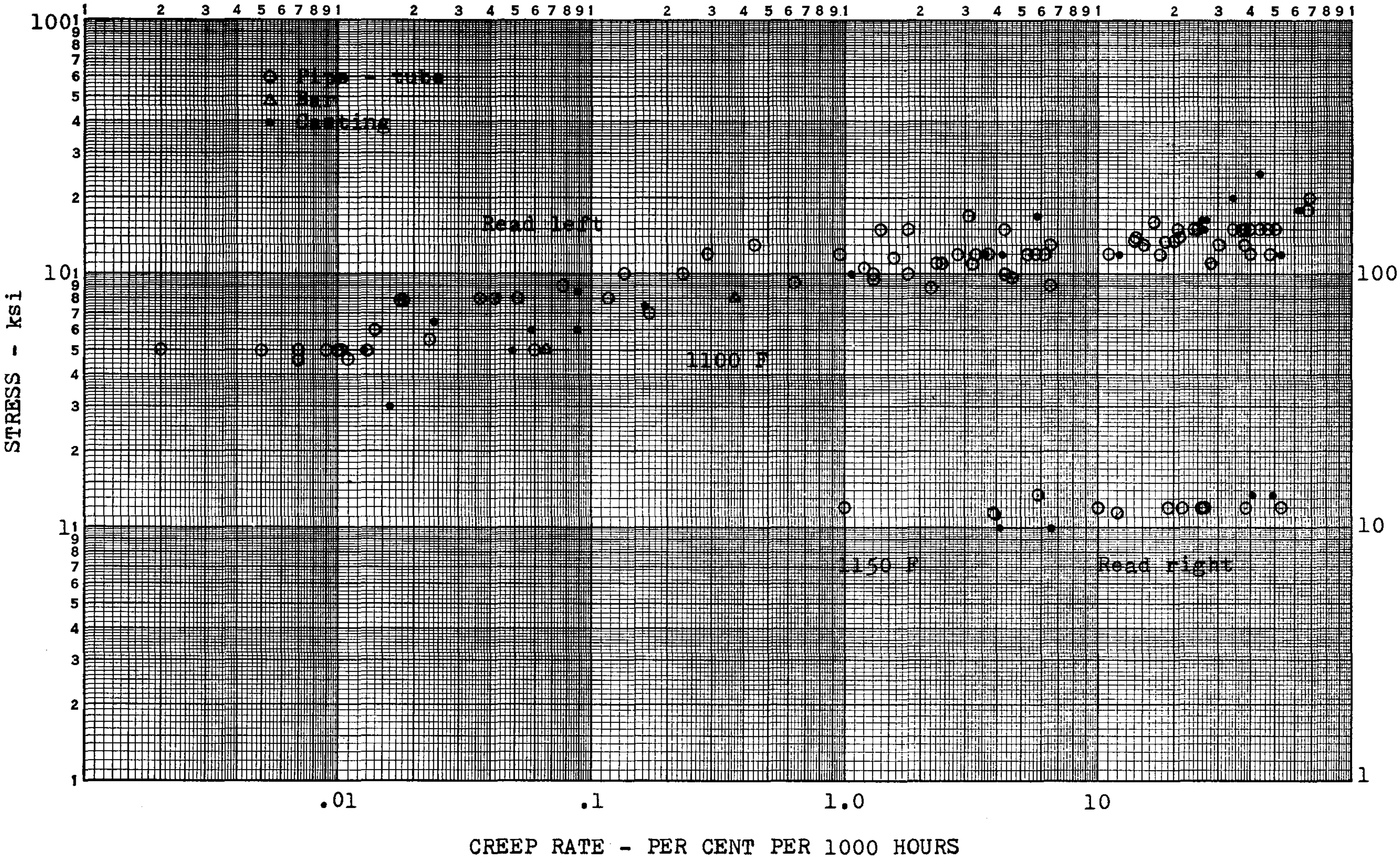

Fig. 14b - Stress vs secondary creep rate for annealed material.

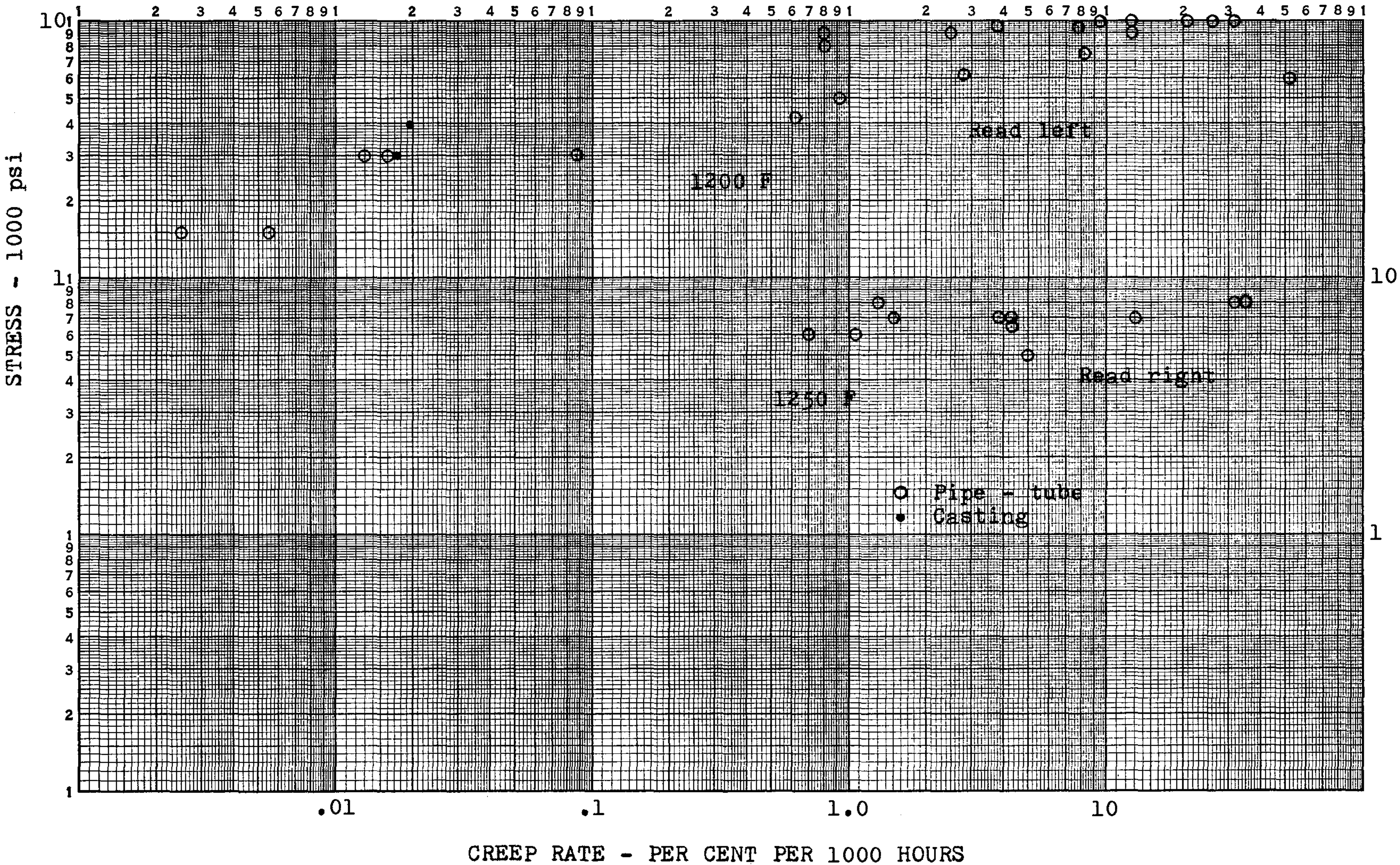

Fig. 14c - Stress vs secondary creep rate for annealed material.

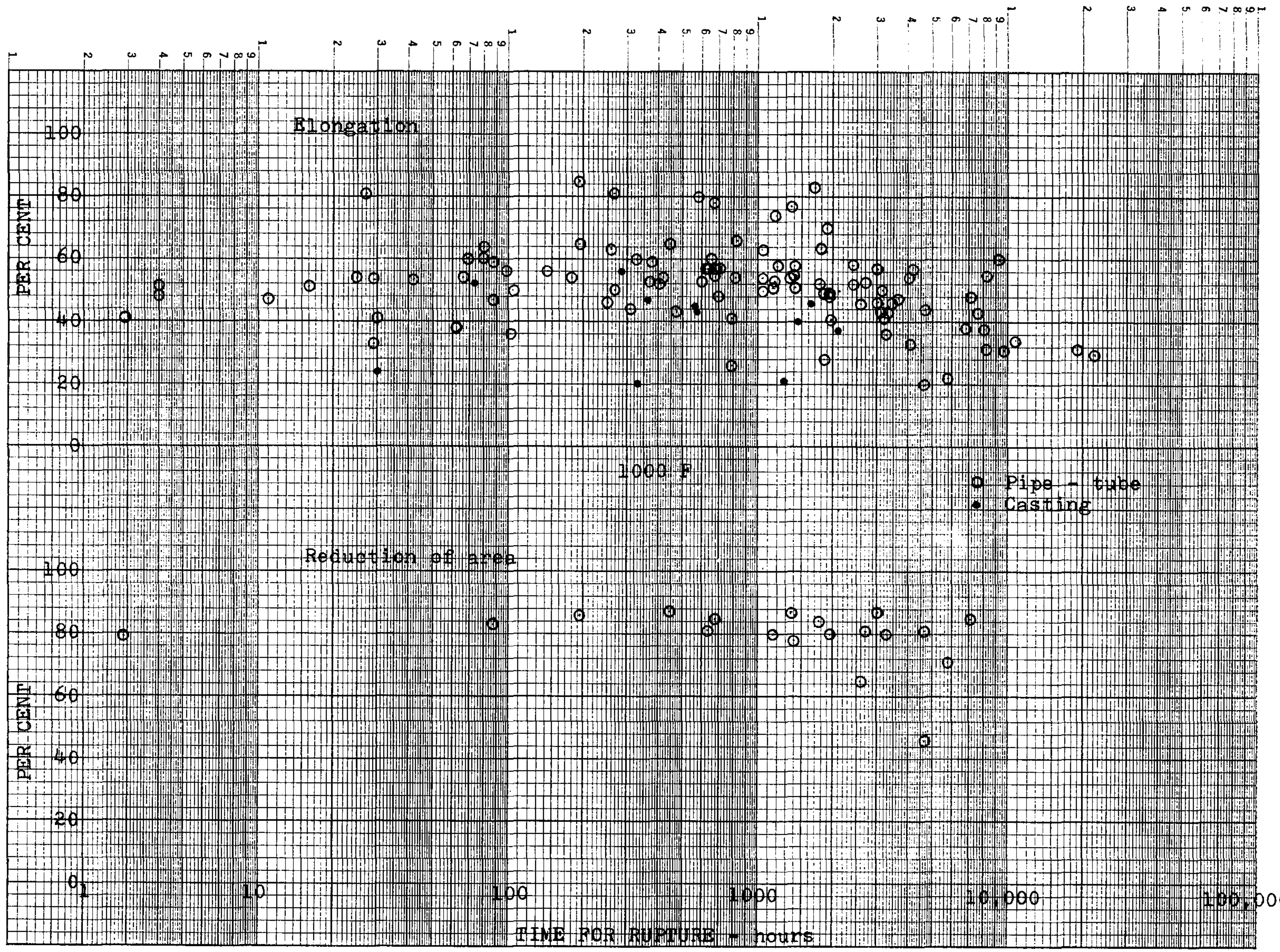

Fig. 15a - Variation of rupture ductility with time for rupture for annealed material.

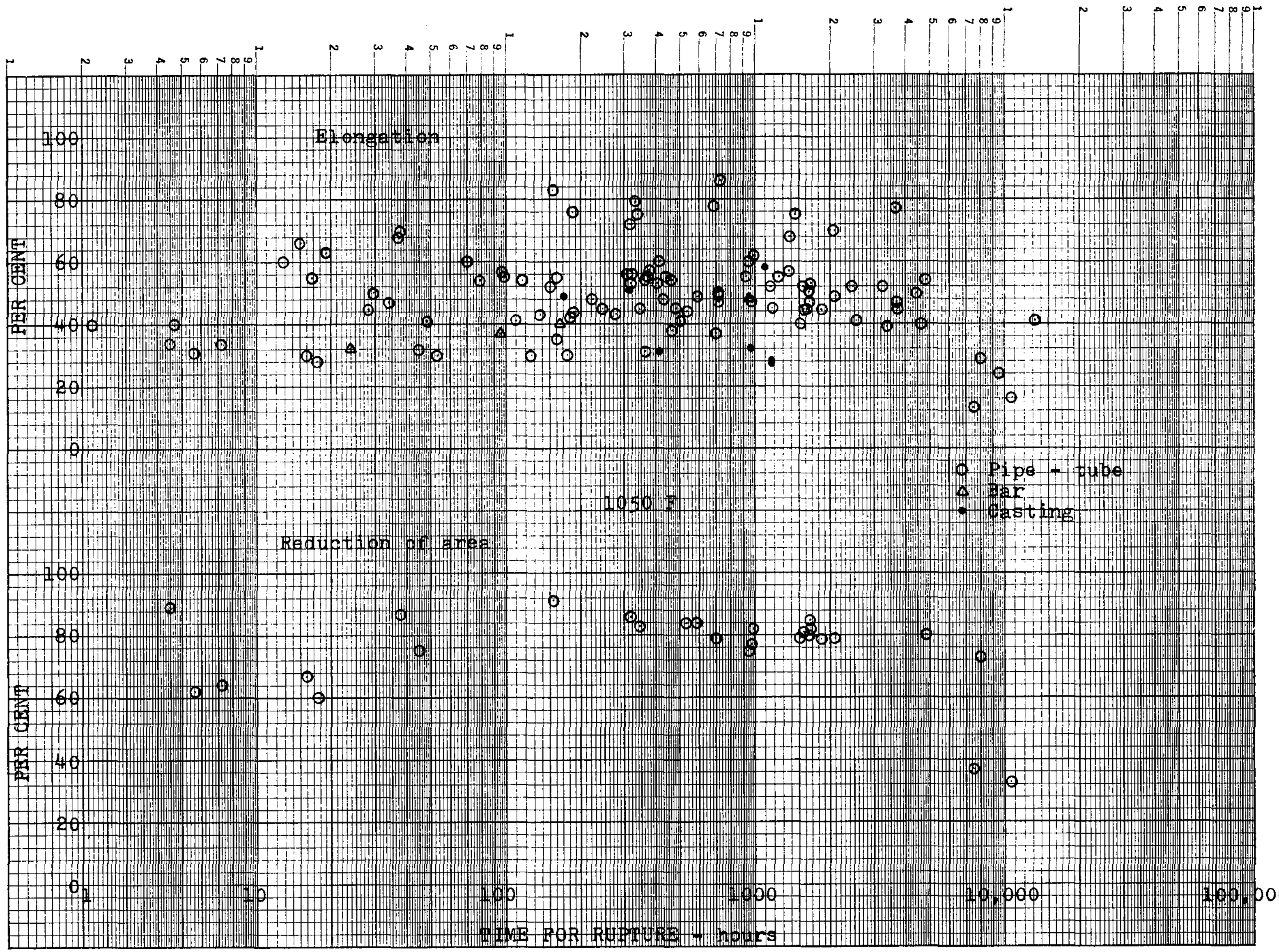

Fig. 15b - Variation of rupture ductility with time for rupture for annealed material.

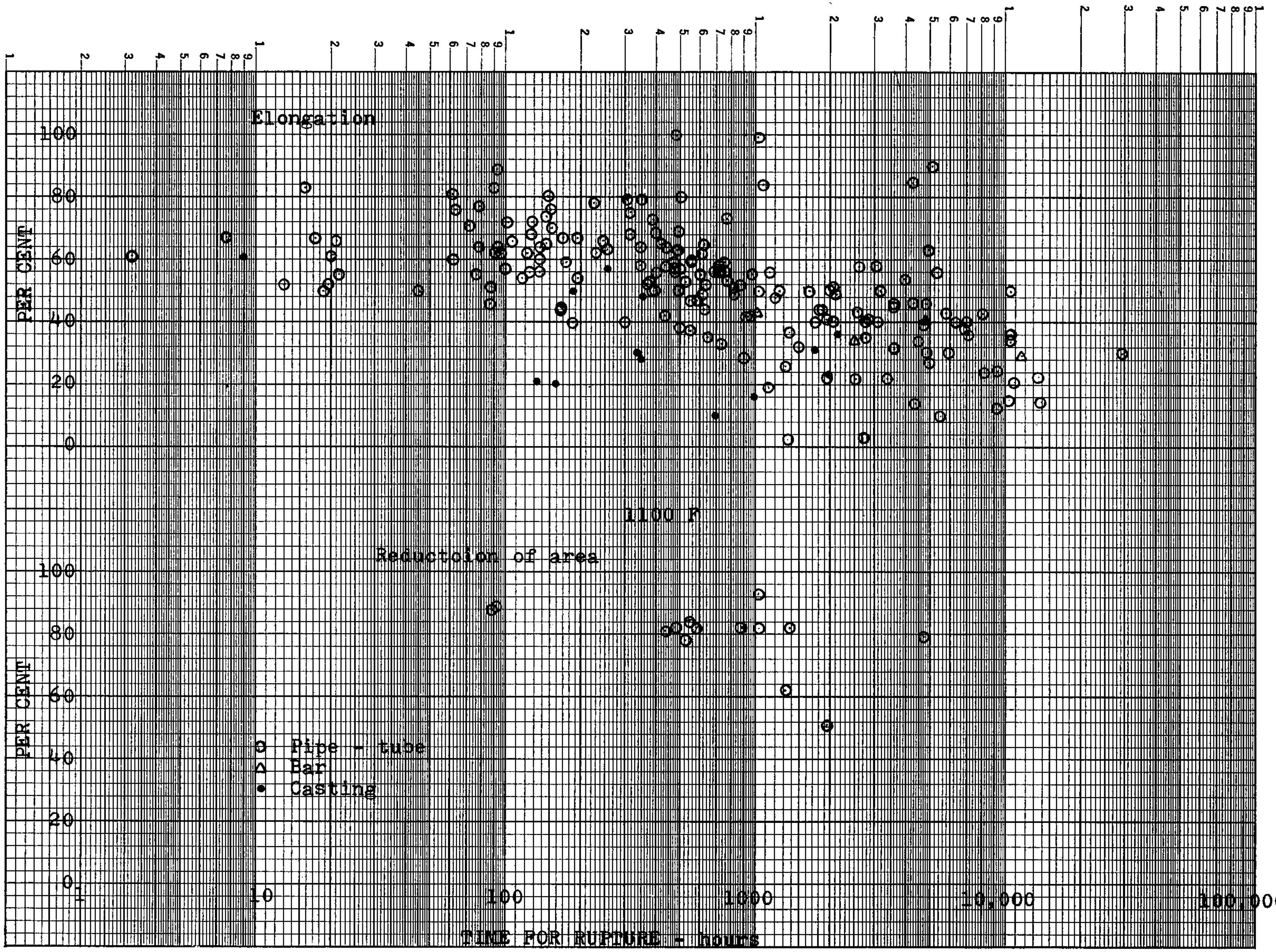

Fig. 15c - Variation of rupture ductility with time for rupture for annealed material.

