EVALUATIONS OF THE ELEVATED TEMPERATURE TENSILE AND CREEP-RUPTURE PROPERTIES OF C-Mo, Mn-Mo and Mn-Mo-Ni STEELS

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

DS 47

AMERICAN SOCIETY FOR TESTING AND MATERIALS

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Supplemental Report on the Elevated-Temperature Properties of Chromium-Molybdenum Steels (An Evaluation of 2¼ Cr-1 Mo Steel), DS 6S2 (1971), $6.00

Contents

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ABSTRACT: This report evaluates the elevated temperature strength properties of carbon-moly steel, and various modified versions of that steel commonly identified as manganese-molybdenum or manganese-molybdenum-nickel steels. The data that have been evaluated encompass test results previously included in ASTM Data Series DS 6 (1953)$^{(1)}$ and DS6-S1 (1966)$^{(2)}$, and previously unpublished test results gathered by The Metal Properties Council.

Employing the method of least squares, trend curves depicting in ratio form the characteristic temperature variations of yield and tensile strengths have been developed. The rupture data have been evaluated by both direct isothermal interpolation or extrapolation, and by time-temperature parameters, to establish the temperature dependences of the average and minimum stresses to cause rupture in 1000, 10,000 and 100,000 hours. The secondary creep rate data have been evaluated by direct interpolation or extrapolation to determine the temperature dependences of average and minimum stresses to cause secondary creep rates of 0.1 and 0.01 percent per 1000 hours. These latter trend curves could be developed only for C-Mo steel, there being too few data for the remaining grades to warrant such evaluation. Elongation and reduction of area data are included for both the short time elevated temperature tensile tests and for the rupture tests.

Several summary figures immediately following this abstract, Figs. 1-6, show the temperature dependence of strength properties for the various grades evaluated in this report. In these figures, the yield and tensile strength curves have been computed from the respective ratio trend curves so that they correspond at room temperature to the specified minimum values of common ASTM specifications.

The body of the report provides in tables, text, and figures, details concerning the identification of the individual lots of material, the evaluation procedures, and the results.

KEY WORDS: elevated temperature, tensile strength, yield strength, creep strength, rupture strength, elongation, reduction of area, carbon moly and manganese moly steels, time-temperature parameter, data evaluation, mechanical properties.

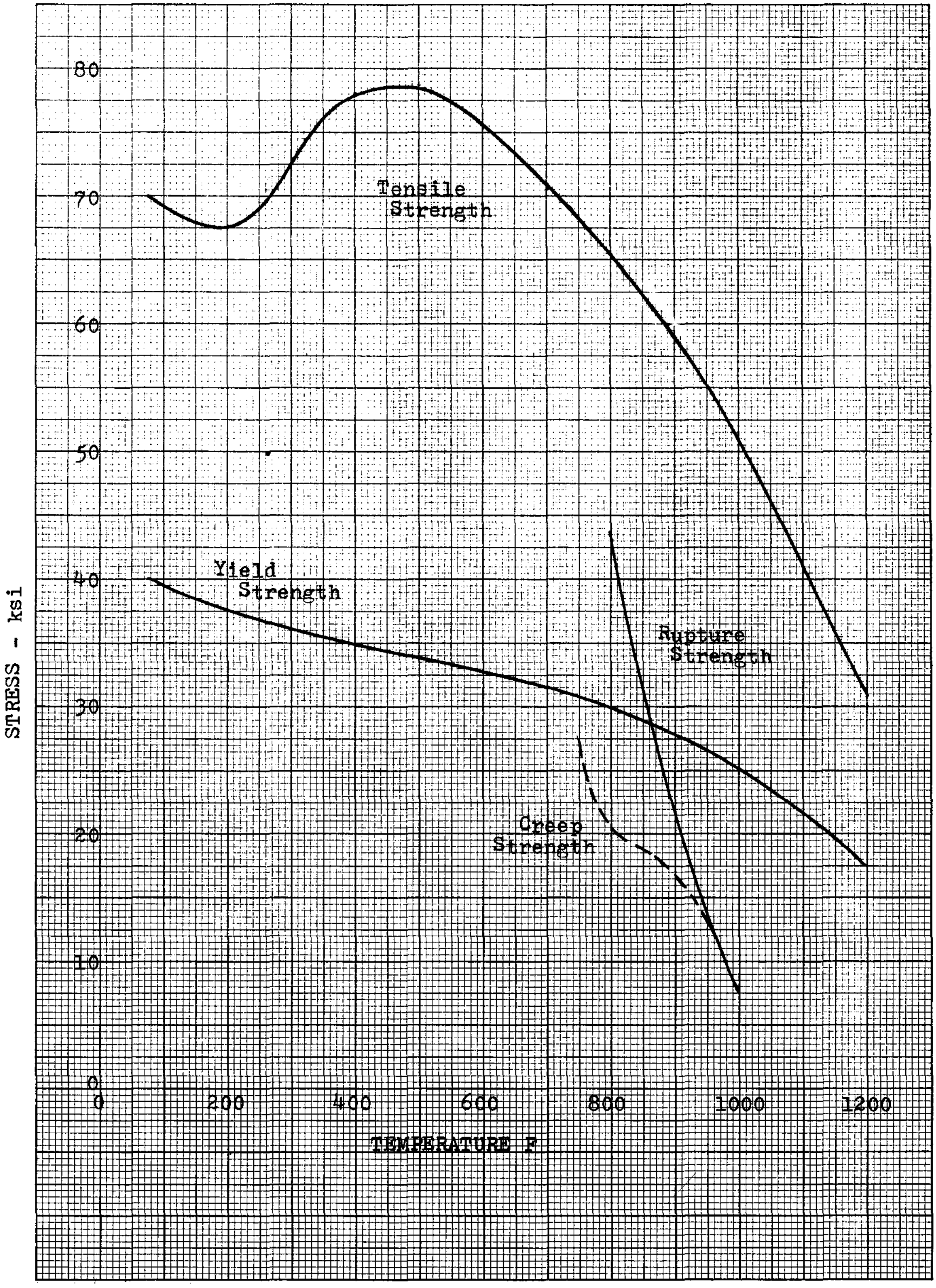

Fig. 1 Effect of temperature on yield strength, tensile strength, creep strength (0.01% per 1000 hrs) and rupture strength (100,000 hrs) of C-Mo steel. Yield and tensile strengths are adjusted to 40 and 70 ksi at 75 F. Creep and rupture strengths are averages of available data.