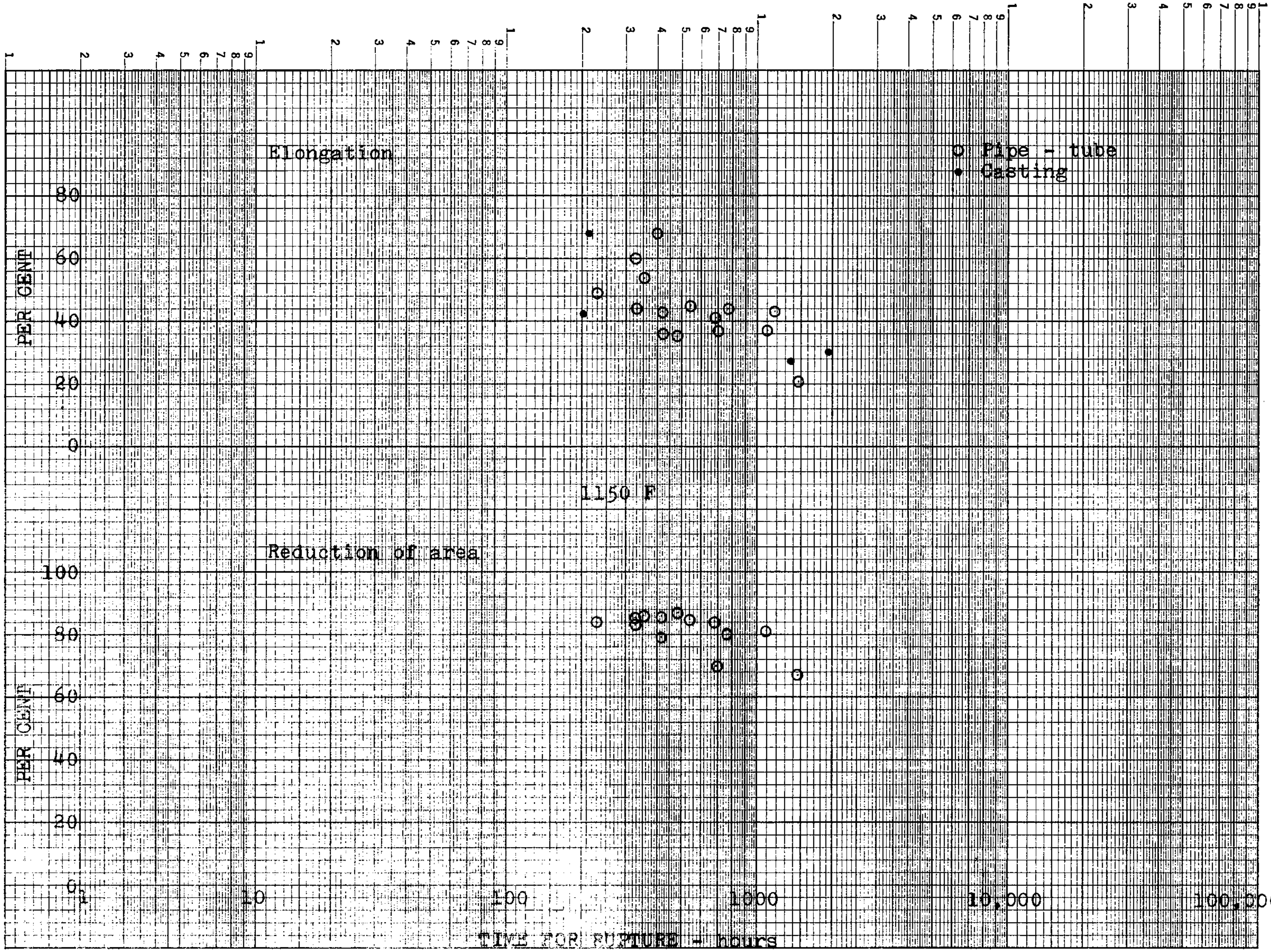

Fig. 15d - Variation of rupture ductility with time for rupture for annealed material.

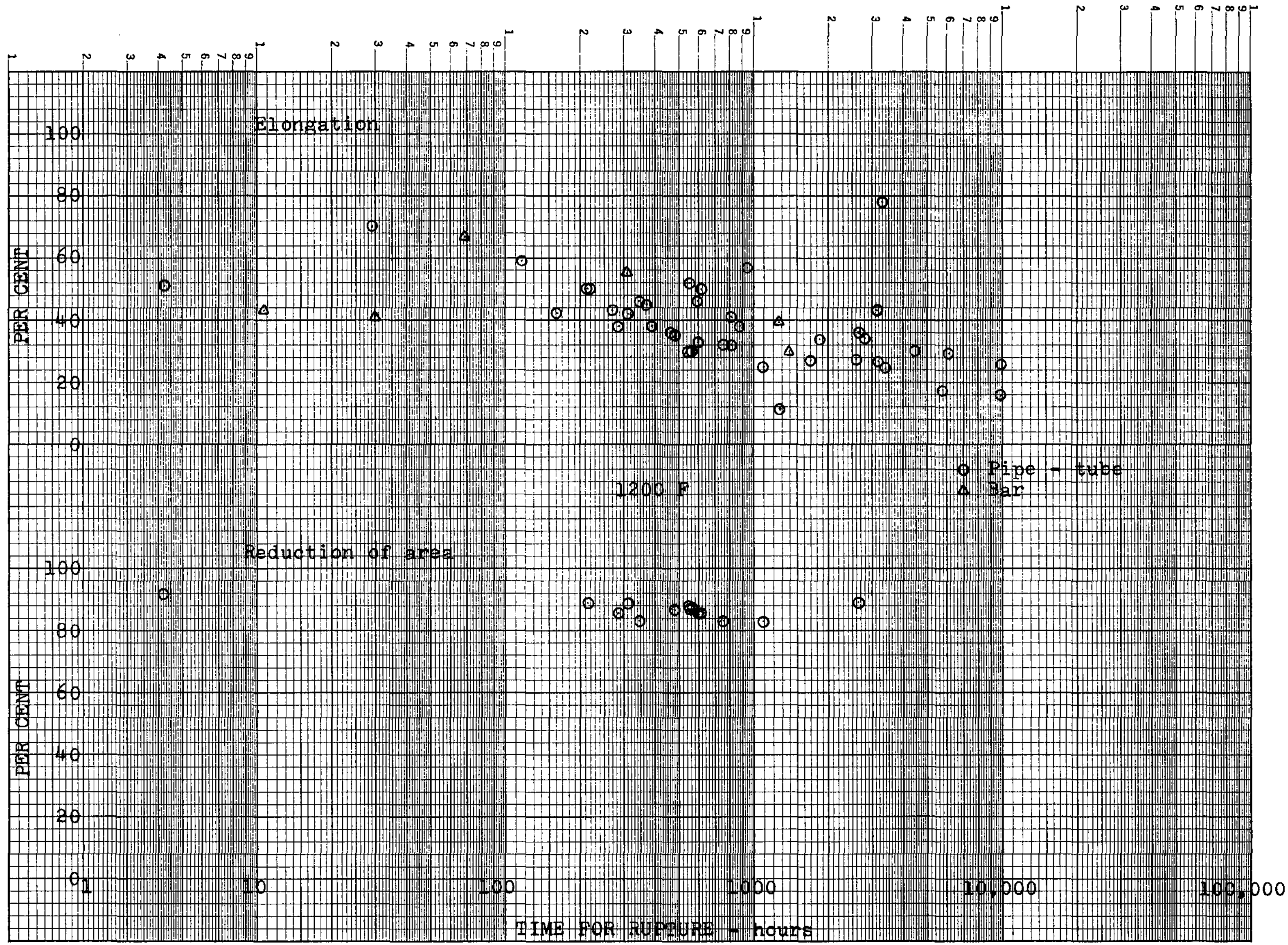

Fig. 15e - Variation of rupture ductility with time for rupture for annealed material.

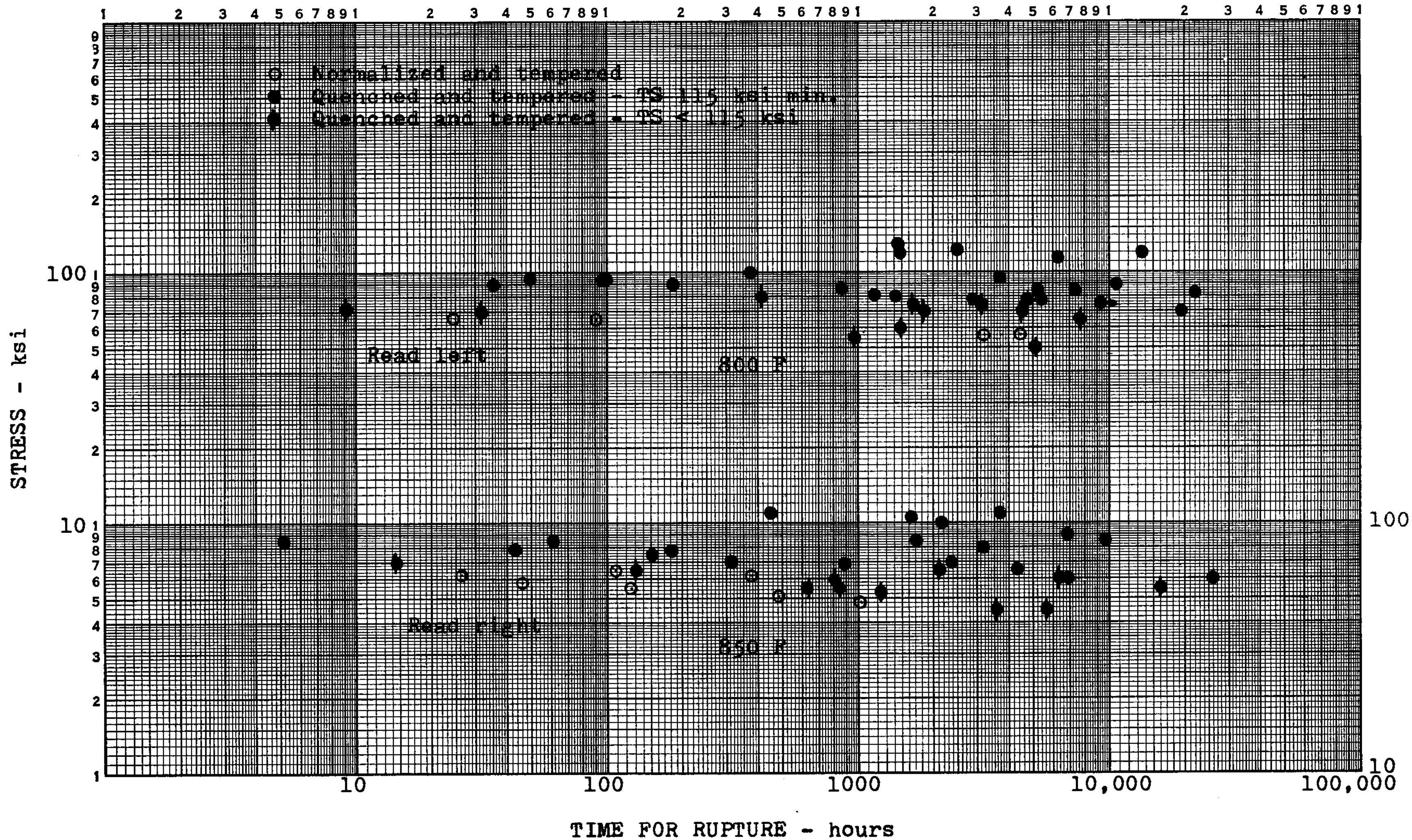

Fig. 16a - Stress vs time for rupture for normalized-and-tempered and quenched-and-tempered material.

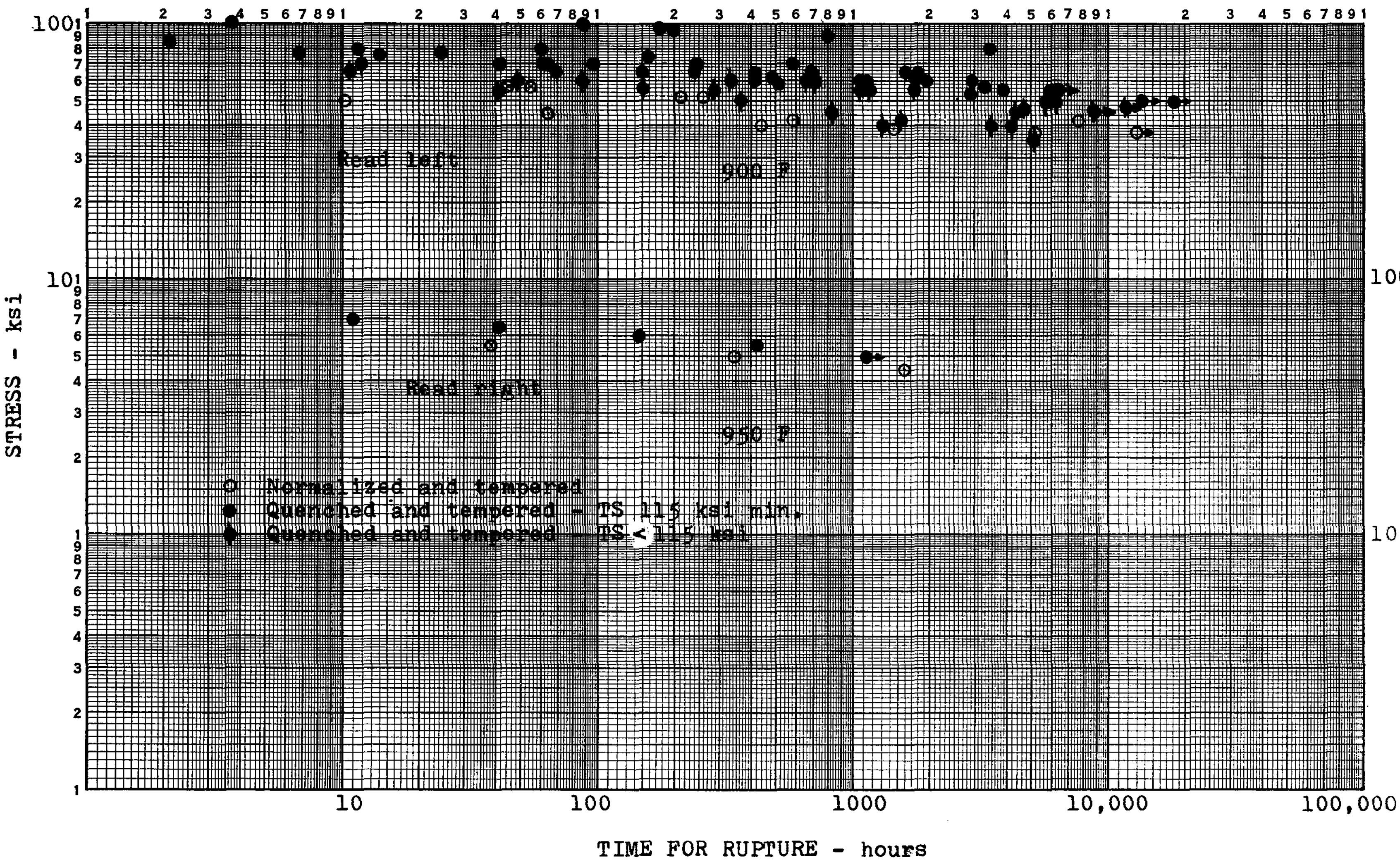

Fig. 16b - Stress vs time for rupture for normalized-and-tempered and quenched-and-tempered material.

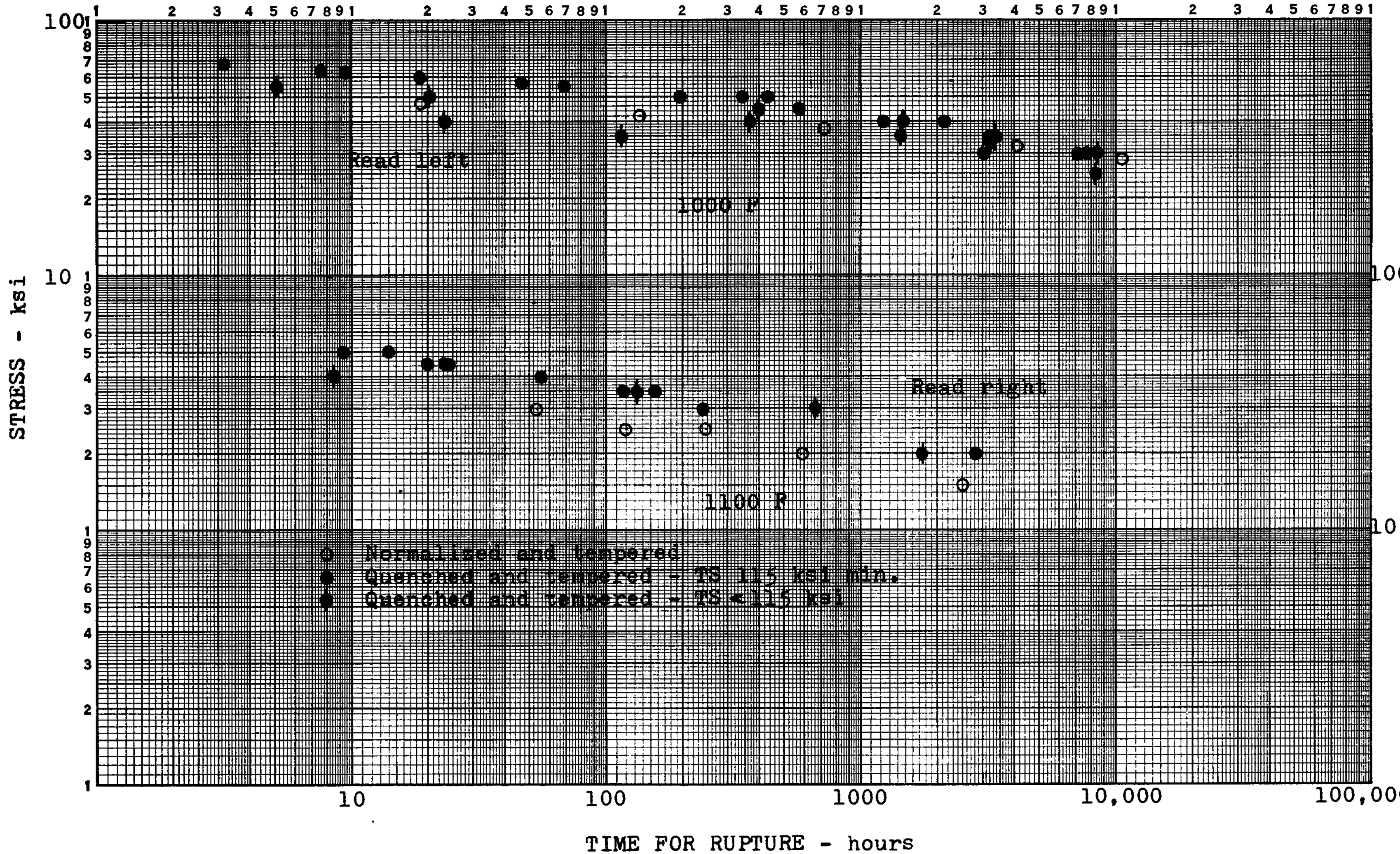

Fig. 16c - Stress vs time for rupture for normalized-and-tempered and quenched-and-tempered material.

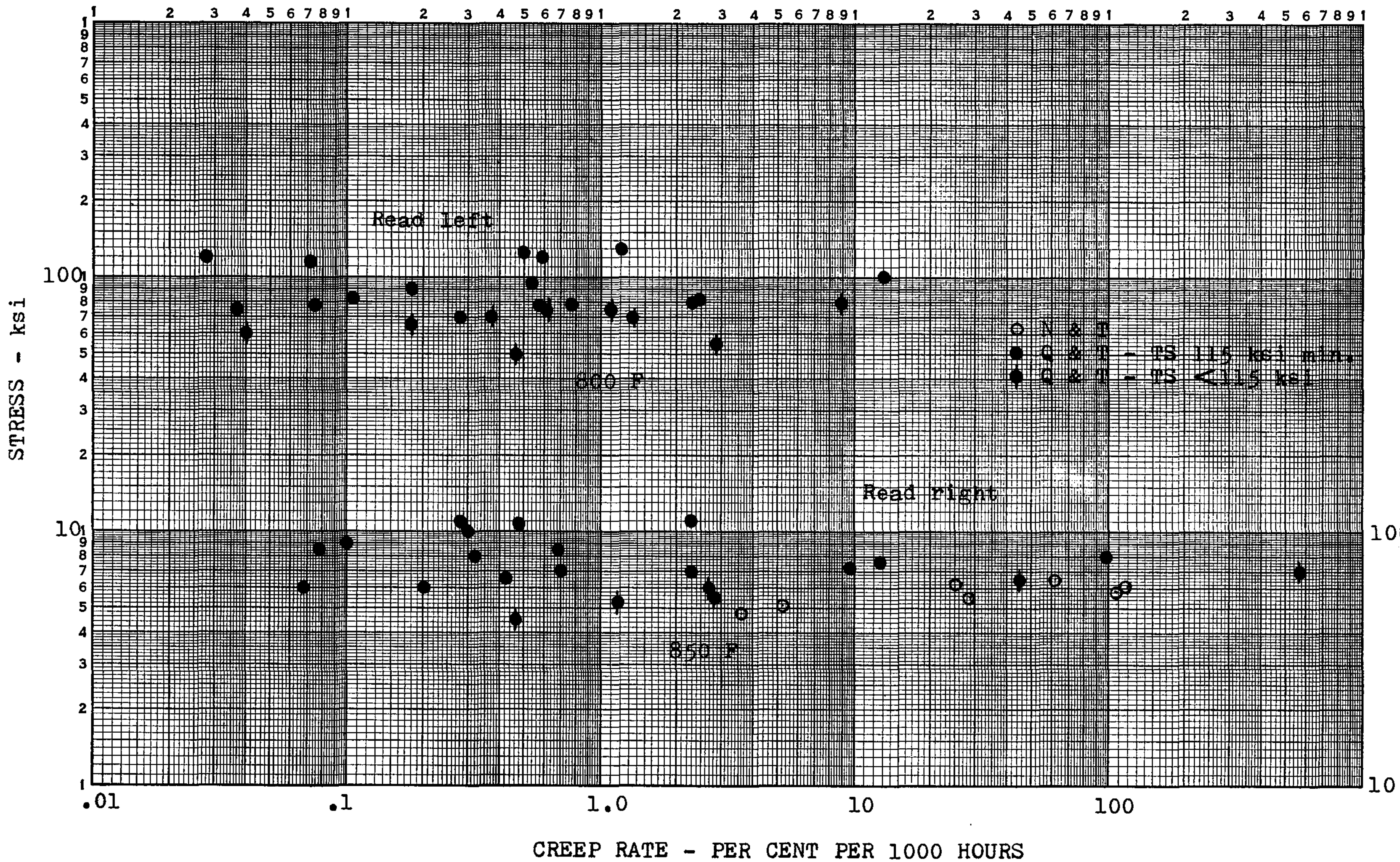

Fig. 17a - Stress vs secondary creep rate for normalized-and-tempered and quenched-and-tempered material.

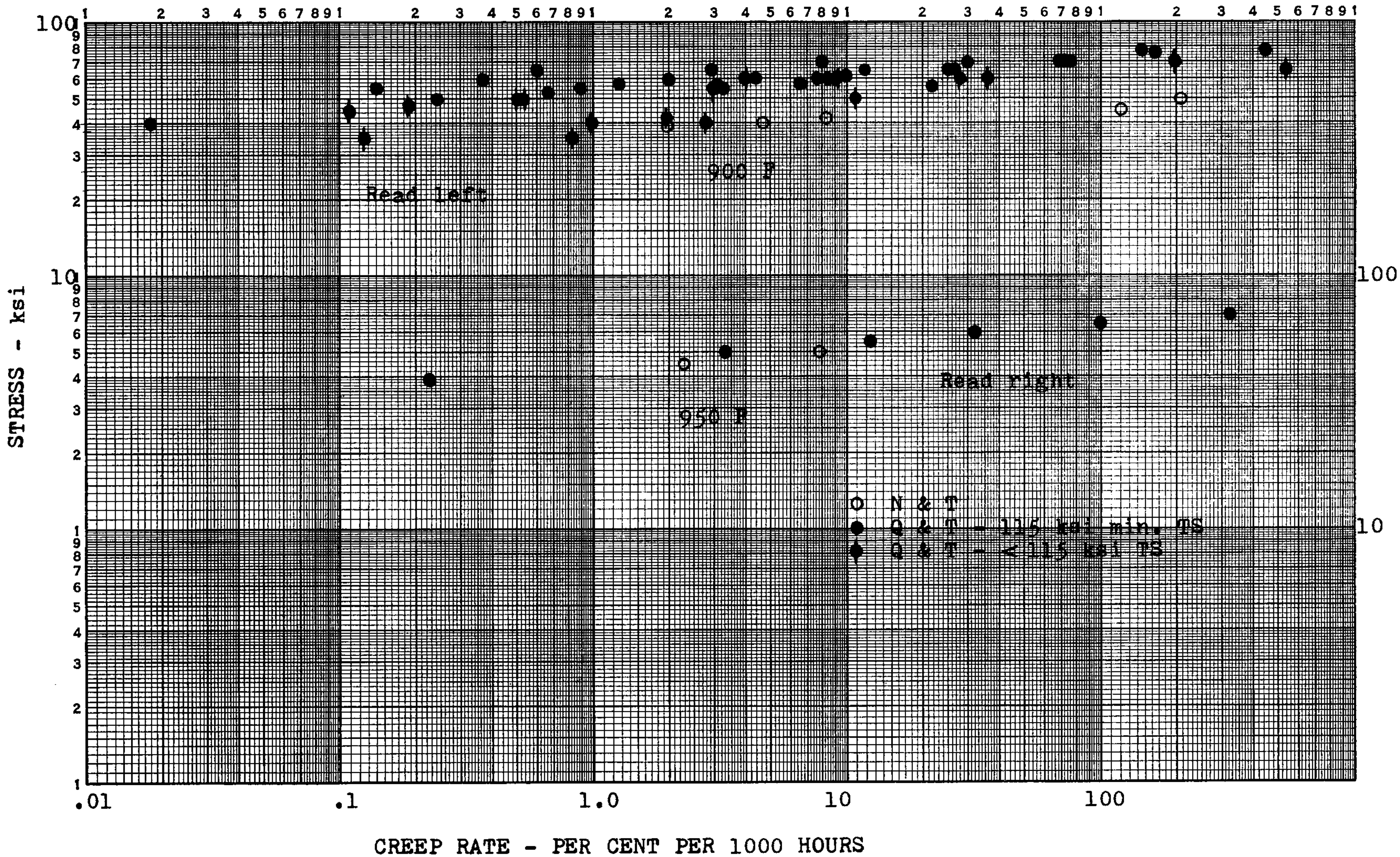

Fig. 17b - Stress vs secondary creep rate for normalized-and-tempered and quenched-and-tempered material.

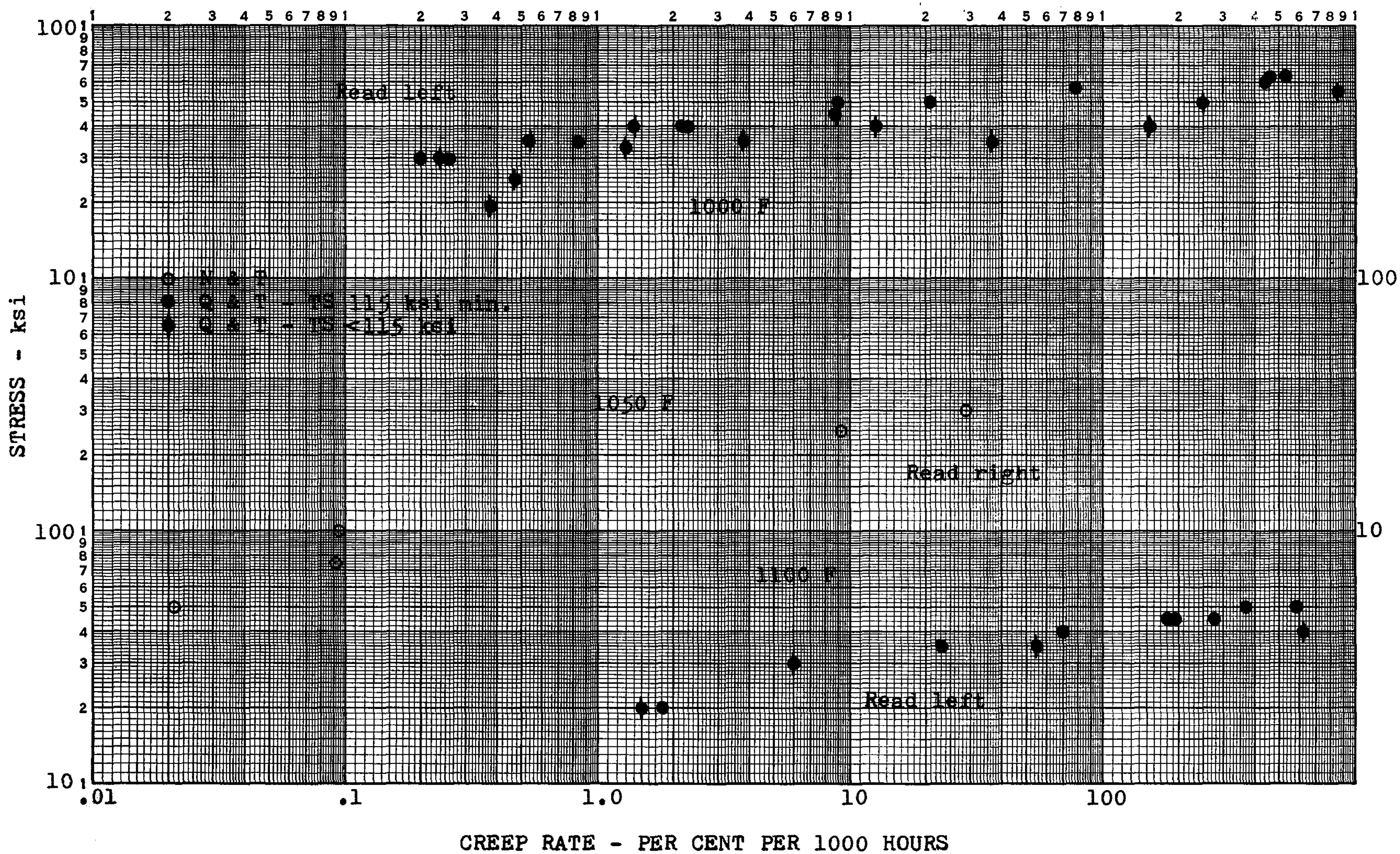

Fig. 17c - Stress vs secondary creep rate for normalized-and-tempered and quenched-and-tempered material.

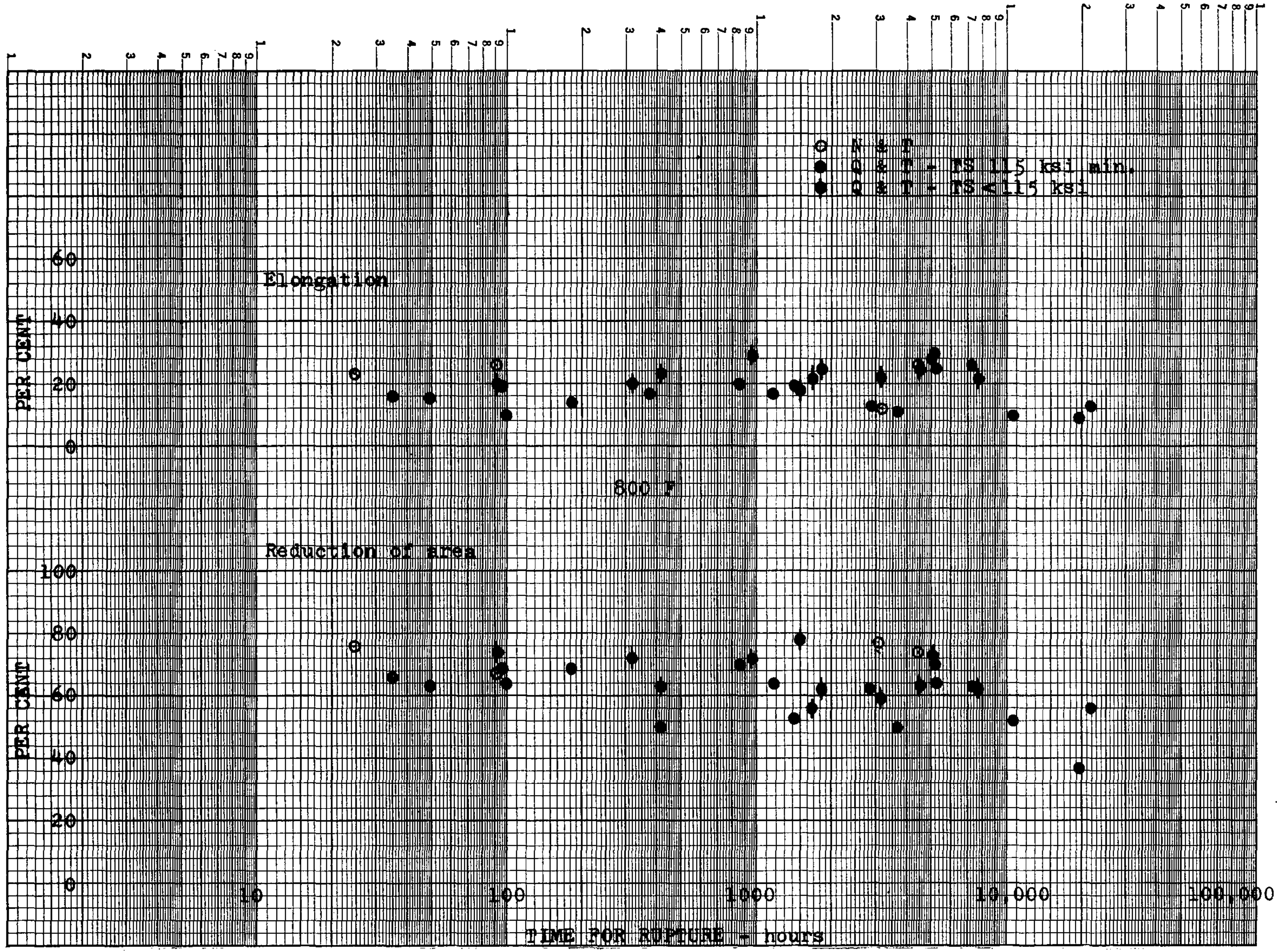

Fig. 18a - Variation of rupture ductility with time for rupture for normalized-and-tempered and quenched-and-tempered material

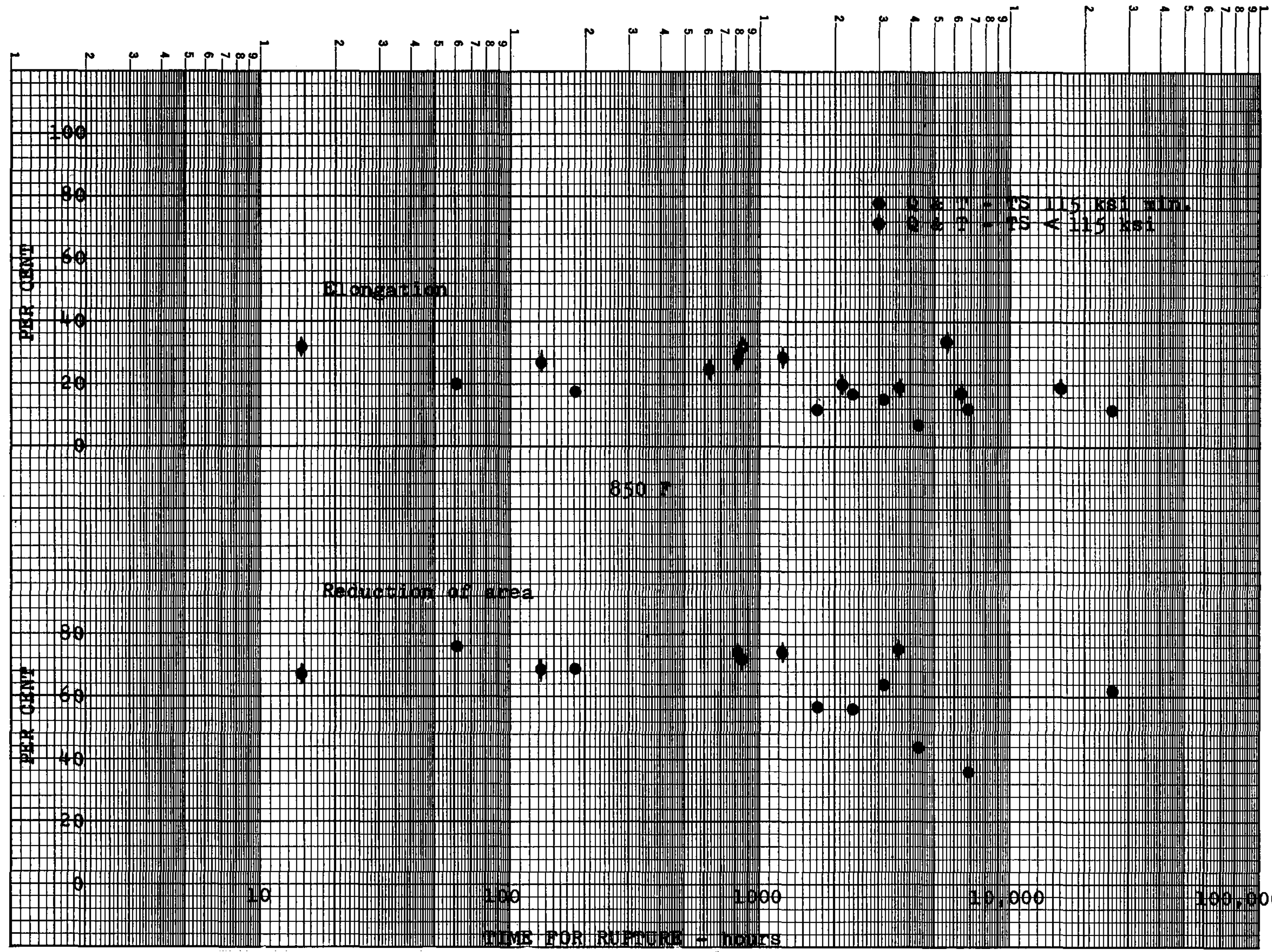

Fig. 18b - Variation of rupture ductility with time for rupture for normalized-and-tempered and quenched-and-tempered material.