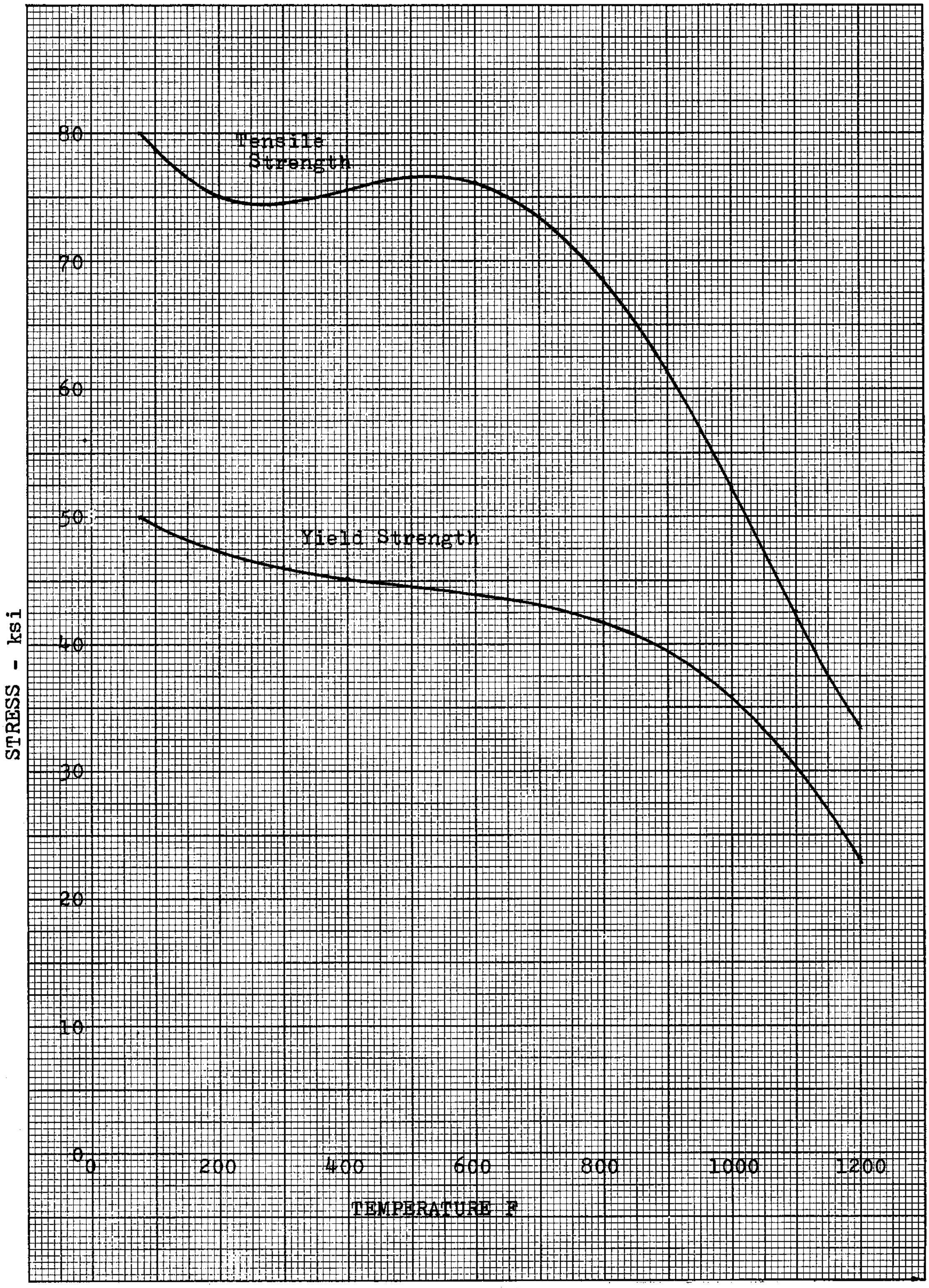

Fig. 2 Effect of temperature on yield strength and tensile strength of Mn-Mo-(Ni) steel, A 302 (or A 533, Class 1), adjusted to 50 and 80 ksi at 75 F.