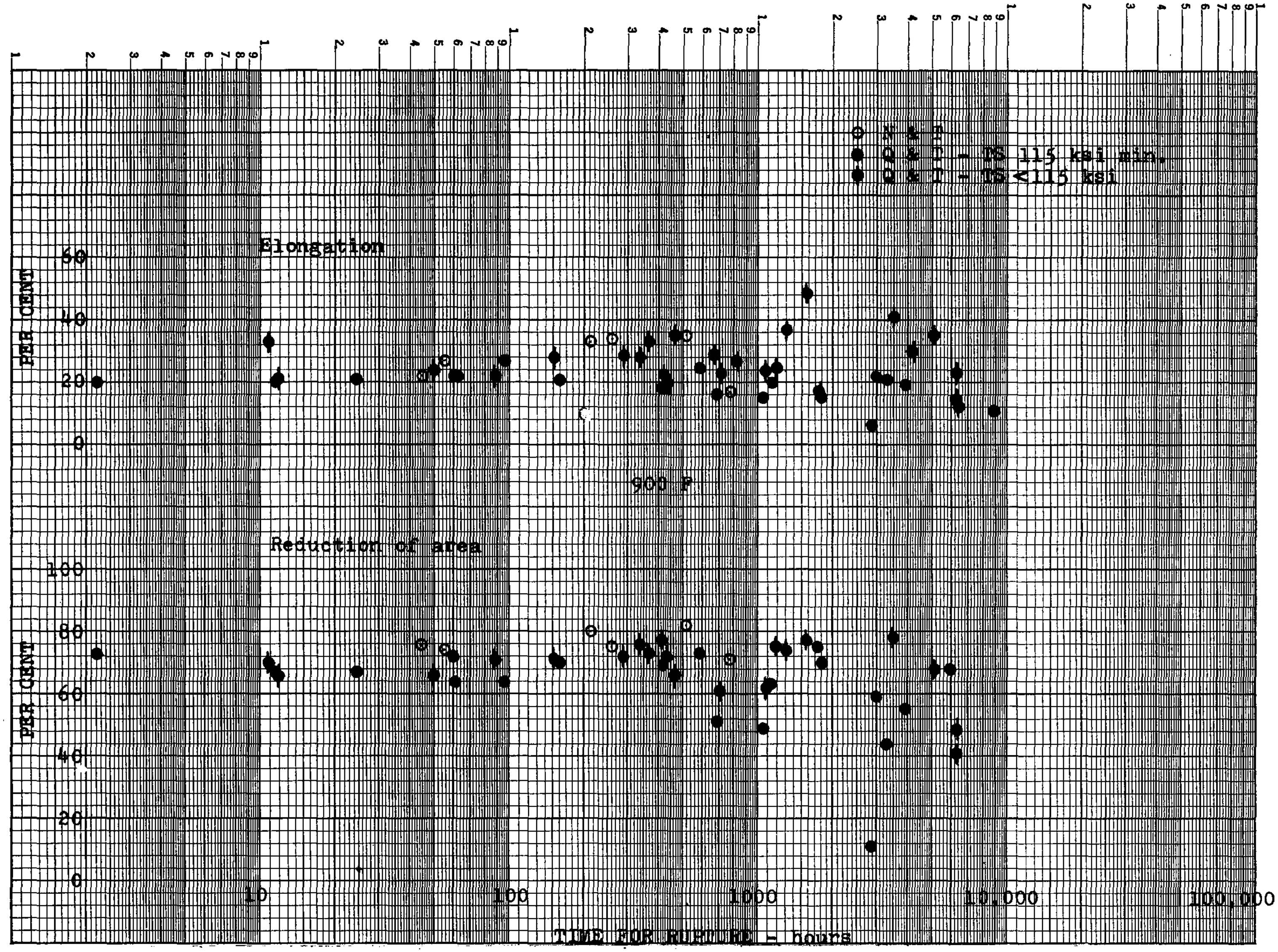

Fig. 18c - Variation of rupture ductility with time for rupture for normalized-and-tempered and quenched-and-tempered material

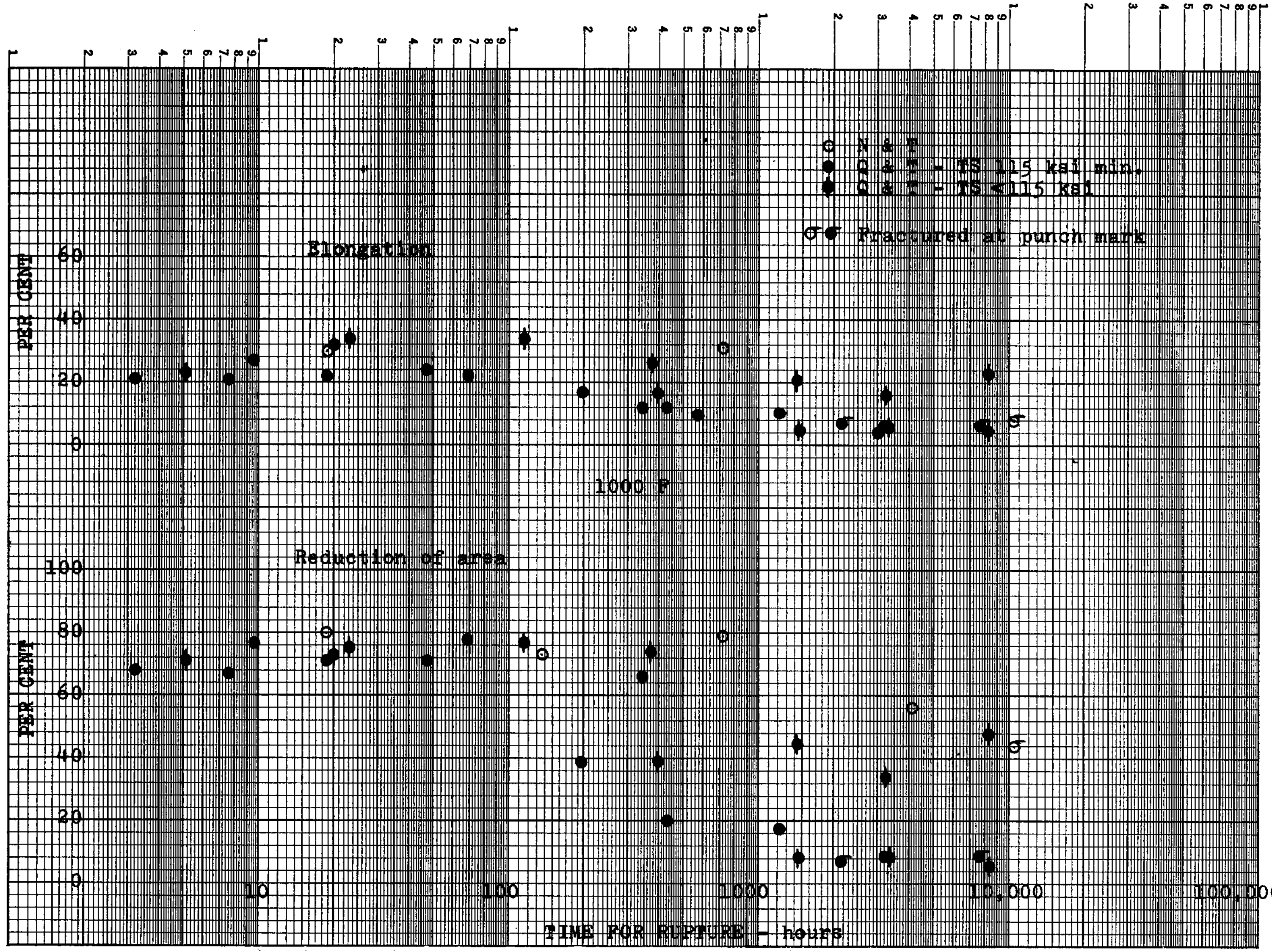

Fig. 18d - Variation of rupture ductility with time for rupture for normalized-and-tempered and quenched-and-tempered material.

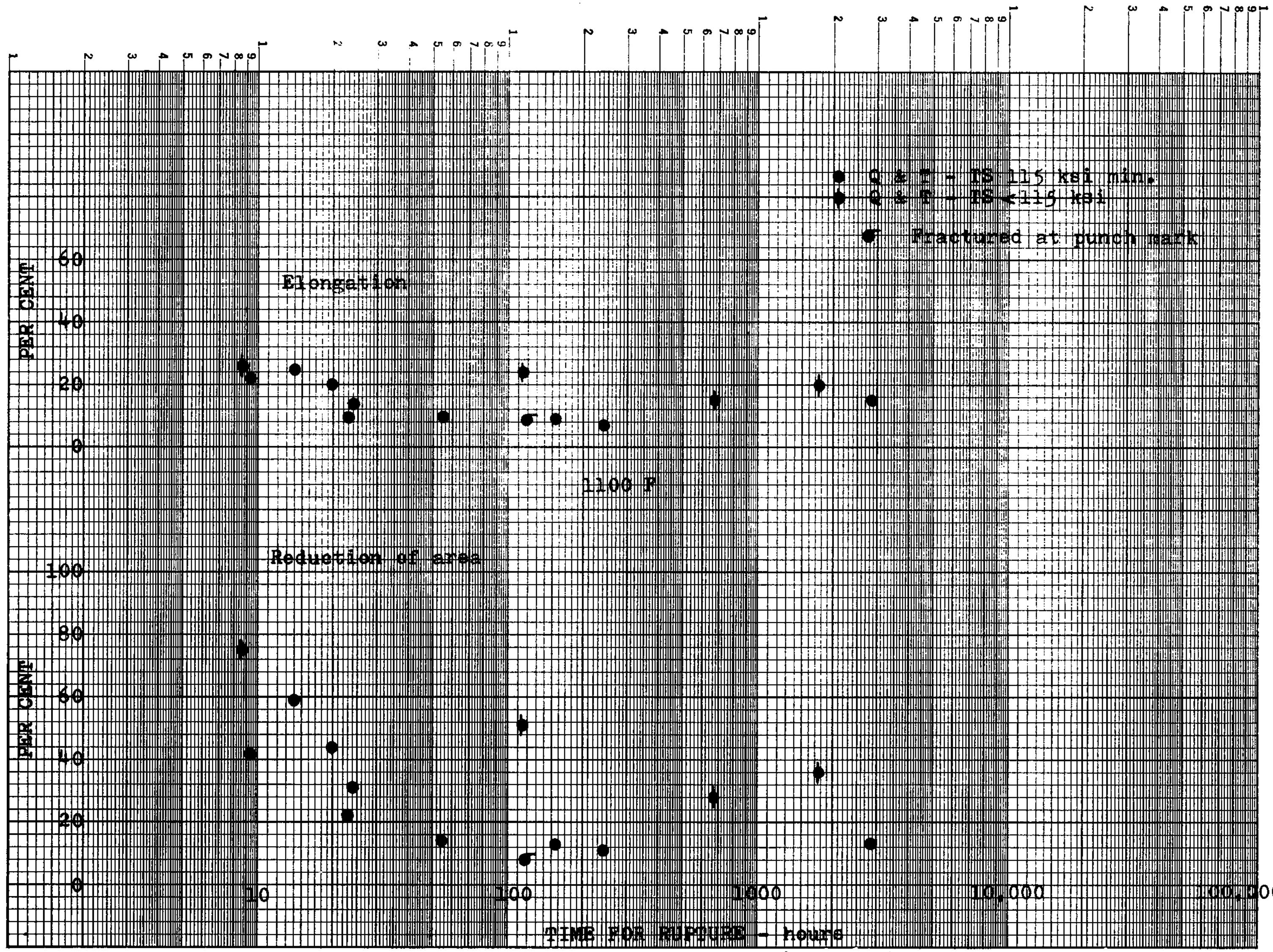

Fig. 18e - Variation of rupture ductility with time for rupture for normalized-and-tempered and quenched-and-tempered material.

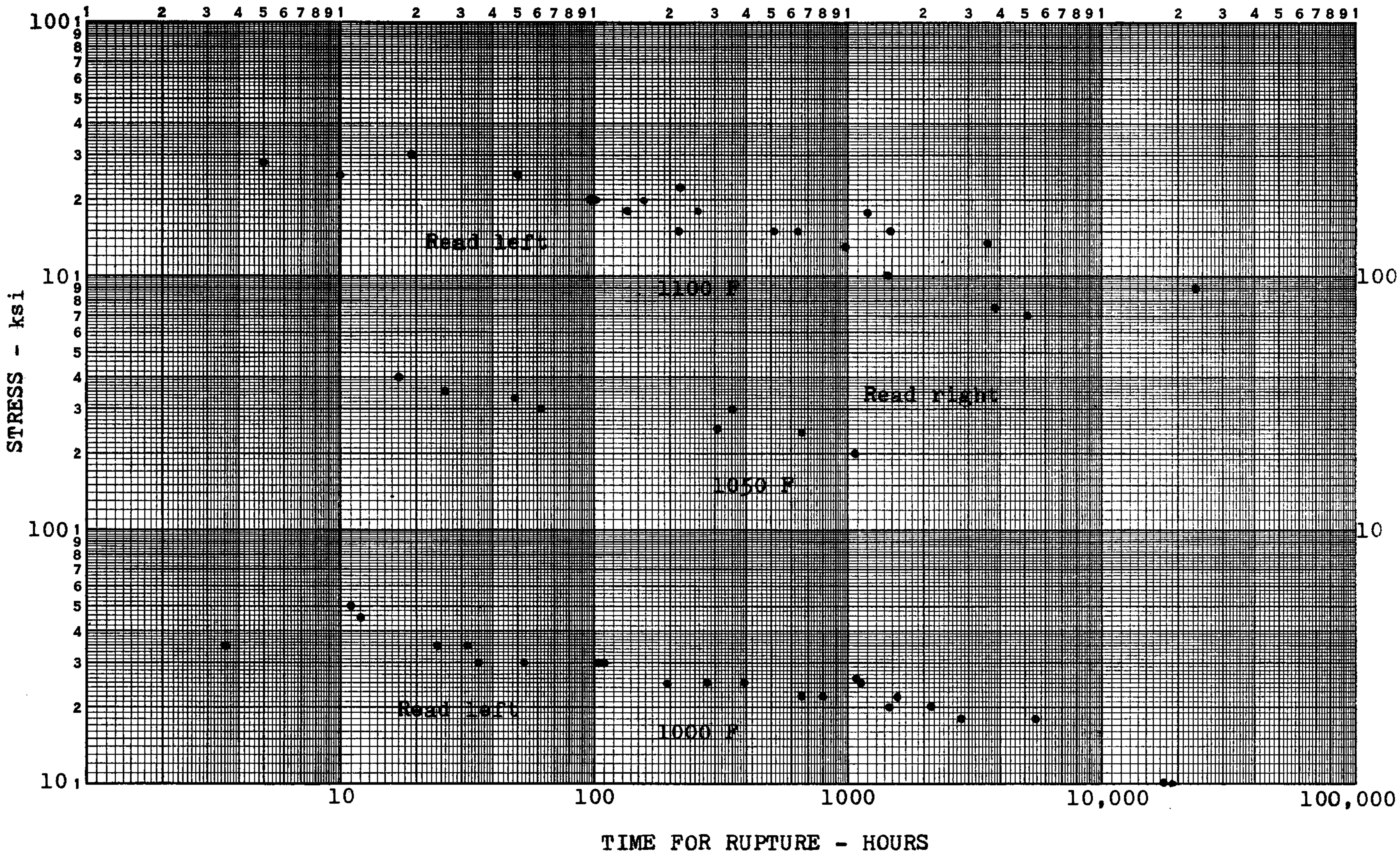

Fig. 19a - Stress vs time for rupture for annealed weld metal.