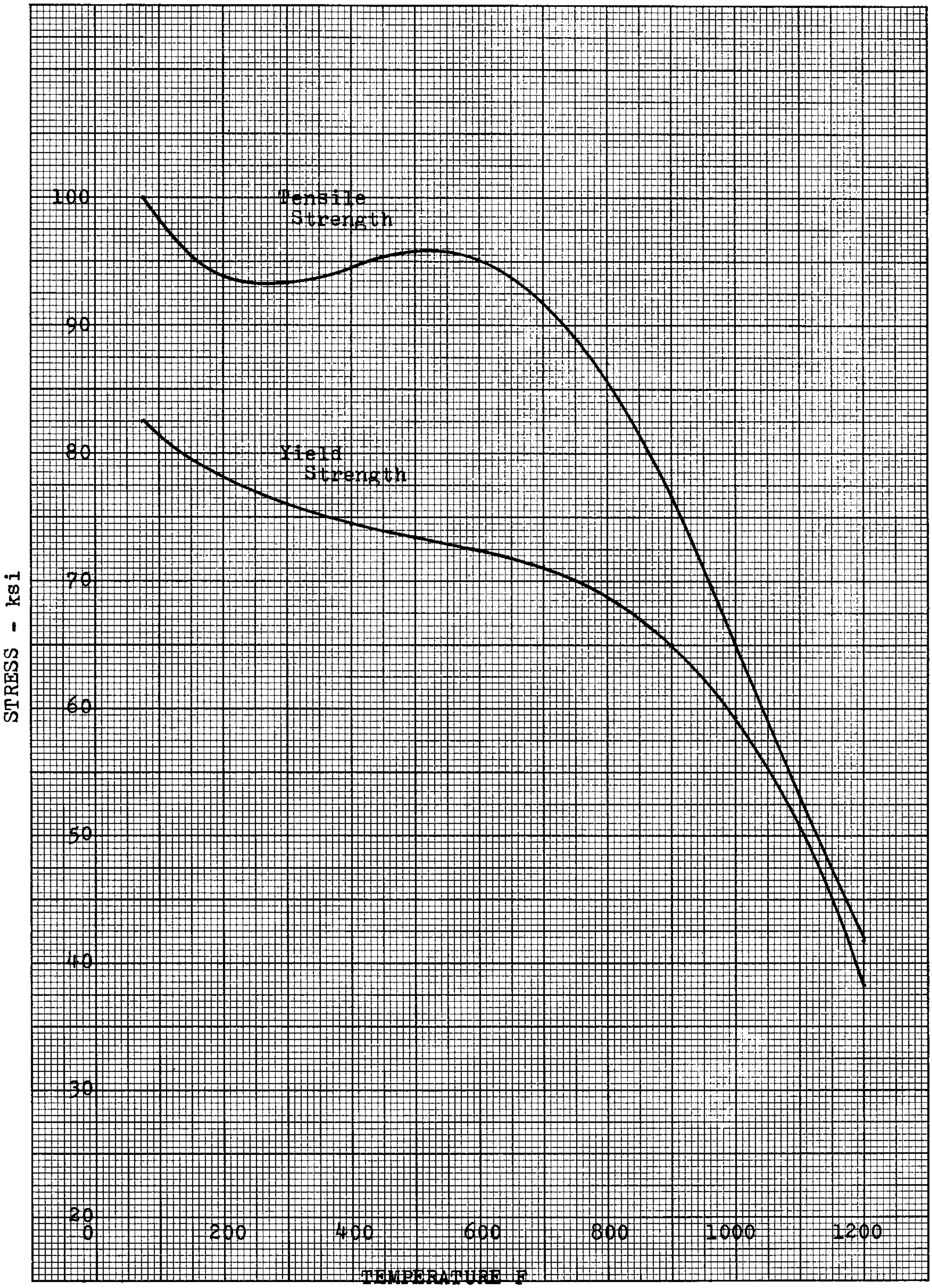

Fig. 3 Effect of temperature on yield strength and tensile strength of Mn-Mo-(Ni) steel, A 533, Class 3, adjusted to 82.5 and 100 ksi at 75 F.

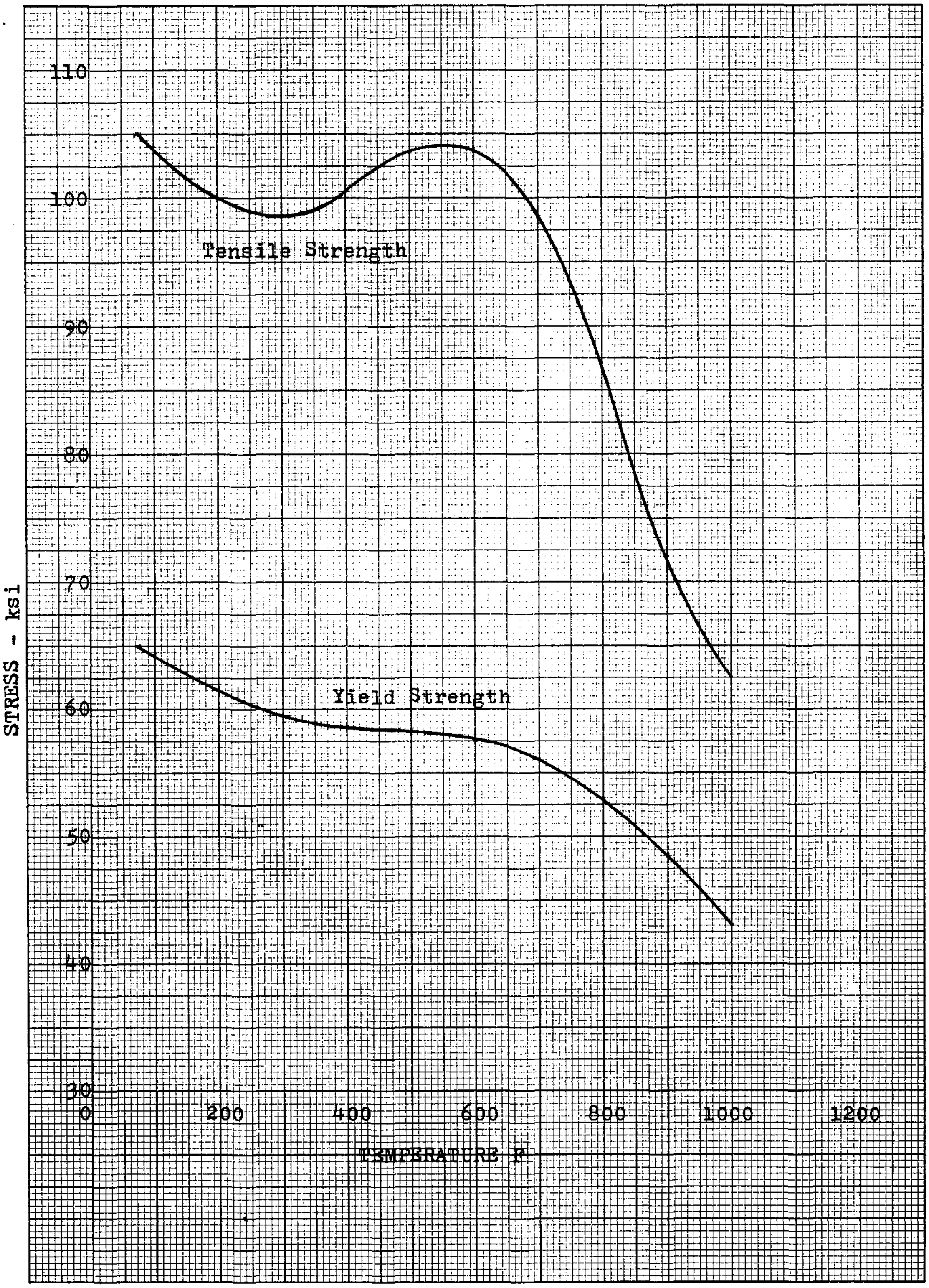

Fig. 4 Effect of temperature on yield and tensile strengths of Mn-Mo steel, A 372, Class IV, adjusted to 65 and 105 ksi at 75 F.