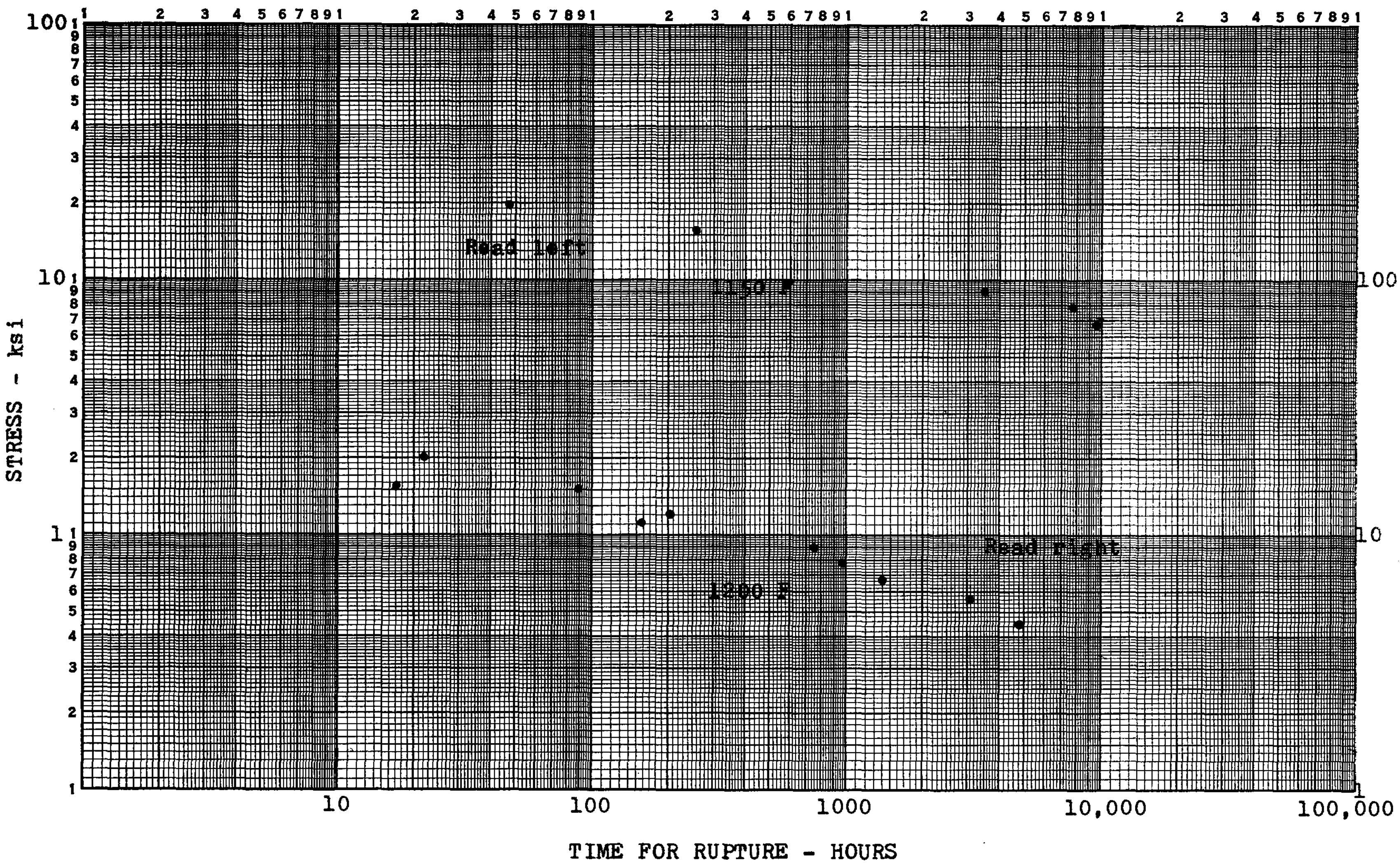

Fig. 19b - Stress vs time for rupture for annealed weld metal.

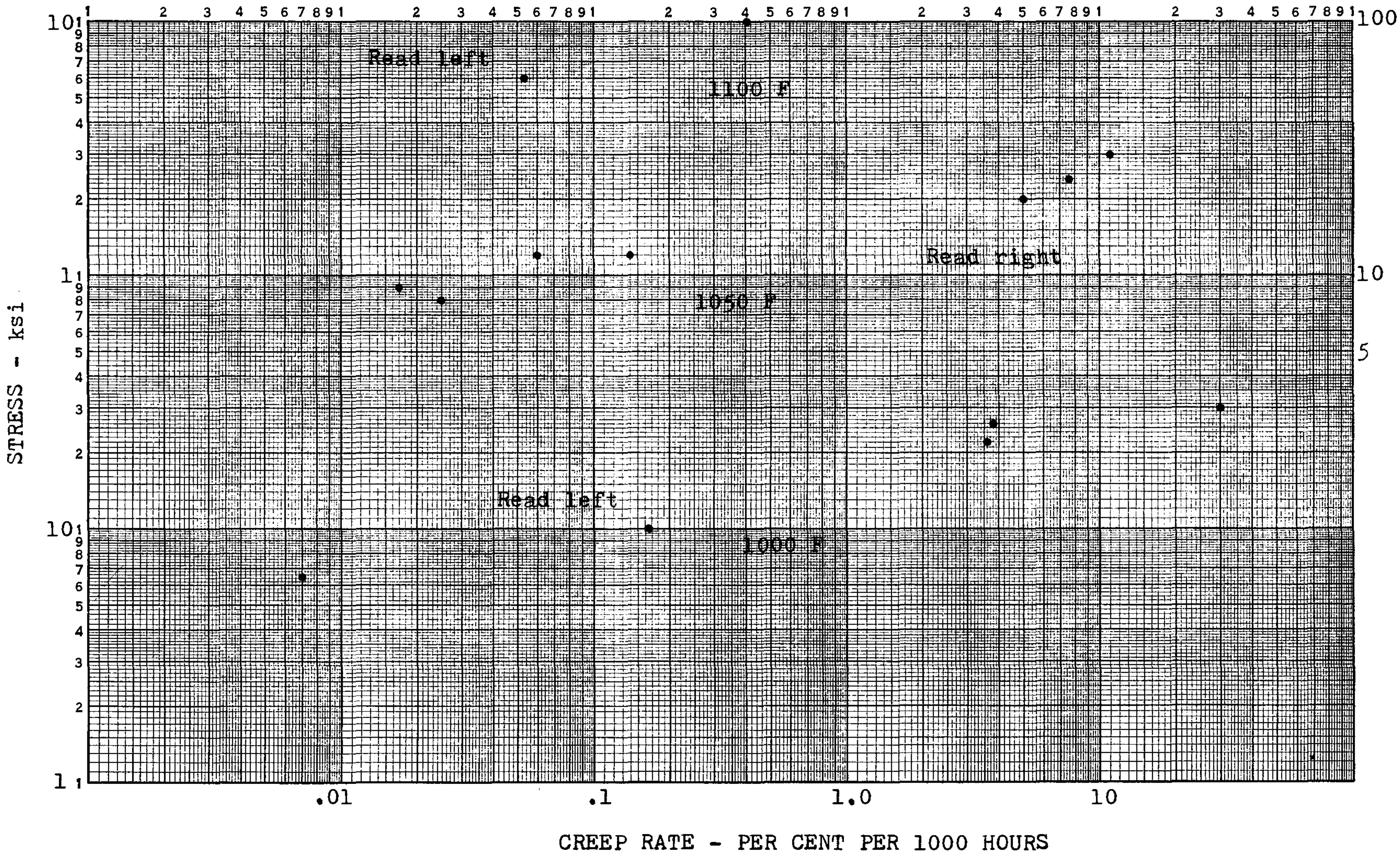

Fig. 19c - Stress vs secondary creep rate for annealed weld metal.

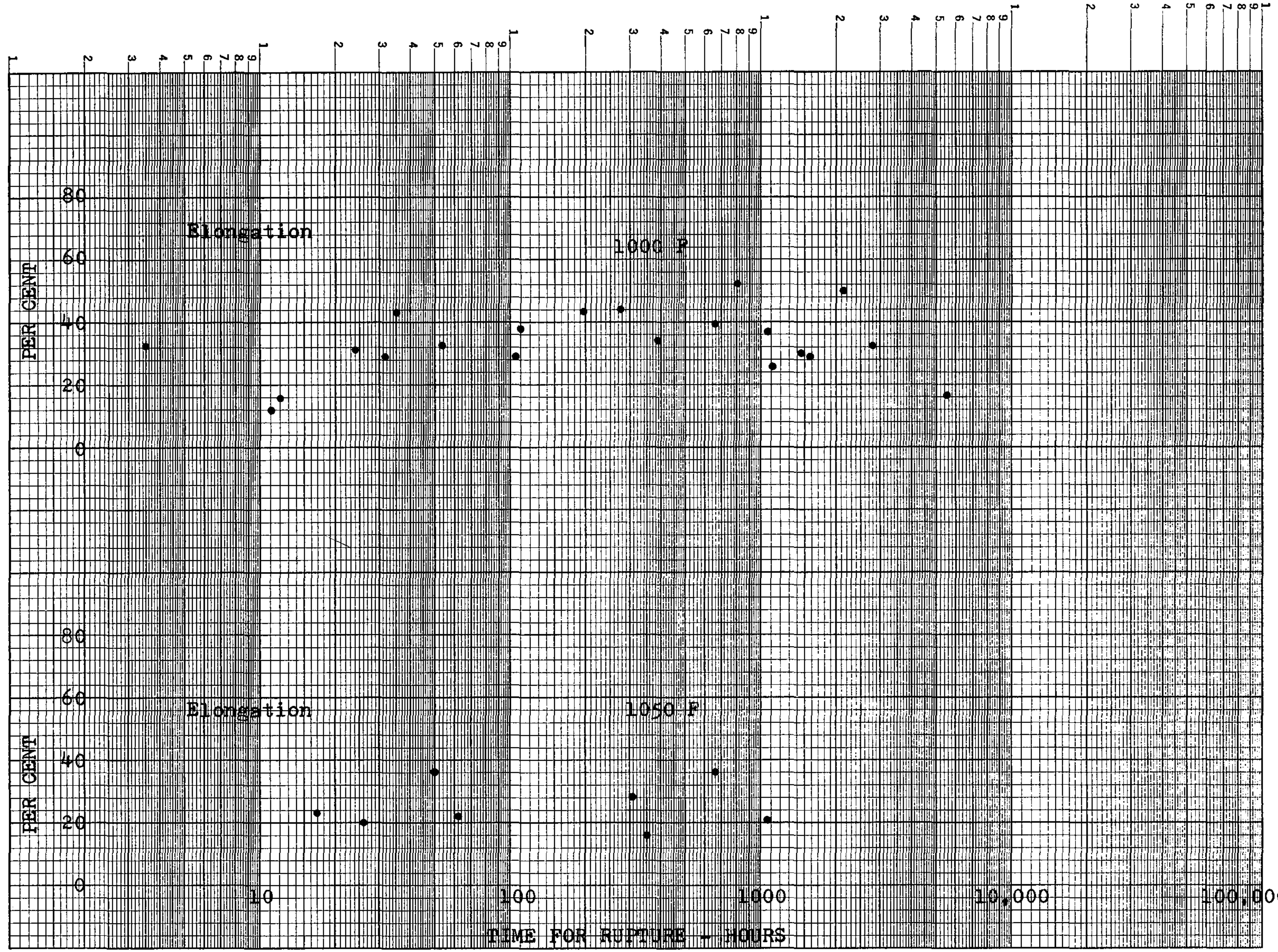

Fig. 19d - Variation of rupture ductility with time for rupture of annealed weld metal.

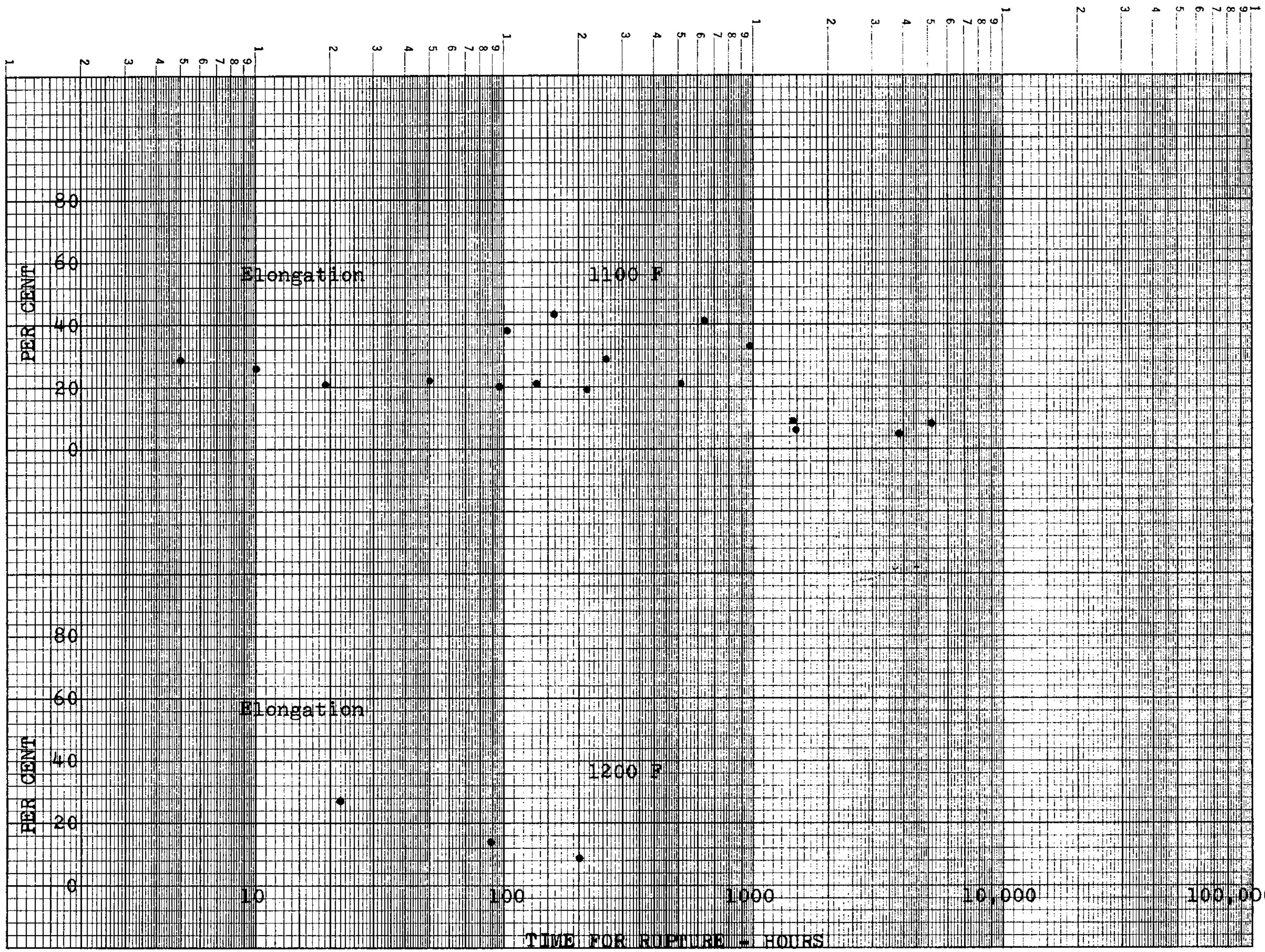

Fig. 19e - Variation of rupture ductility with time for rupture of annealed weld metal.

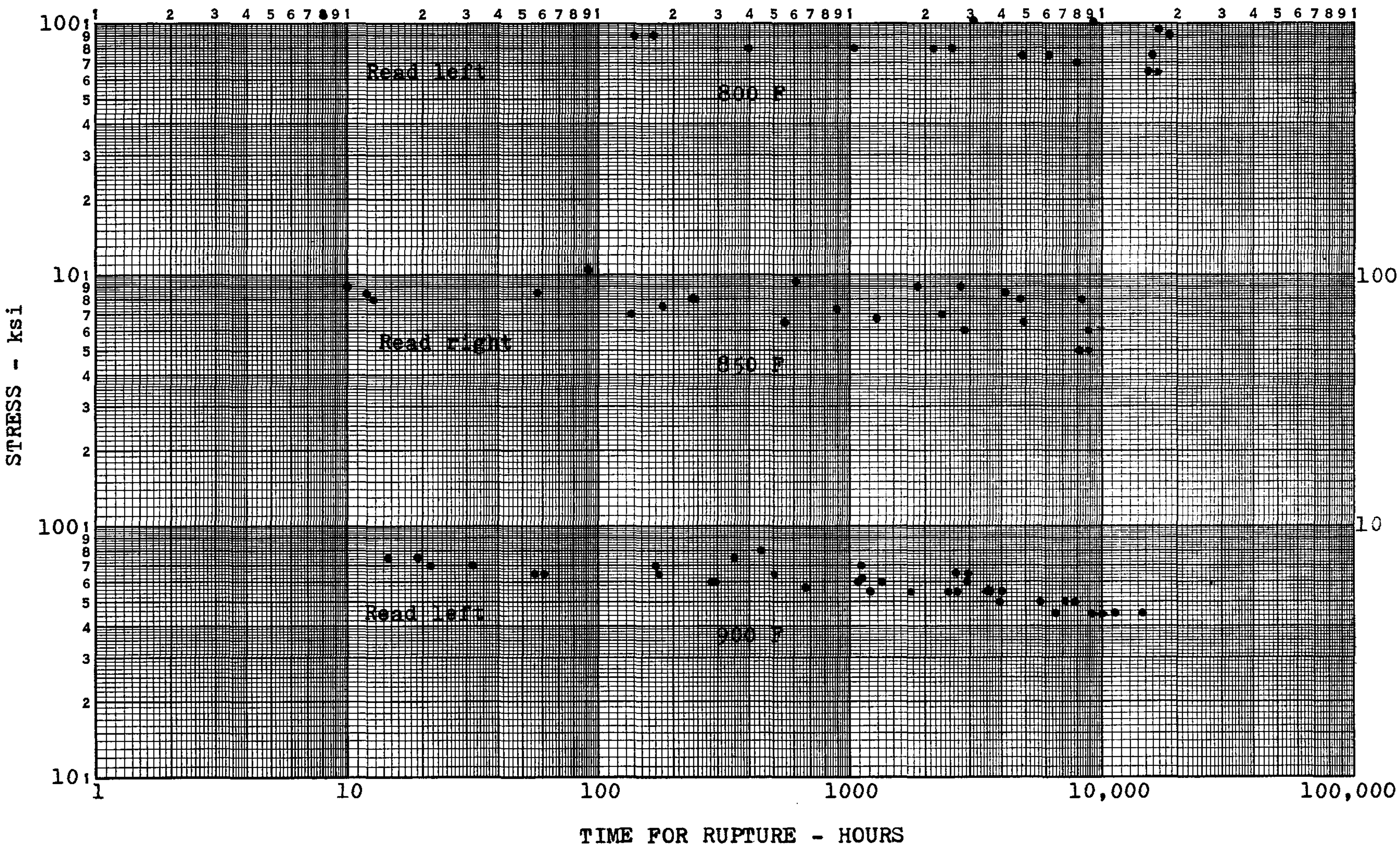

Fig. 20a - Stress vs time for rupture for quenched-and-tempered or tempered weld metal.