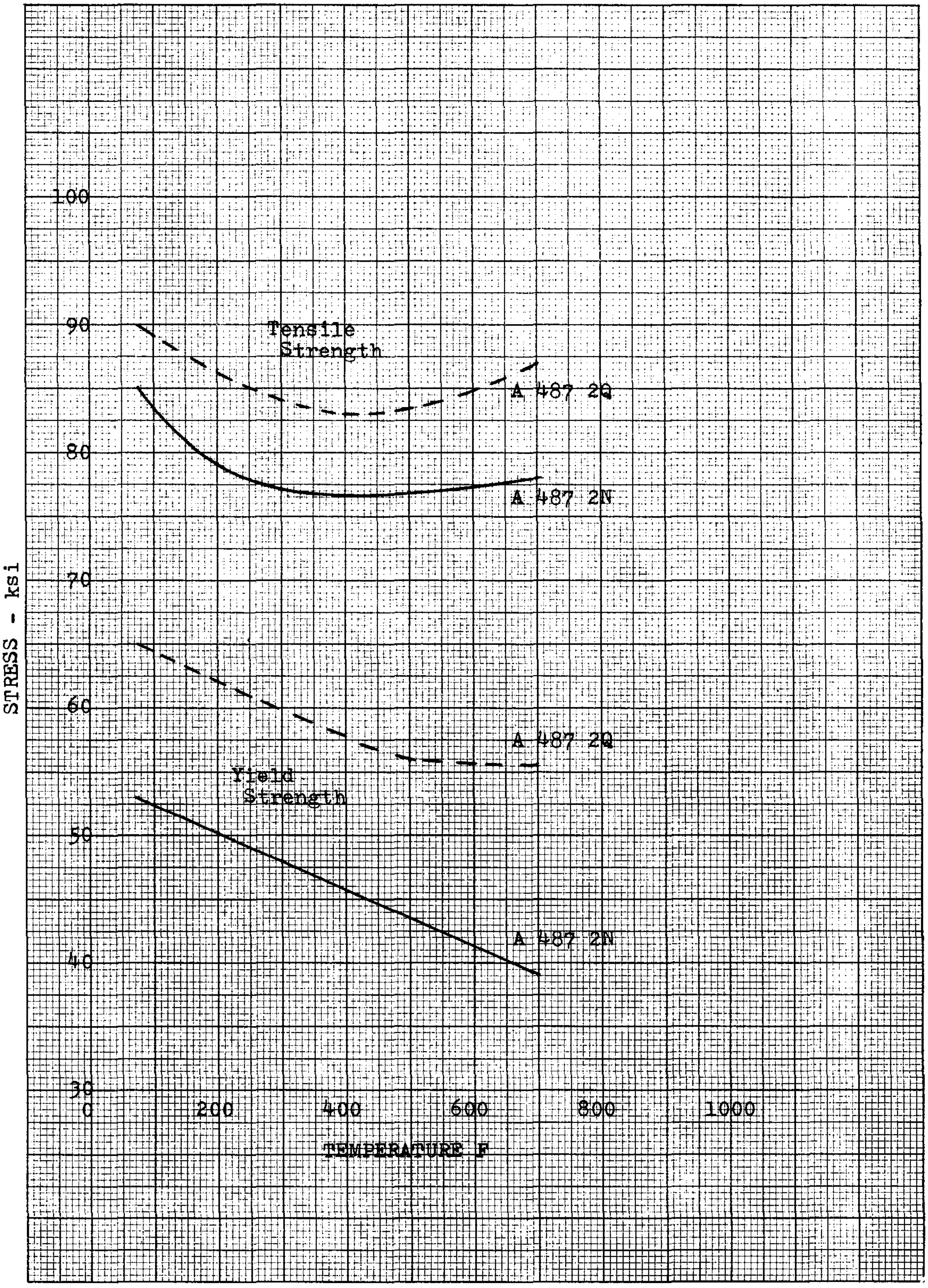

Fig. 5 Effect of temperature on yield and tensile strengths of cast Mn-Mo steel, A 487, Grades 2N and 2Q, adjusted to 53 and 85 ksi (for 2N) and 65 and 90 ksi (for 2Q) at 75 F.

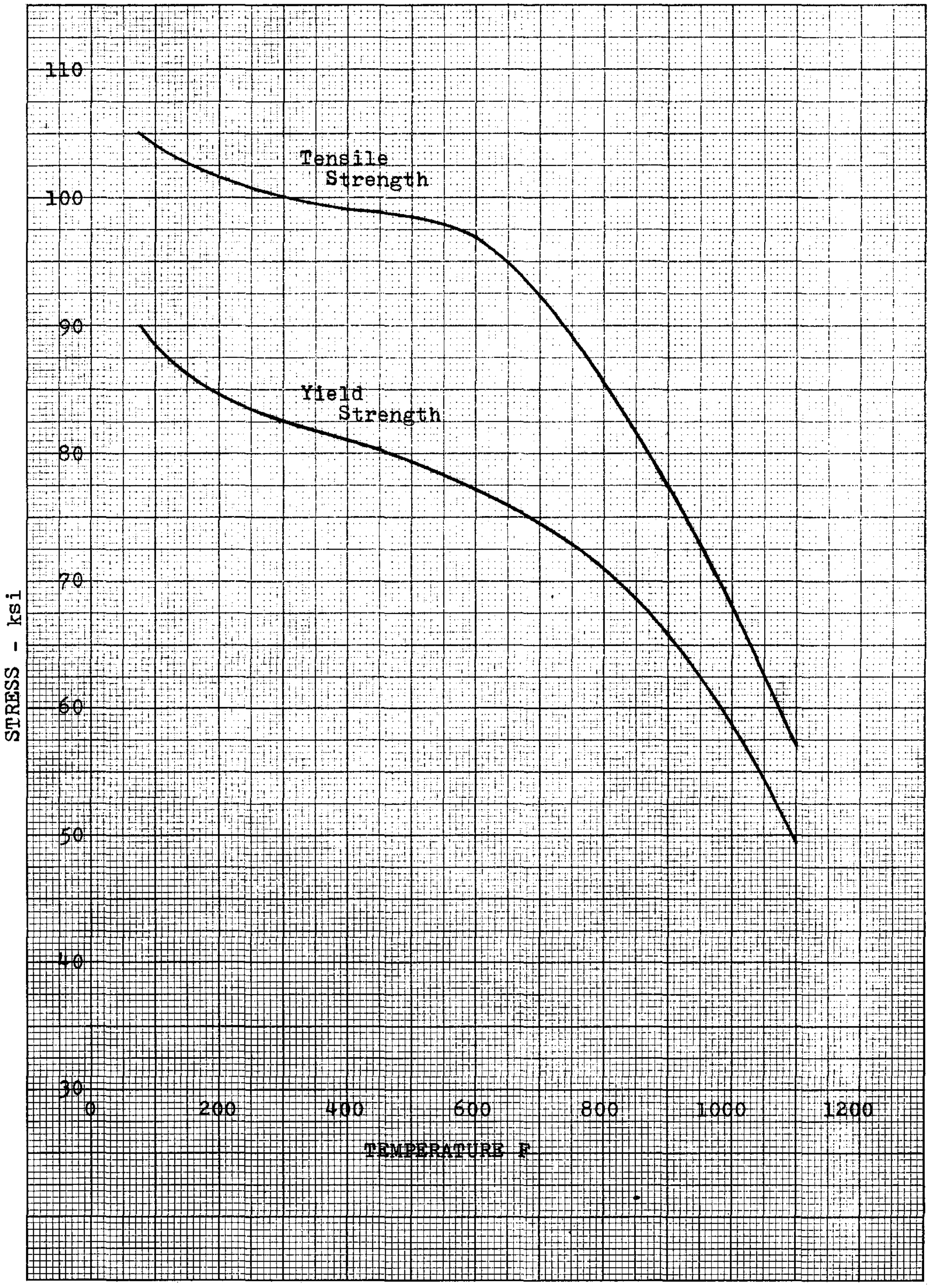

Fig. 6 Effect of temperature on yield strength and tensile strength of Mn-Mo steel, A 514, Type C, adjusted to 90 and 105 ksi at 75 F.

INTRODUCTION

The materials evaluated in this report include C-Mo steel (0.5 percent molybdenum) which has been widely used in elevated temperature service over many years, and the newer Mn-Mo, and Mn-Mo-Ni modifications of this basic grade. Evaluations have been made for various heat-treated conditions, including quenching and tempering, and for various product forms. The report is another in a continuing series of evaluations sponsored by The Metal Properties Council (MPC)(16-18).

Included in the evaluations are data previously reported in ASTM's DS Data Series,(1,2,19) under sponsorship of the Joint ASTM-ASME Committee on the Effect of Temperature on the Properties of Metals, as well as data recently gathered by MPC from cooperating laboratories. Pertinent data reported many years ago in the 1938 Creep Data Compilation(6) have also been included. All of the data are identified in Table I as to ASTM specification, deoxidation practice, heat treatment, product form and size, grain size, and data source, to the extent that these were known, and in Table II with respect to chemical composition. Some of the data sets from DS 6 and DS 6S1(1,2) were excluded from the evaluation, owing to inadequate identification or non-conformance with specifications. The data gathered by MPC are tabulated in this report; data from DS 6 and DS 6S1 have not been copied into this report, but a coding key to the DS data that have been integrated into the evaluations is provided in Table I of the present report.

The tabular data for each of the several types of materials, or heat treatment variations of a given type of material, included in the evaluations, have been grouped separately, as follows:

Part 1:	C-Mo steels (Specs. A204, A209, A335, A369, A182, A217)
Part 2:	Mn-Mo and Mn-Mo-Ni Steel Plates (A302)
Part 3:	Mn-Mo and Mn-Mo-Ni Steel Plates, Quenched and Tempered (A533)
Part 4:	Mn-Mo Steel Forgings (A372, Class IV)
Part 5:	Mn-Mo Steel Castings (A487, Classes 2N, 20)
Part 6:	Mn-Mo Steel Plate, Quenched and Tempered (A514, Type C).

In considering the data of Part 1, a distinction has been preserved in the early stages of the evaluation as to product form (bar, plate, tube or pipe, casting), but in the final stage of trend curve evaluation, it has seemed appropriate to consider the data for different product forms as from one population. In the remaining Parts, the product form was unique to the individual Part.

The properties that have been evaluated in this report include yield and tensile strengths, and creep and rupture strengths. Unfortunately, the latter two properties could be evaluated only for Part 1, the number of data being either too few or nonexistent for the remaining Parts. For Part 1, rupture strength has been evaluated for three rupture intervals, namely; 1000, 10,000 and 100,000 hours, and creep strength for two secondary creep rates, namely 0.1 and 0.01 percent per 1000 hours. Elongation and reduction of area at fracture have been included in the report for both the tensile and rupture tests, when available.

Yield Strength, Tensile Strength, Elongation and Reduction of Area

The original tensile test results, excepting those previously reported in DS 6 and DS 6S1, are tabulated in Table III. Many of the reported values represent the average of replicate tests. As with the previous evaluations in this series, the tests are presumed to have been conducted generally at strain rates within the limits permitted by ASTM Recommended Practice E 21, and the yield strengths to represent either 0.2% offset, or the lower yield point. Unless otherwise indicated, elongation values represent a gage length of two inches, and in the case of plate material, test specimens were taken from the quarter thickness position.

Employing a data normalizing procedure that has proved useful in previous evaluations,(16-18) the elevated temperature yield and tensile strengths of individual lots have been ratioed to the room temperature yield and tensile strengths of the same lots. Then, each set of such ratios, representing individual data populations, e.g. C-Mo steel, has been evaluated by the procedure of least squares to establish a "ratio trend curve" of best fit through all the data. With the temperature dependence of strength expressed in terms of strength ratios, it becomes possible to compute strength trend curves for any specific room-temperature strength level of interest, within the limits encompassed by the original data.

The tensile test results for the different categories are plotted as dependent upon temperature in Figures 7-12, corresponding with the individual Parts into which the data have been grouped. 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. No data for either weld metal or weldments are included in the figures inasmuch as no elevated temperature test results were received by MPC, nor were there data in an earlier report covering weld metal and weldments.(19)

Specific comments concerning the individual groups follow:

Part 1: C-Mo steels, Figs. 7a, b and c

Data for the different product forms, plate, pipe-tube, bar, and castings have been distinguished from one another. All of the plate materials fell within limits corresponding to Grade B of A204, with several lots also meeting the requirements of either Grade A or C. Considerable scatter is evident, especially for yield strength,* and normalizing the strength data by

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*As suggested in an earlier publication(18), a significant portion of the scatter in yield strength probably reflects the difficulty of measuring small strains at elevated temperatures, the possible presence of residual stresses from straightening or specimen preparation procedures, and possible differences in strain rate, factors which have a lesser effect upon tensile strength than upon yield strength.

ratioing has not proved particularly effective in reducing scatter. Inspection of the ratio plots suggests somewhat greater yield strength ratios for plate than for bar, but this difference is not evident for tensile strength ratio. Unfortunately, the extent of overlap in temperature for these two product forms is limited, there being no plate data above 1000°F, and only isolated data for bar below 700°F. For the other two product forms, the number of data are quite limited. All in all, the character of the data is such that it has seemed appropriate to treat all of the yield and tensile strength ratios as belonging to the same individual populations for the purposes of the least squares analyses. The resulting regression lines of best fit, or trend curves, have been superimposed on the ratio plots, and are included in the tabulations of Table V.

The tensile strength ratios that resulted from the least squares analyses using a computer began increasing immediately above room temperature, and it is apparent that the two values at 200°F, having a ratio less than one, were "overwhelmed" by the weighting of all the other data. Since carbon and low alloy steels typically exhibit(17) a decreasing ratio immediately above room temperature, before dynamic strain aging can be manifested, the trend curve shown in Fig. 7b and included in Table V has been drawn visually for temperatures between room temperature and 700°F. It is of interest to note that the spread in tensile strength ratio at intermediate temperatures is probably in part associated with differences in strain-aging susceptibility of the different lots, the degree of susceptibility depending primarily upon nitrogen concentration, deoxidation practice and heat treatment. It is also of interest to note that the maximum susceptibility evident in Fig. 7b is on the order of that exhibited by carbon steel.(17)

Elongation and reduction of area of C-Mo steel also exhibit much scatter, Figure 7c, with some tendency for reduced ductility in the range of temperature in which dynamic strain aging is indicated in the tensile strength data. At higher temperature, ductility trends to higher levels. Plate and castings tend to exhibit somewhat less ductility than bar and pipe.