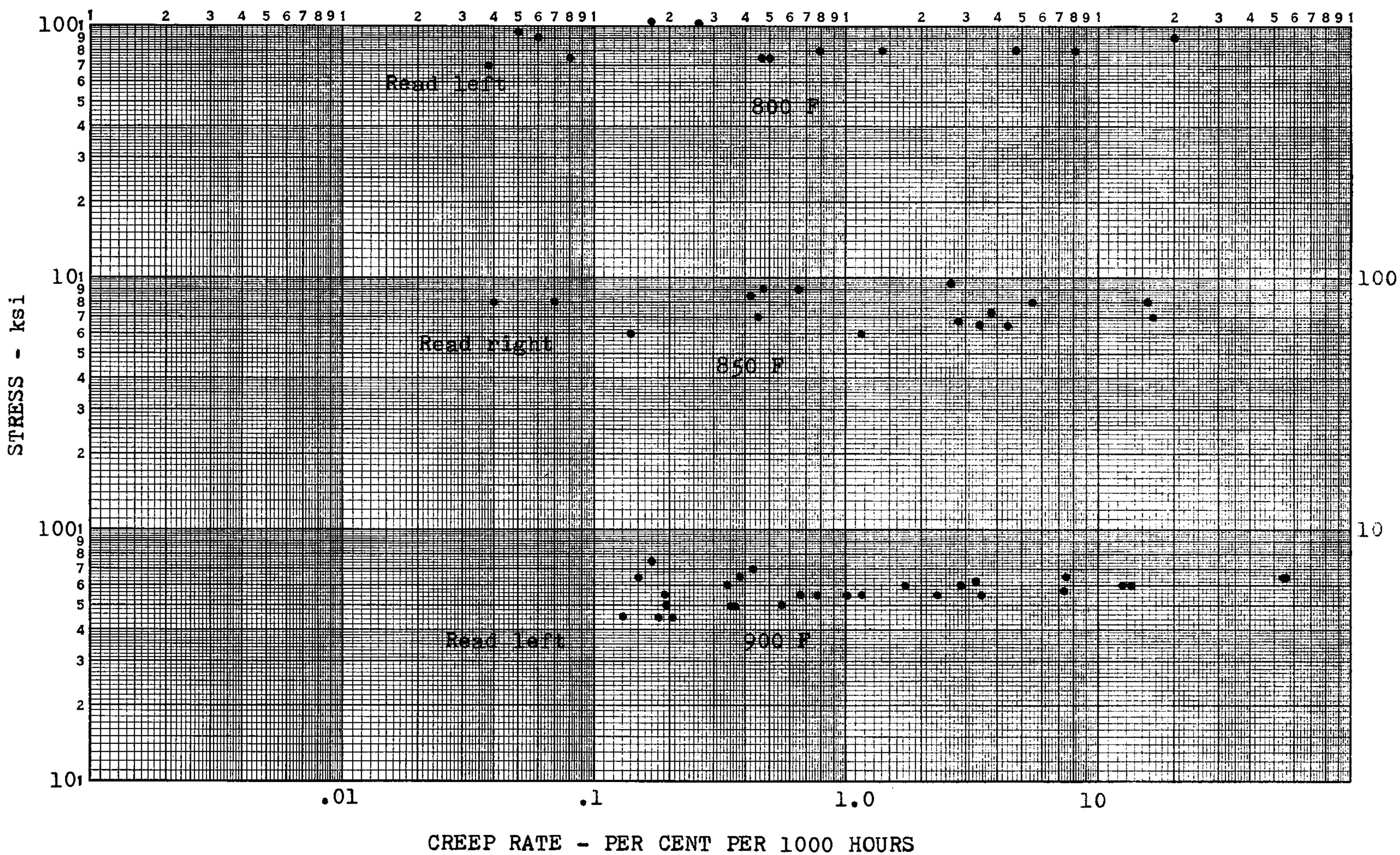

Fig. 20b - Stress vs secondary creep rate for quenched-and-tempered or tempered weld metal

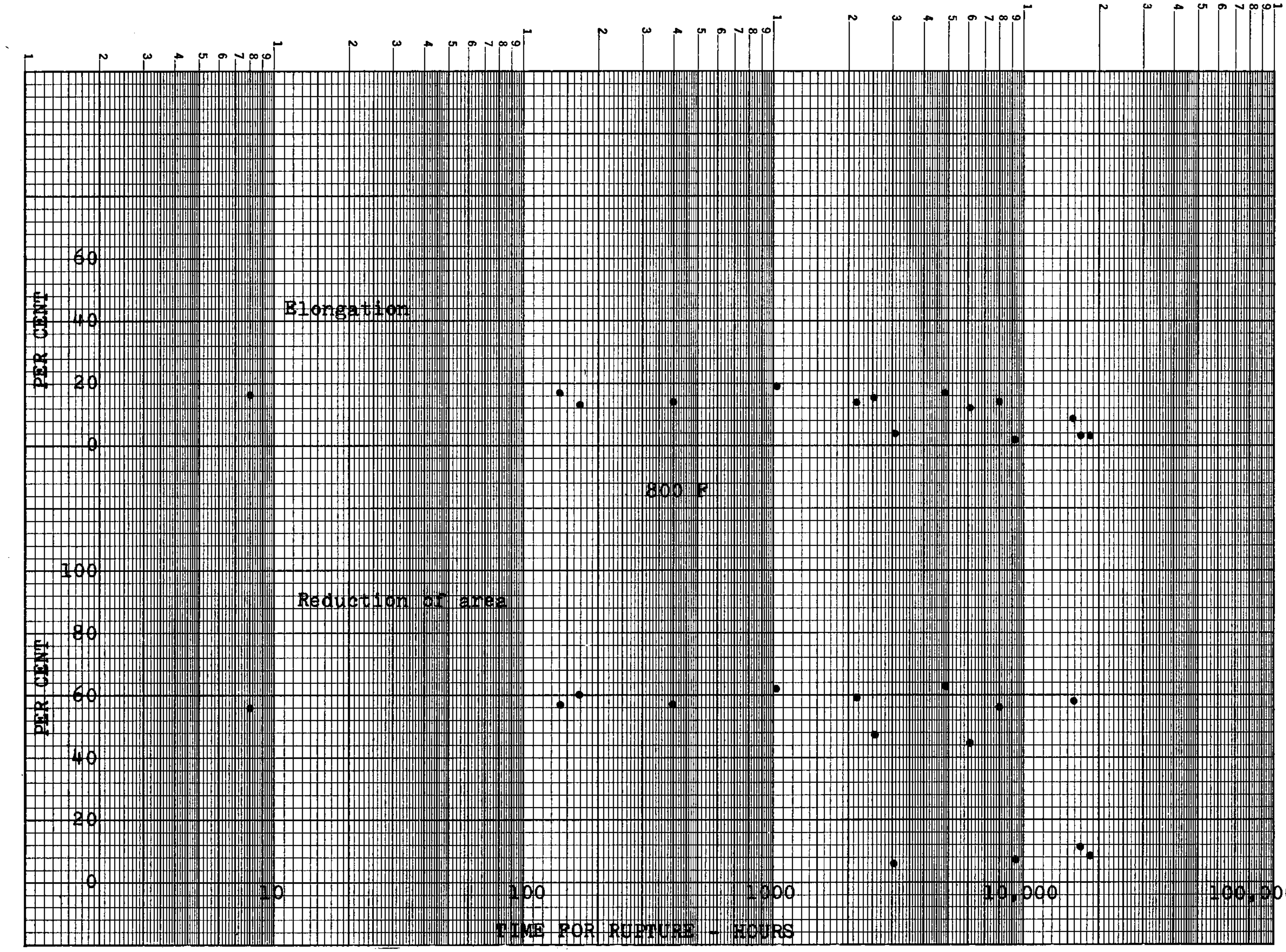

Fig. 20c - Variation of rupture ductility with time for rupture for quenched-and-tempered or tempered weld metal.

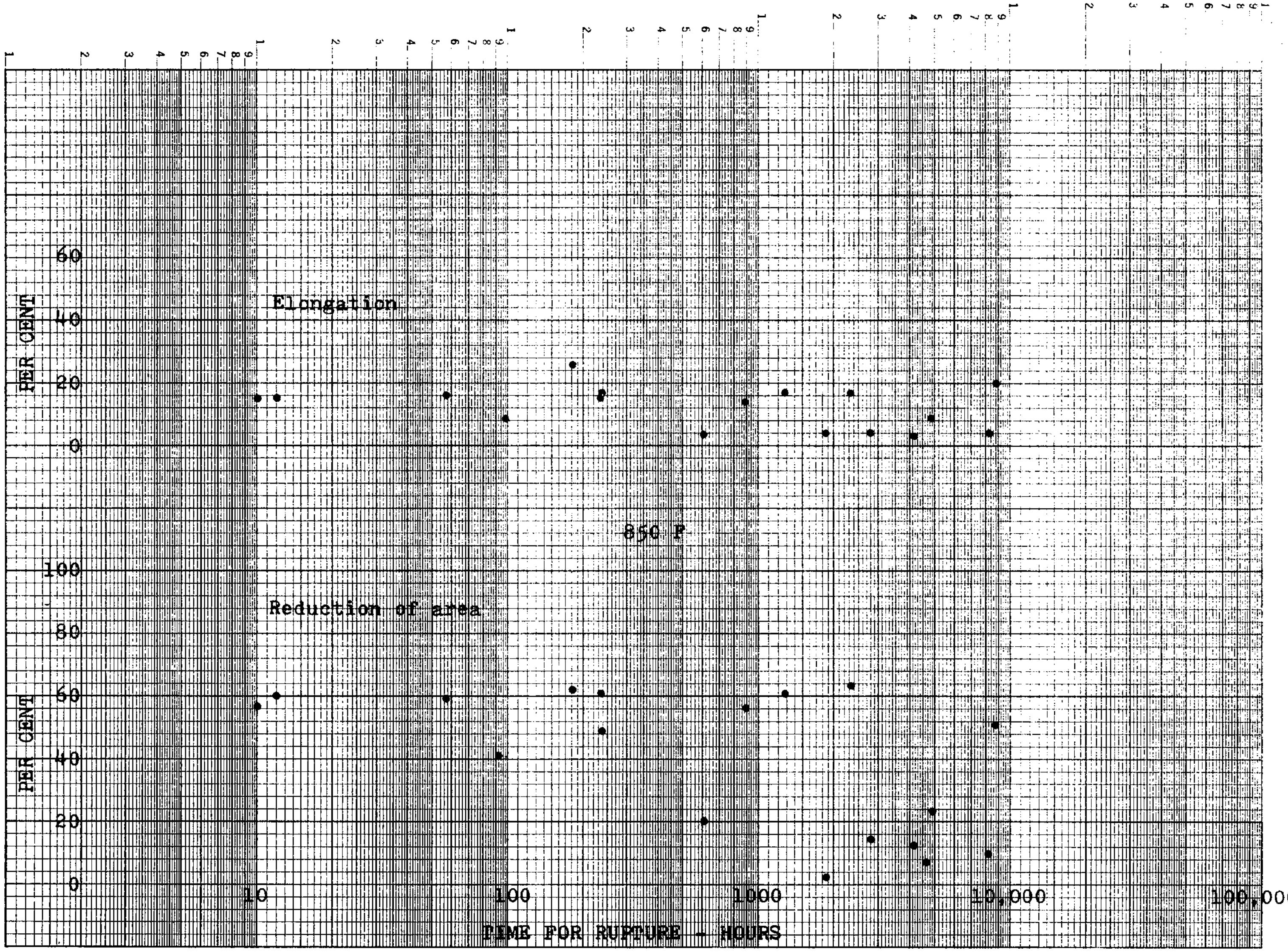

Fig. 20d - Variation of rupture ductility with time for rupture for quenched-and-tempered or tempered weld metal.

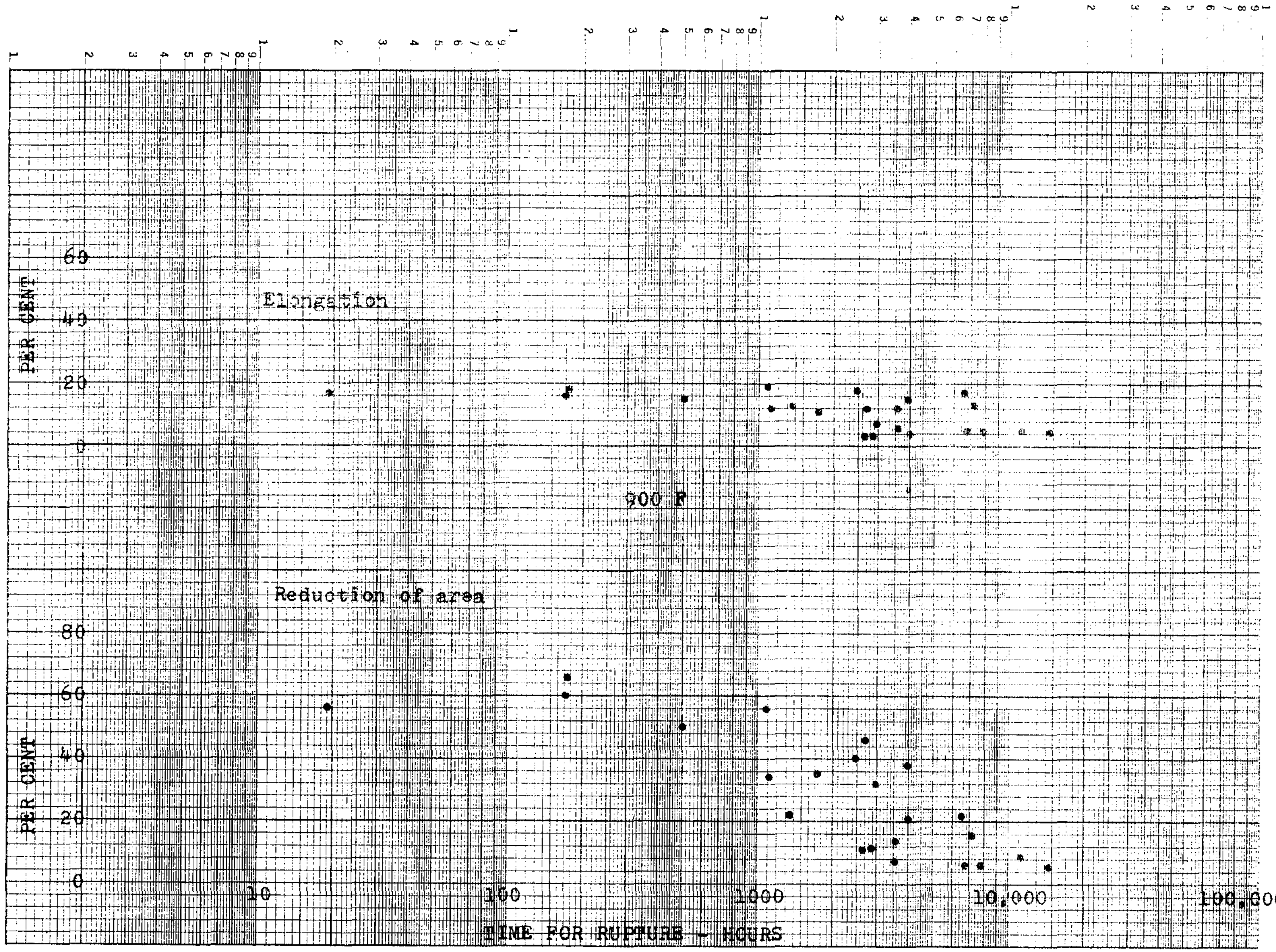

Fig. 20e - Variation of rupture ductility with time for rupture for quenched-and-tempered or tempered weld metal.

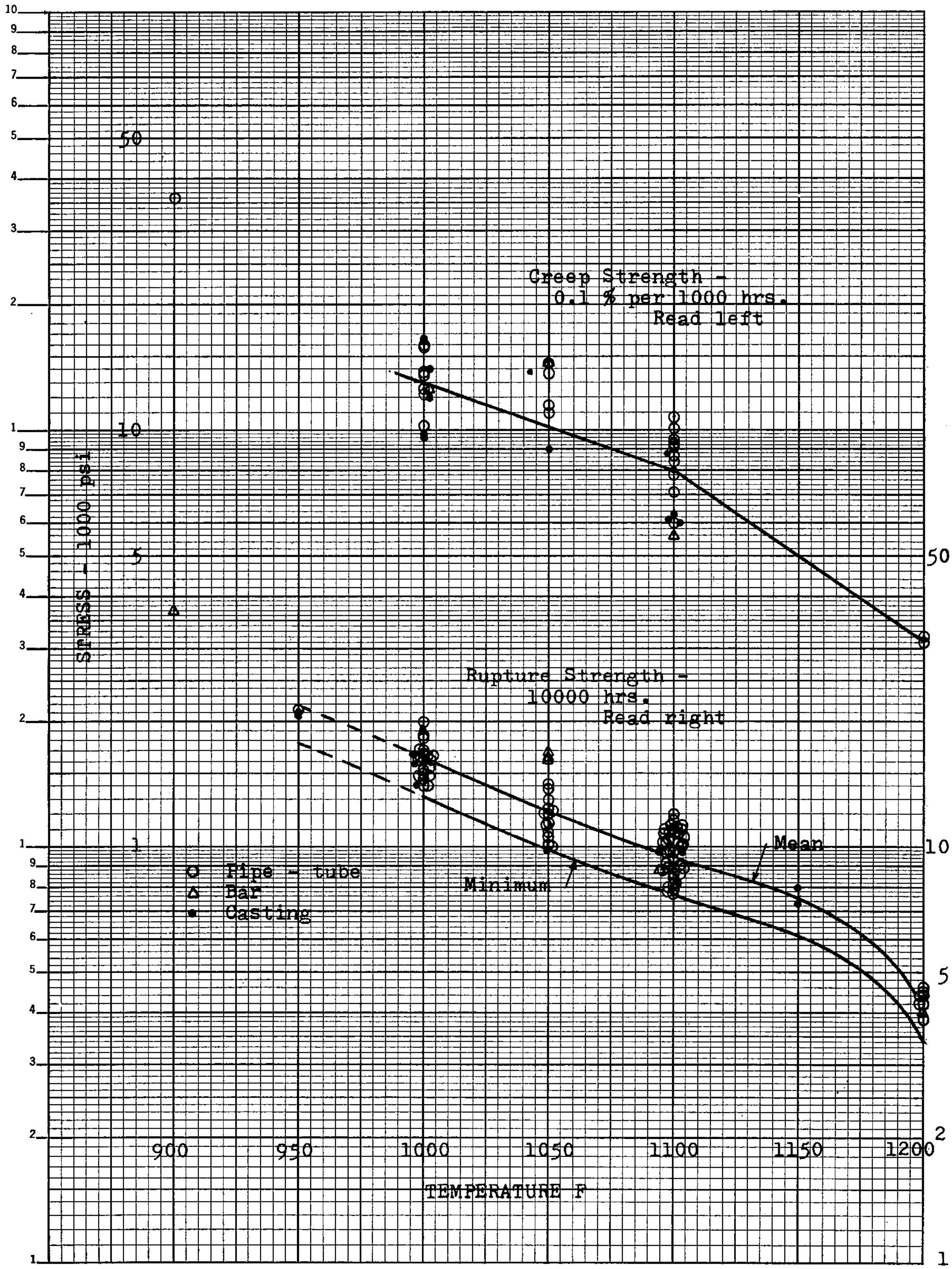

Figure 21 - Variation of rupture strength (10,000 hours) and creep strength (0.1 % per 1000 hours) with temperature for annealed material.

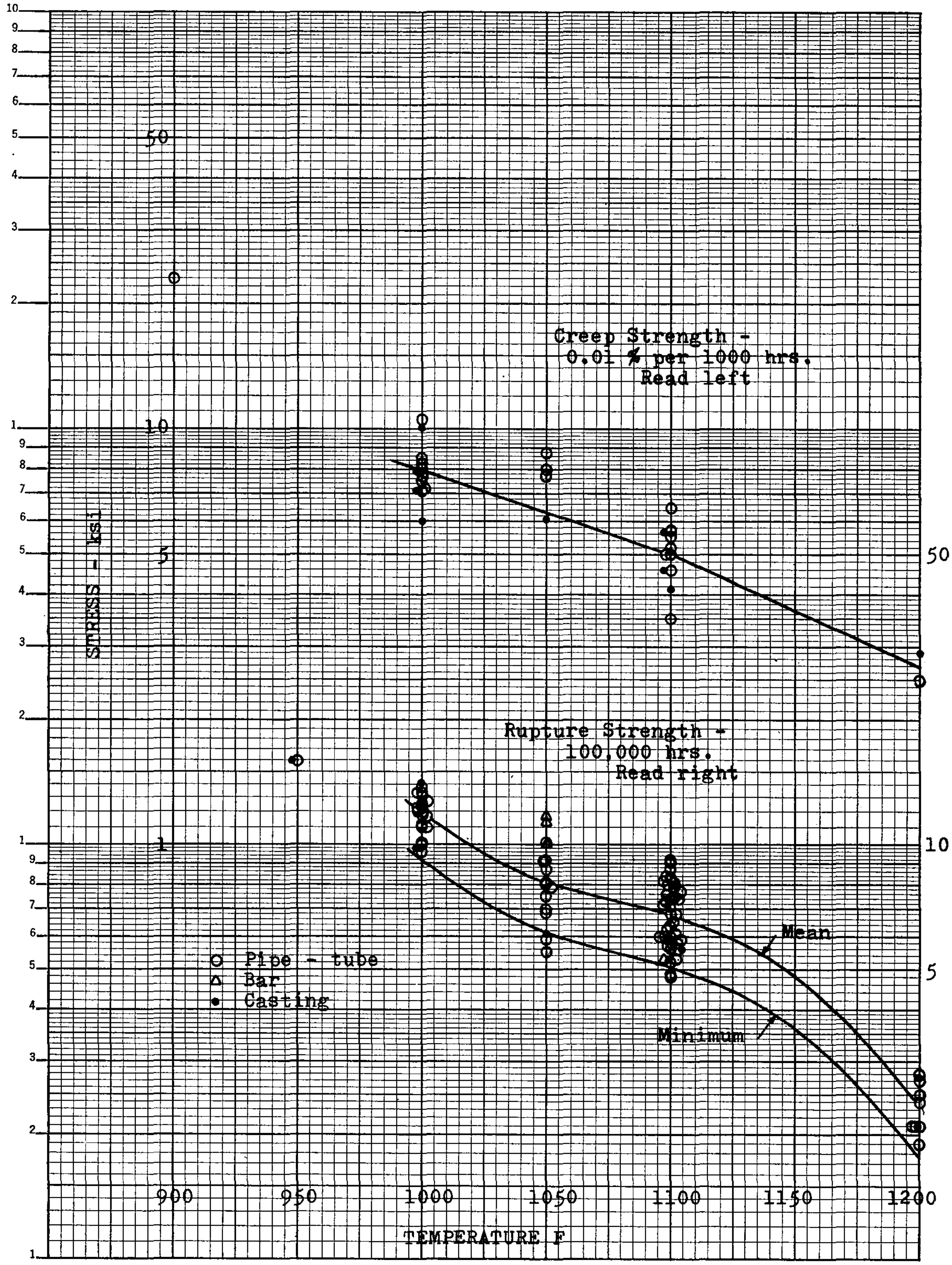

Fig. 22 - Variation of rupture strength (100,000 hours) and creep strength (0.01 % per 1000 hours) with temperature for annealed metal.

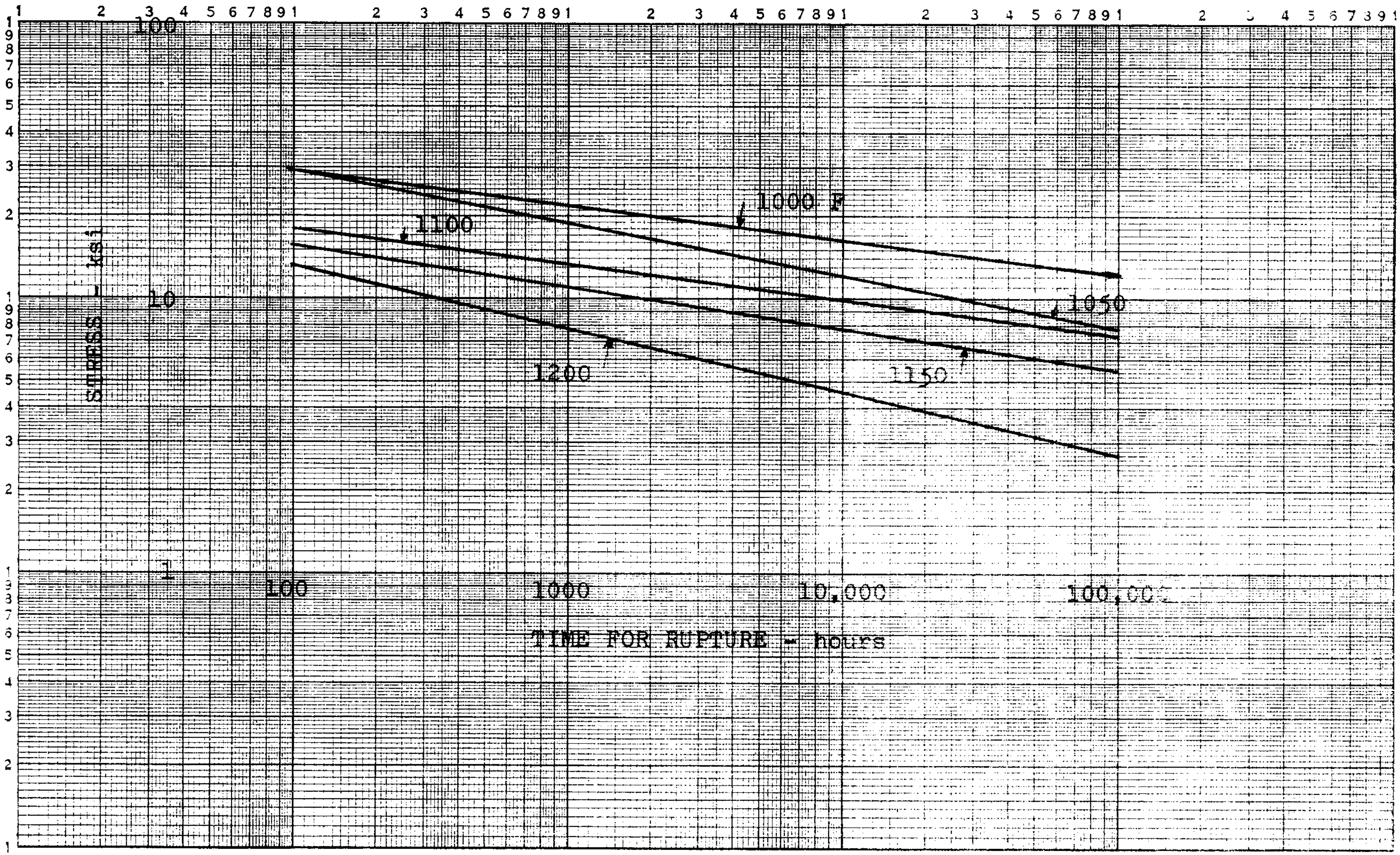

Fig. 23 - Family of regression lines for isothermal log stress vs log time-for-rupture scatter bands, extended to 100,000 hours.

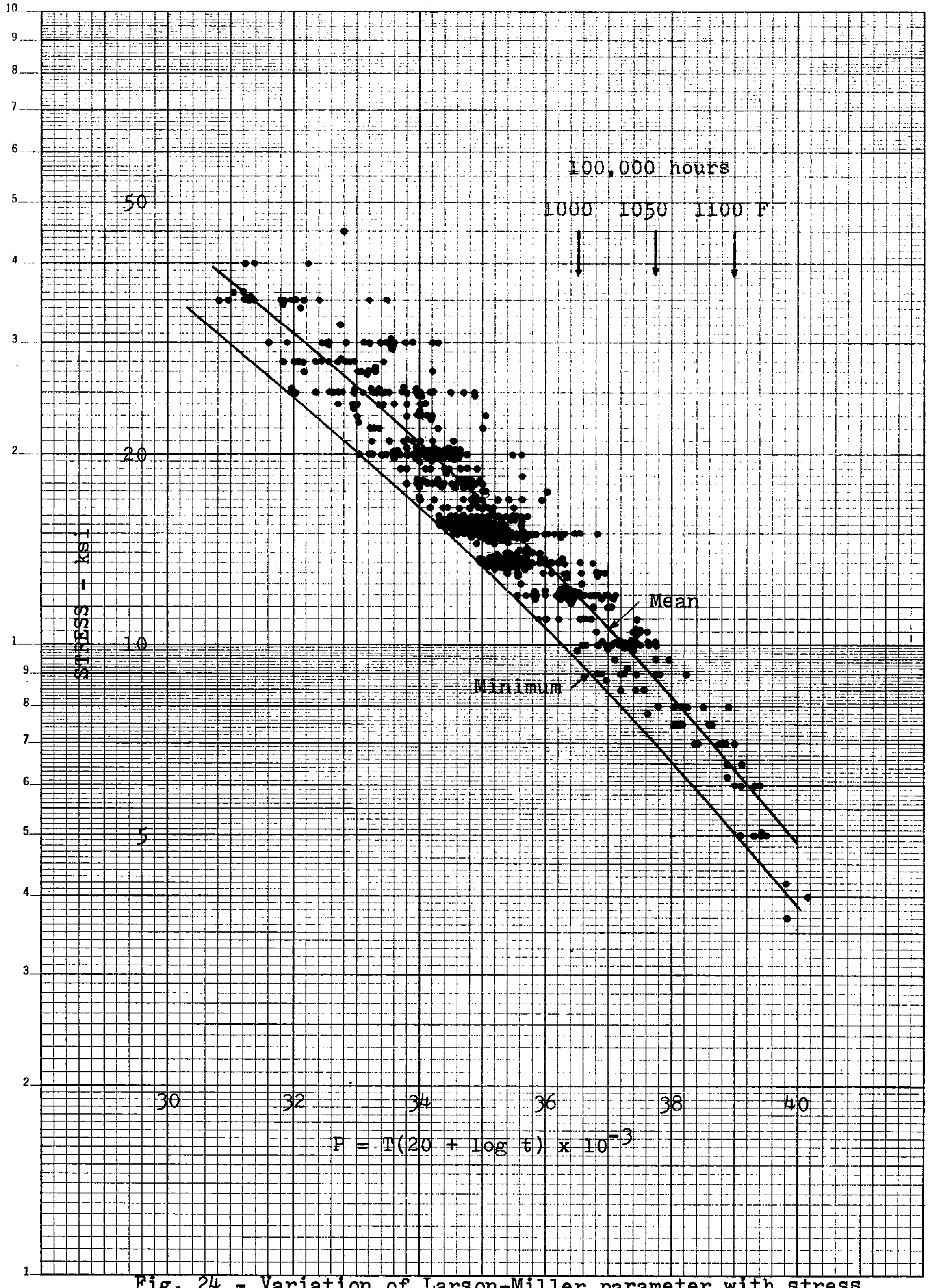

Fig. 24 - Variation of Larson-Miller parameter with stress for rupture of annealed material.

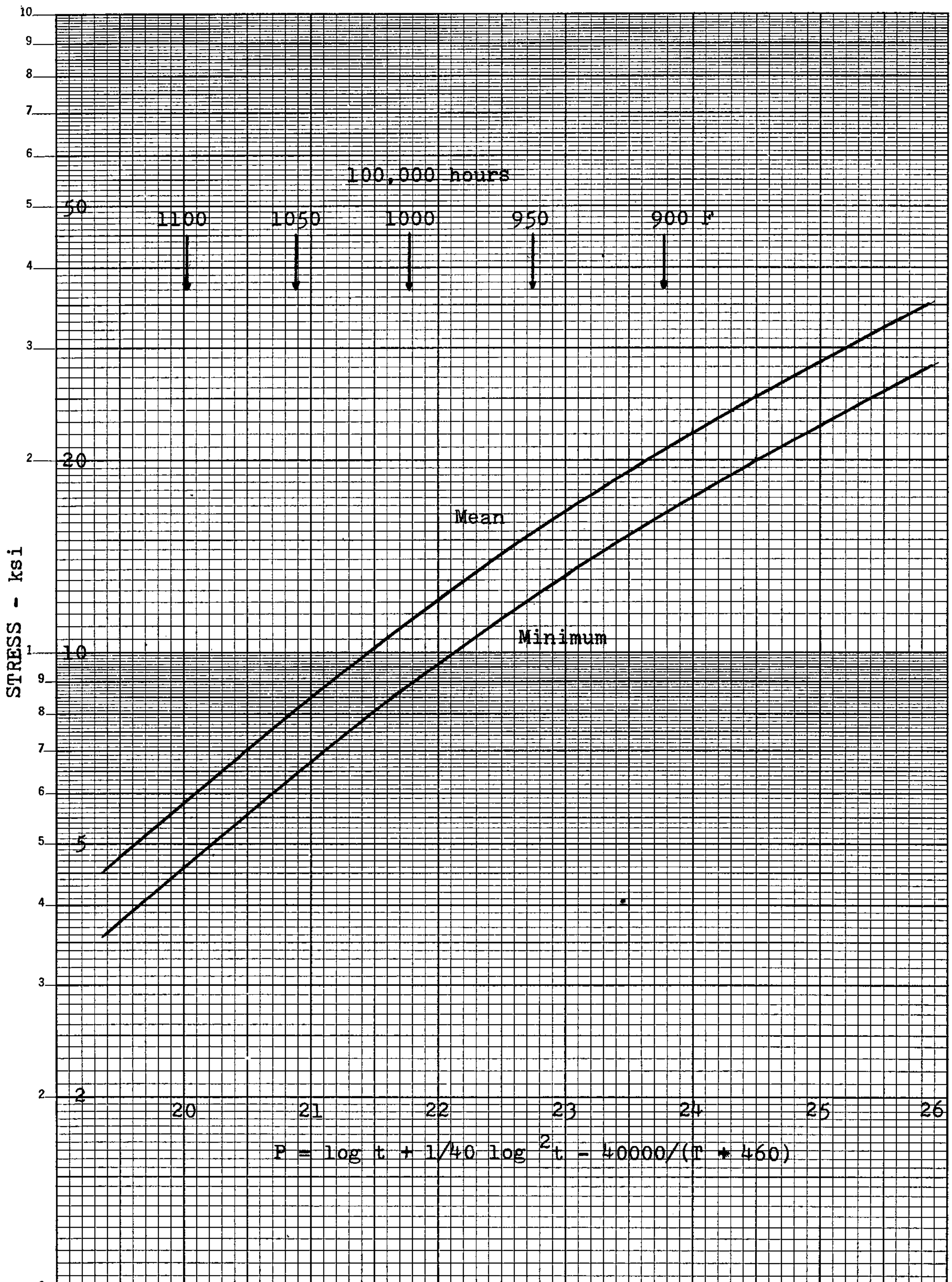

Fig. 25 - Variation of Manson compromise parameter with stress for rupture of annealed material.