Part 2. Mn-Mo and Mn-Mo-Ni steel plates, Figs. 8a, b and c

The data that were available were reported to represent either grade B or Grade C of ASTM specification A302, and are so distinguished in Figs. 8a, b and c. However, it will be recognized that Grade B requirements overlap those of Grade A, and hence a number of the Grade B data may equally well represent Grade A material. Inspection of the ratio plots, Figs. 8a and b does not indicate any need to distinguish between grades B and C as to trend curves. Some data representing material having room temperature tensile strengths greater than permitted by spec. A302 have been included in the evaluation. Work previously reported,(20) as well as analysis of the present data, has indicated that for a specific grade of material the dependence of strength upon temperature, when expressed in ratio form, is insensitive to absolute strength level within wide limits. A common population has been assumed for the least squares regression analyses. The resulting trend curves have been superimposed upon the ratio plots, and included in Table V.

The trend curve for tensile strength indicates by the rise at intermediate temperatures a slight tendency for dynamic strain aging. However, the strength ratio remains below 1.0, in contrast to the C-Mo steels of Part 1, and the peak occurs at a slightly higher temperature, 550°F as compared to 400°F. Again, the scatter in strength ratio at the peak temperature is probably to be associated with differing susceptibilities to strain aging.

Perhaps reflecting the reduced strain-aging susceptibility indicated by the tensile strength results, there is little tendency for reduced ductility at intermediate temperatures, Fig. 8c. The scatter in ductility for the plate represented in Fig. 8c, is less than that evident in Fig. 7c, which represented various product forms.

Part 3. Mn-Mo and Mn-Mo-Ni steel plates, quenched and tempered, Figs. 9a, b and c

ASTM Spec. A533 includes 4 grades A, B, C and D corresponding with different levels of nickel within the range 0 to 1% and fixed amounts of the remaining elements, and 3 classes of tensile requirements, Classes 1, 2 and 3. Because the strength classes overlap one another and because experience has indicated an insensitivity of strength ratio to strength level, within a given material category, the plots of Figs. 9a, b and c distinguish only among the several grades. At least some data were available for each of the grades A, B and D, but none for grade C. Although it is possible that more adequate samples of data for the different grades might reveal differences amongst them, the character of the strength ratio data that are available are such that it has not seemed appropriate to distinguish at this time amongst the different grades. Hence the ratioed data have been considered as belonging to a common population. The trend lines resulting from the regression analyses are shown on the ratio plots and included in Table V.

The tendency for dynamic strain-aging has been lessened still further relative to the materials of Parts 1 and 2, with the tensile strength ratio trend curve essentially level at intermediate temperatures.

The ductility data, Fig. 9c, showed only limited scatter, with no evident differentiation amongst the three grades for which data are available.

Part 4. Mn-Mo steel forgings, Figs. 10, b and c

Data were available for only one lot of Mn-Mo steel forgings, and thus the conversion of the strength data into ratios serves only the purpose of making it possible to express the trend curves in ratio form. With data for only one lot, there is, of course, no way of knowing how representative the trend curves shown on the ratioed plots and in Table V are. The requirements of ASTM Specification A372, IV covering this material, overlap in many respects with those for the materials of Parts 2 and 3 of this report, and the strength ratios fall within the scatter bands of Figs. 8 and 9. However, the specified molybdenum content for A372, IV is only about one-half of that required of the other materials, and it has not seemed appropriate to include this material with the others. Clearly, further testing of this material is desirable.

Part 5. Mn-Mo steel castings, Figs. 11a, b and c

Data were available for 3 lots of this material, but each lot had been tested in both the normalized-and-tempered and quenched-and-tempered conditions, conforming to grades 2N and 2Q of ASTM Specification A487. The data are distinguished as to heat treatment in the plots. Ratioing of the strength data has been effective in reducing scatter, especially for tensile strength. Yield ratios for Grade 2N exhibit relatively high scatter, but except for this grade, the ratio trend curves shown in Figs. 11a and b and included in Table V seem reasonably well defined by the data from only three lots.

The ductility values, Fig. 11c, exhibit only modest scatter.

Part 6. Mn-Mo steel plate, quenched and tempered, Figs. 12a, b and c

Data were available for only two lots of material in this category, and although it is possible that the availability of further data at some future date may reveal that this material can be grouped with one or another of the other material groups evaluated in the present report, it has seemed desirable to treat it separately for the present. Interestingly, a relatively small difference between the strengths of the two lots has been even further reduced by ratioing, giving a measure of confidence in the trend curves that have been developed, Figs. 12a and b and Table V. Gaps in test temperature between room temperature and 300°F and between 300 and 600°F, do raise some uncertainty as to the true shapes in the range below about 600°F.

Comparisons of the Trend Curves

Tabular comparisons of the yield and tensile strength ratio trend curves are afforded for all of the material categories in Tables Va and Vb, respectively, and a graphical comparison is provided in Fig. 13 for the three categories for which there were significant volumes of data. It may be seen in Fig. 13 that the trend curves for material categories corresponding to Specifications A302 and A533 are reasonably similar to one another. For this reason, trend curves for the combined populations have also been developed, and are included in Tables Va and Vb. The common trend curves have been used for summary Figures 2 and 3.

Creep and Rupture Properties

The original creep and rupture data not previously reported in DS 6 and DS 6S1 (References 1 and 2) have been tabulated in Table IV, separated into Parts according to specification or nominal composition. Only a few data were available for Parts 2 and 3 (corresponding to specifications A302 and A533) and for Part 6 (A514C), and none at all were available for Parts 4 and 5 (A372IV and A487, 2N and 2Q). Only for Part 1 (C-Mo) were the data adequate to warrant evaluation to the extent of developing trend curves suitable for establishing allowable stresses.

As in earlier evaluations(17,18), both direct and indirect procedures have been employed in extrapolating the rupture data to 100,000 hours. The former procedure involves extending the isothermal relation between stress and rupture time, commonly plotted on log-log coordinates, to 100,000 hours, whereas the latter involves one or another time-temperature parameter. For reasons described in the earlier evaluations, the character of the available data is such that the indirect or parameter extrapolations have not been performed on an individual lot basis, but rather on a "universalized" basis, assuming universal values for the parameter constants.

Part 1. C-Mo steels

To show both the quantity of data and their scatter, all of the data are shown in isothermal scatter band plots of log stress versus log time for rupture (Figs. 14a, b and c); of log stress versus log secondary (or minimum) creep rate (Figs. 15a, b and c); and of percent elongation and reduction of area at rupture versus log time for rupture (Figs. 16 a-g). In each plot, data for different product forms are differentiated. A few data available for weld metal have been plotted, for purposes of visual comparison, but these have not otherwise been included in the evaluations. A few weld metal data for temperatures of 842, 932 and 1022°F have not been plotted, but inspection reveals that these are not inconsistent with the data for the several product forms, as true also of the plotted data. A few data for weldments (as contrasted with weld metal) have not been included in this report owing to the inhomogeneous nature of weldment test specimens, and the dependence of the results upon geometrical considerations.

Rupture Strength

The rupture data have been extrapolated isothermally to 100,000 hours both visually on an individual lot basis, giving weight to the longer time tests, and by extending the line of best fit resulting from least squares analysis of the scatter bands, assuming all of the data to have come from a common population. No clearly identifiable effect of product form is evident in the scatter bands, nor in the results of the individual lot extrapolations assembled into plots of strength versus temperature (see later). However, for some product forms, there are few or no data. In contrast to earlier evaluations in this series(16-18), these evaluations have indicated that the relation between log stress and log time to rupture may be bilinear or curvilinear. Thus, for a number of the isothermal scatter bands, the variance of the data was observed to decrease as the order of the assumed relation between the variables was increased beyond the first degree. In the individual-lot extrapolations some of the log-log plots (not included here) seemed to exhibit a break from one slope to another steeper one; such breaks might well be reflected as curvilinearity in the scatter bands. Unfortunately, departure from linearity introduces an element of uncertainty into the direct extrapolations, beyond the usual uncertainty associated with extending a linear line for one or more log cycles.

The results of the individual lot evaluations of the stress to cause rupture in 1000, 10,000 and 100,000 hours, by interpolation or extrapolation, as required, have been assembled in Table VI, and plotted in Figs. 17a and b. Most of the data of Figs. 17a and b represent bar stock. The relatively few data for pipes or tube and for castings fall reasonably within the scatter of the bar data. Least squares evaluations were made for each rupture time, Figs. 17a, b, assuming the data to represent common populations; the resulting regression lines, of third order in each instance, have been superimposed upon the data, and included in tabular form in Table IX. It is of interest that the regression curves for the three intervals have similar shapes. Minimum position curves, derived from the mean curves by a procedure described previously(21), are also shown in Figs. 17a and 17b, and tabulated in Table IX.

In the least squares evaluations of the isothermal scatter bands, the longer time data were weighted by the expedient of excluding rupture times less than 50 hours, and time was taken as the independent variable, for reasons given earlier.(21) The results of the evaluations, in terms of the stresses to cause rupture in 1000; 10,000; and 100,000 hours, are assembled in Table VIII. For each of the temperatures evaluated, rupture strengths are shown corresponding to a first order relation between log stress and log time-for-rupture. In addition, for a number of temperatures, rupture strengths are given, corresponding to a second or third order equation, exhibiting a reduced variance. Even when the variance is reduced only marginally (expressed as a percentage), the 100,000 hour rupture strength, developed in all instances by extending the regression line, may be reduced significantly, and for larger reductions in variance, the reduction in strength is even greater. Note particularly, the 100,000 hour strength at 900°F corresponding to a third order equation. The differences in 10,000 hour and 1000 hour strengths corresponding to different orders of the regression equation are correspondingly less than those for 100,000 hours as might be expected, but may still be significant (as for example at 900°F). It must be concluded from a study of Table VIII that extension of the isothermal scatter regression line to 100,000 hours is an especially hazardous procedure, and increasingly so as the order of the assumed equation increases (see also reference 21). For this reason values for 100,000 hours rupture strength by this procedure have not been included in the comparisons of Table IX. However, 1000 hour and 10,000 hour rupture strengths have been included in Table IX (for the linear case only), as of possible comparative interest.

Two "universalized", time-temperature parameter evaluations were made, in which all of the rupture data, except those for rupture time less than 5 hours, were "parameterized", and the resulting scatter bands of stress versus parameter evaluated by the method of least squares. Universal values were assumed for the constants, and all data were assumed to come from a common statistical population. The parameters that were employed were firstly, the well-known Larson-Miller parameter, with an assumed value of 20 for the constant:

$$T(20 + \log t) = F_1(s);$$

and the more recent compromise parameter proposed by Manson:(22)

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

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

Scatter band plots showing the dependence of log stress upon the two parameters are provided in Figures 18a and b. Parameter values corresponding to 100,000 hours at specific temperatures have been superimposed upon the Figures. Also superimposed upon the plots are the results of least squares evaluations, taking parameter as the independent variable. Mean curves together with minimum curves (90% confidence) derived from the mean curves(21) are shown. Mean and minimum values for the stresses to cause rupture in 1000; 10,000 and 100,000 hours are included in Table IX, for comparison with the results derived by the other procedures employed.

Figure 19 shows a graphical comparison of the results for rupture in 10,000 and 100,000 hours, derived by regression of the temperature dependence of the individual lot extrapolations and by the two universalized parameter procedures. Both of the parameter evaluation procedures give a more conservative result than the procedure involving individual lot visual extrapolation, but the differences may be viewed as relatively modest. (In past evaluations of carbon steel(17) and 2 1/4 Cr-1 Mo(18), the individual lot procedure had given a more conservative result than the universalized Larson-Miller procedure.) Of the two parameter procedures, the Manson compromise parameter gave the more conservative result, as expected, with divergence increasing towards higher temperature. Since the parameter procedures provide an estimate of long time strength (e.g. 100,000 hours) from shorter time tests at higher temperatures, it follows that they are inherently unable to provide estimates of 100,000 hour rupture strengths over the entire range of temperatures for which there are test data (except as questionable extrapolations of the "master" parameter curve might be employed). Thus 100,000 hour rupture strengths can be derived in the present instance only to a maximum temperature of 1000°F, and even at this temperature, only a small portion of all the data actually define the corresponding value of parameter. To be sure, many engineers would not choose to use C-Mo steel above 1000°F because of the excessive scaling to be expected.

In choosing amongst the three sets of 100,000 hour rupture strengths in Table IX or Fig. 19, one obtained by direct and two by indirect extrapolation, the advantages by the direct individual lot extrapolation procedure of visual weighting of the longer time results seems to be outweighed by the uncertainties associated with possible bilinearity or curvilinearity. It follows then that greater weight should be given to the results of the indirect or parameter procedures, in spite of inherent reservations about such procedures, previously expressed.(21,20) Also, as previously noted, either parameter procedure leads to a more conservative estimate. The choice between the two parameter results is more difficult; several considerations seem appropriate. Firstly, the maximum difference between the two results is at 1000°F, at which the Manson compromise parameter result is 13% less than that by the Larson-Miller procedure; the difference diminishes progressively to zero at 800°F. Interestingly, the positions of the parameter master curves are least well defined by data at 1000°F, and best defined at 800°F. Secondly, at 1000 hours, at which the direct result might be reasonably viewed as superior to the result of any indirect procedure, since it can be derived by interpolation, the Larson-Miller result more closely approximates the direct result. Similarly, at 10,000 hours, the need for extrapolation was minimal, with a few values derivable by interpolation, and again the Larson-Miller result more closely approximates the direct result. The foregoing train of reasoning suggests that the Larson-Miller procedure has given the most reasonahle estimates of 100,000 hour rupture strength; and it is this result that has been integrated into the summary chart of Fig. 1. Also as a matter of possible interest, isothermal log stress vs. log time-for-rupture curves have been computed from the Larson-Miller master curve, and these have been superimposed upon the scatter bands, Figs. 14a, b and c.