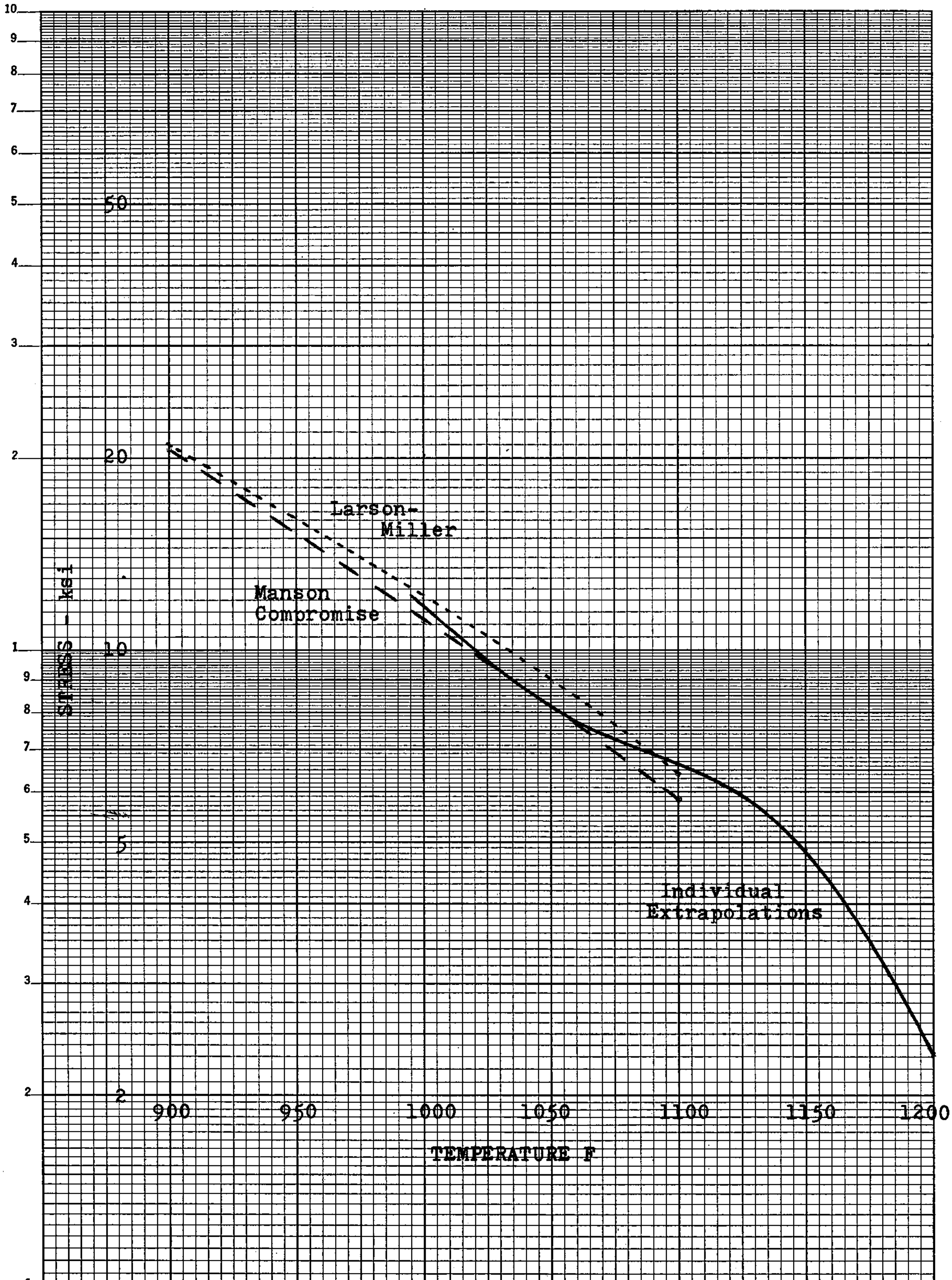

Fig. 26 - Comparison of rupture strength (100,000 hours) trend curves developed by several evaluation procedures.

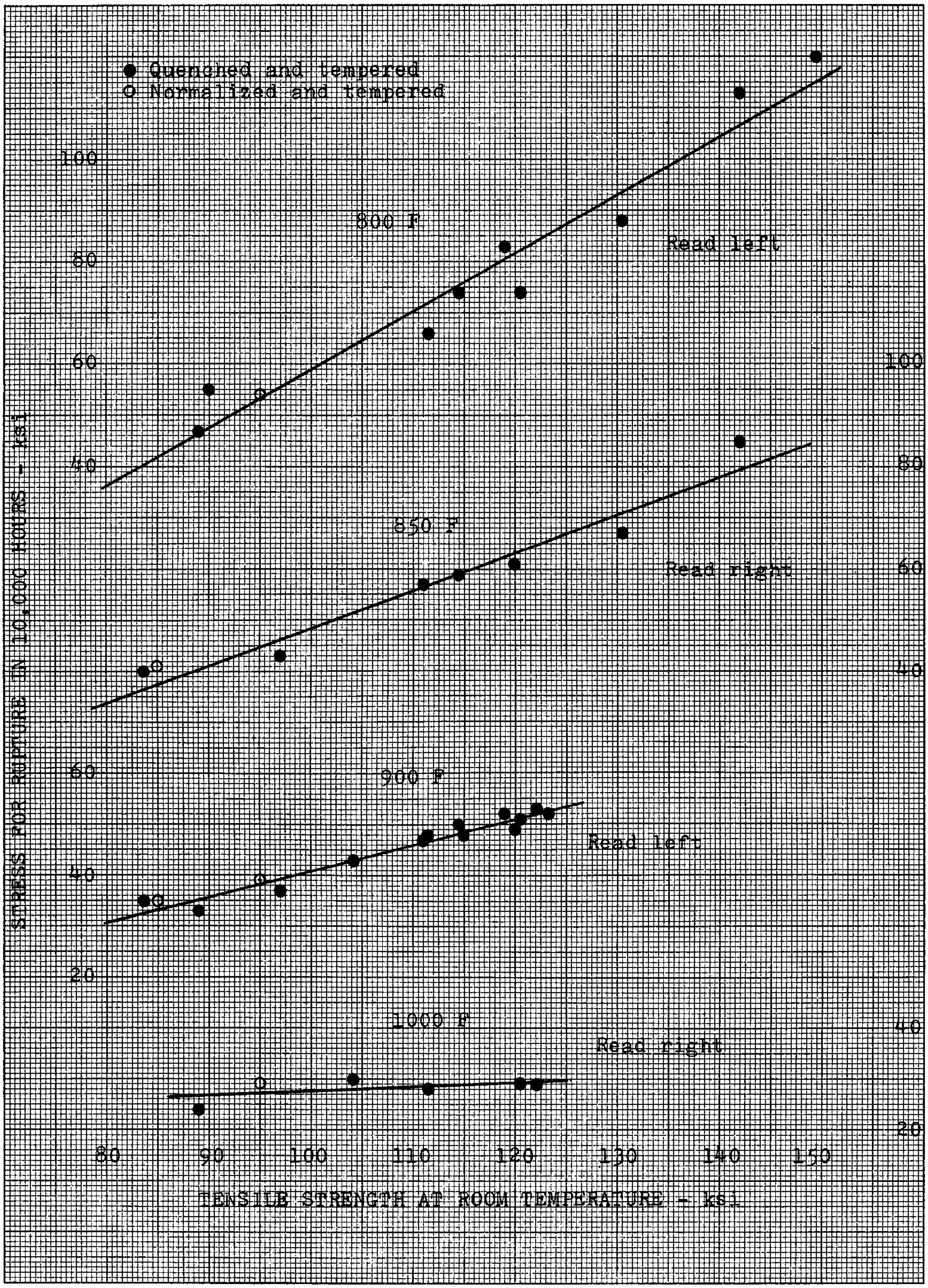

Fig. 27a - Variation of rupture strength (10,000 hours) of normalized-and-tempered and quenched-and-tempered material with tensile strength at 75 F.

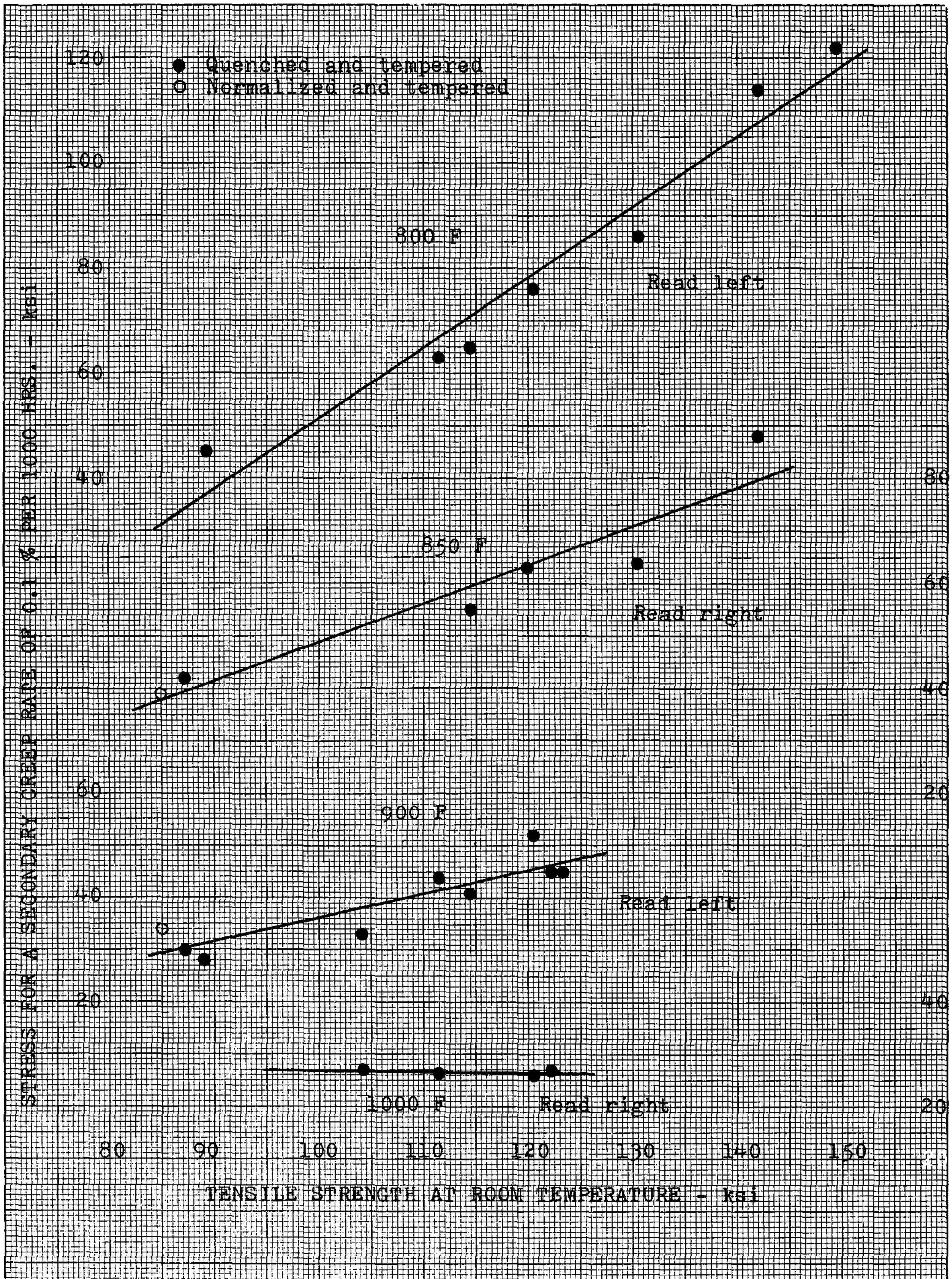

Fig. 27b - Variation of creep strength (0.1 % per 1000 hours) of normalized-and-tempered and quenched-and-tempered material with tensile strength at 75 F.

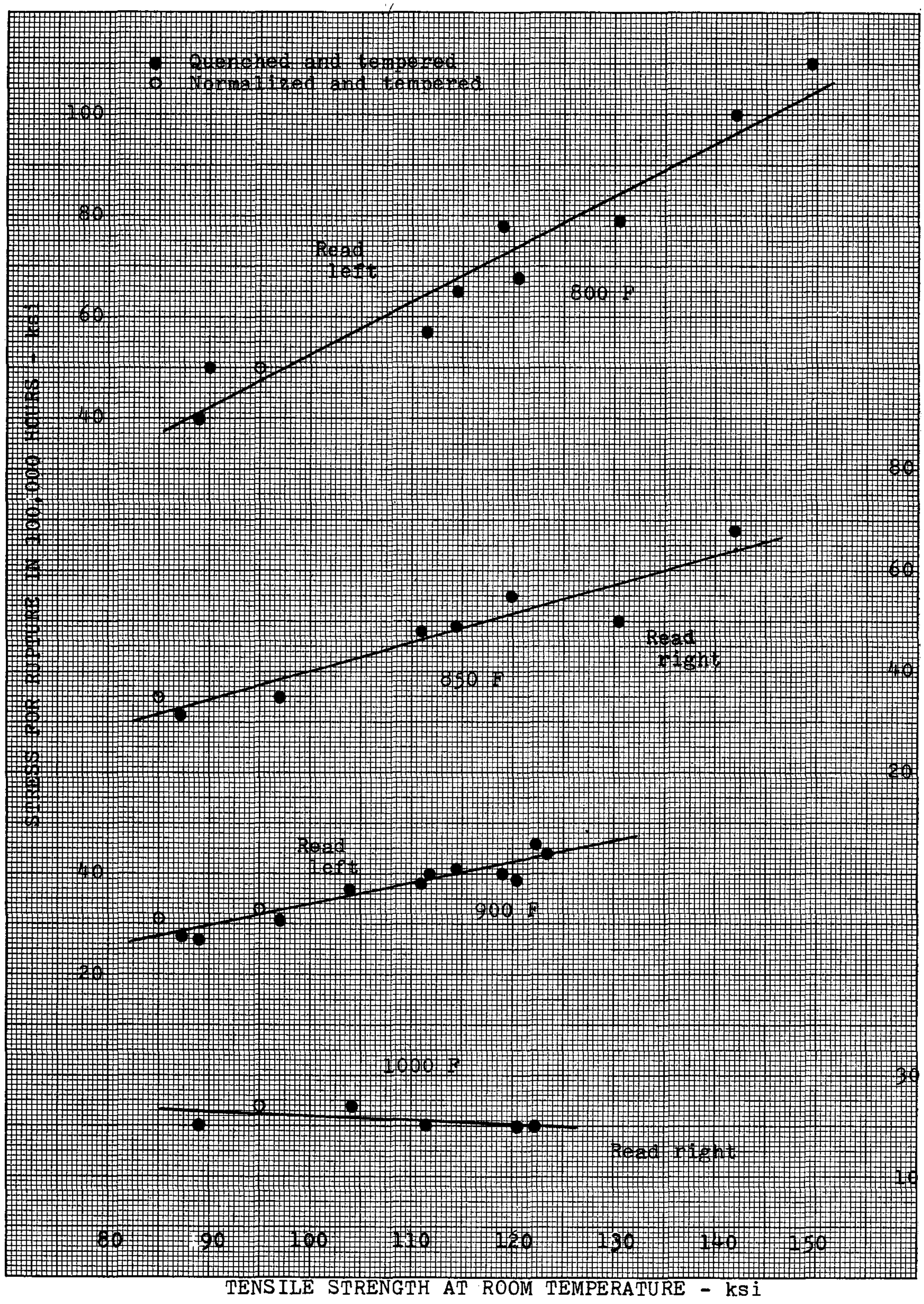

Fig. 27c - Variation of rupture strength (100,000 hours) of normalized-and-tempered and quenched-and-tempered material with tensile strength at 75 F.

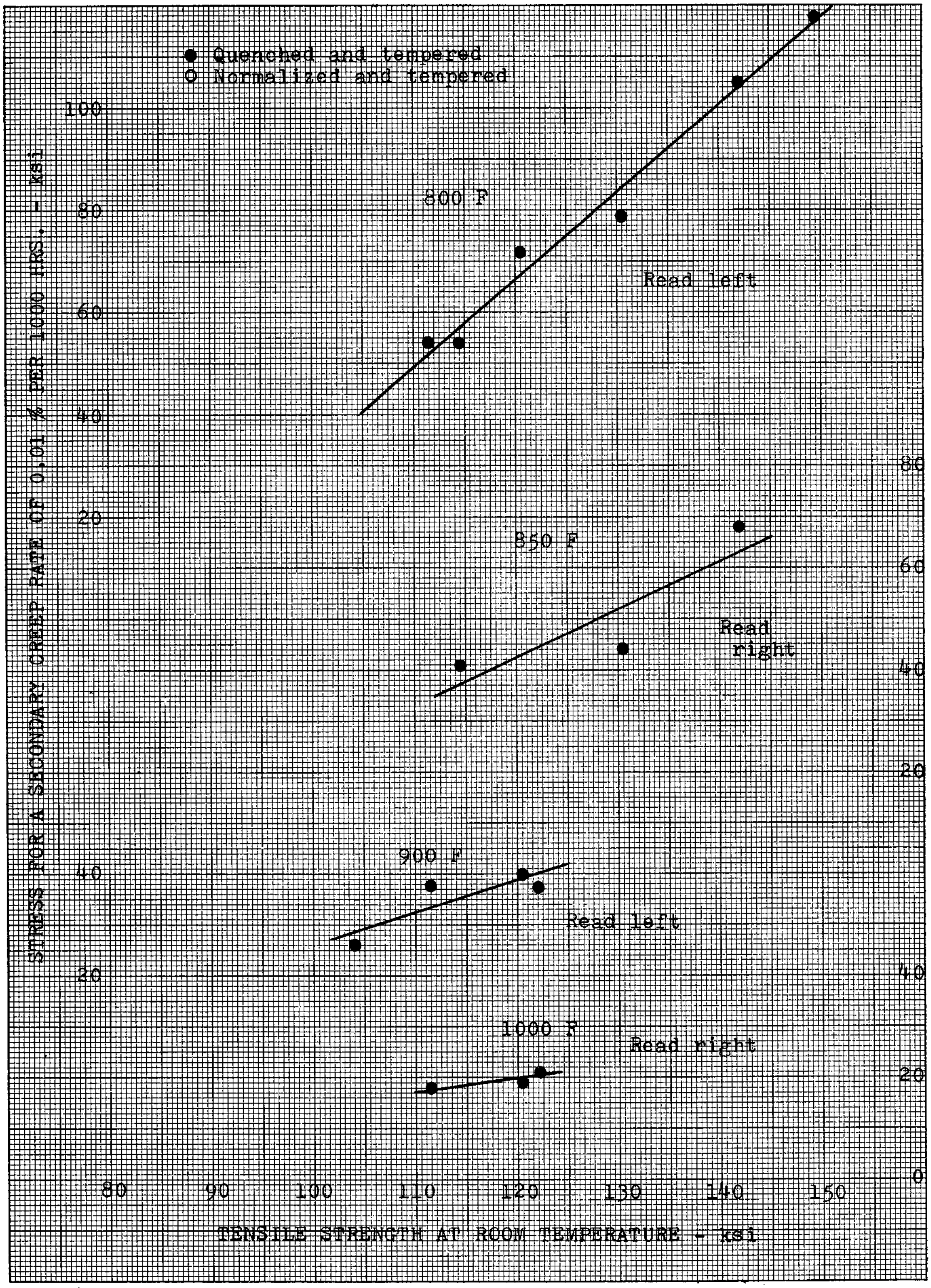

Fig. 27d - Variation of creep strength (0.01 % per 1000 nours) of normalized-and-tempered and quenched-and-tempered material with tensile strength at 75 F.