Creep Strength

The secondary creep-rate data shown in the scatter bands of Figs. 15a, b and c were visually interpolated or extrapolated (by not more than about 1 log cycle) on an individual lot basis, to determine creep strengths corresponding to 0.1 and 0.01 percent per 1000 hours. Curvilinearity in the relation between log stress and log secondary creep rate in the region 0.1 to 0.01% per 1000 hours was evident for many of the individual lots. The results are assembled in Table VII and plotted in Figs. 20a and b. There is no effect of product form evident in the data, but the number of data for other than bar is severely limited. The scatter plots of strength vs. temperature have been evaluated by the method of least squares and the resulting lines of best fit (trend curves) superimposed upon the plots and tabulated in Table X. Minimum position trend curves, derived from the mean curves, are also given.

The trend curves for variation of creep strength with temperature, Fig. 20, exhibit a complex character, requiring a third or higher order equation, if the entire range of temperature is to be represented by a common curve. As a consequence, the result becomes sensitive to the distribution of data and at the mercy of the procedure; thus the indicated maximum in the 0.1% per 1000 hours creep strength at 850°F is of questionable validity. It is of interest to note that creep strength falls off rapidly above about 950°F, whereas at lower temperatures there seems to be a levelling tendency. (The variations of 1000 hour and 10,000 hour rupture strengths, Fig. 17a, exhibited a somewhat similar tendency.) This relative insensitivity of strength to temperature at the lower temperatures may be related to the tendency to secondary hardening conferred by molybdenum. The trend curves have been extended to the upper limit of temperature for which data were available, i.e. 1200°F, even though as indicated earlier, extensive scaling may be expected above about 1000°F.

Rupture Ductility

The elongation and reduction of area at rupture of C-Mo steel tend, on the whole, to be relatively low at longer rupture times, Figs. 16 a-g. Thus, at 850 and 950°F, where the trends are fairly well defined and which are in the range of practical interest, ductility at rupture at 10,000 hours is on the order of only 10 percent. This reduced ductility may reflect a trend to intergranular mode fracture at longer time, but no information concerning mode of fracture was made available by the contributors of data.

Parts 2 and 3. Mn-Mo and Mn-Mo-Ni steels (Specifications A302 and A533)

Since the yield strength ratio and tensile strength ratio curves for material corresponding to Specifications A302 and A533 were relatively similar, and since the number of creep and rupture test results available is limited, data from these latter tests have been plotted together, though differentiated by symbol. Figs. 21 a-b shows the interdependence hetween time-for-rupture and stress, Fig. 22, that for secondary creep rate and stress, and Fig. 23a, b that for rupture ductility and time-for-rupture (except that, in the interest of saving space, a few relatively short time rupture ductility results have not been plotted).

The rupture and creep data, extending to a maximum test duration of only about 1000 hours, are so limited in number that it has not seemed worthwhile to attempt the development of trend curves, particularly, when, based upon the behavior of normalized and tempered or quenched and tempered 2 1/4 Cr-1 Mo steel,(18) it is to be expected that the elevated temperature creep and rupture strengths will vary with the level of strength at room temperature, and hence depend upon the tempering temperature. However, individual lot interpolations or extrapolations were made, and these results are summarized in Tables VI and VII. Evidence of dependence upon room temperature strength is apparent when the level of the 900°F scatter band is observed to be higher than that for 850°F, Fig. 21a. The 900°F data represent lots having room temperature tensile strengths in the range 130-140 ksi (which, of course, exceeds the level permitted by specification), whereas the A533 data at 850°F represent a lot having a tensile strength at room temperature of only 87 ksi. Certainly, under the circumstances there is no possibility of differentiating between lots conforming to the two different specifications.

The limited ductility data extending only to 1000 hours test duration are essentially independent of rupture time and at a satisfactory level at 850°F, but trend downward at 950°F.

Part 6. Mn-Mo Steel Plate, Quenched and Tempered (A514, Type C)

The time-for-rupture, secondary creep rate, and rupture ductility for A514, Type C are plotted in Figs. 24, 25, and 26 a-b, respectively, but in view of the limited character of the data, and an expectation that the results depend sensitively upon level of strength at room temperature, no effort has been made to develop trend curves. However, interpolations and extrapolations of the data for the individual lots have been made, and the results are included in Tables VI and VII.

Acknowledgment

The evaluations of this report were developed for The Metal Properties Council under the guidance of a subcommittee of which Dr. M. Semchyshen is Chairman. Appreciation is expressed to the chairman and members of the subcommittee for helpful suggestions.

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Table I

Identification of Steels

Code No.	Spec. No.	Deoxid. Pract.	Heat[(1)] Treatment	Product Form-Size	Grain[(2)] Size	Ref.	Ref. Code No.
Part 1 - Carbon-Molybdenum Steels (Specs. A204, A209, A335, A369, A182, A217)							
1-1	-	Si+Al (1 lb.)	A1550	Bar, 1"	$6\text{-}8_M$	1	1
1-2	A182	-	HR	Plate 18×10×1.5"	-	1	2
1-3	A206	-	N1650, T1250	Rod, 1"	7_M	1	3
1-4	-	Si+Al (.4 lb.)	N1650	Forged	$1\text{-}3_M$	1	4
1-5	-	Si+Al (1.6 lb.)	N1650	"	$6\text{-}8_M$	1	5
1-6	-	Si	N1650	"	$1\text{-}3_M$	1	6
1-7	-	Al (.5 lb.)	N1700, T1300	Cast	3	1	7
1-8	-	CaMnSi (2 lbs.)	N1700, T1150	Cast	-	1	8
1-9	-	Si+Al	N1560, T1380	Wrought	-	1	9
1-10	-	-	N1650, T1300	"	8-9	1	10
1-11	-	-	N1650, T1300	"	8-9	1	11
1-12	-	Si+Al	N1650	"	8-9	1	12
1-13	-	Al (.5 lb.)	A1850	"	-	1	13
1-14	-	-	A1740, T1330, T1200	Cast	-	1	14
1-15	-	-	Annealed	Tube, 14 O.D.×1 1/4"w.	-	1	16
1-16	-	Al (2 lb.)	N1750, T1200	Cast	-	1	18
1-17	-	CaMnSi+Al (3 lbs.)	N1700, T1300	Cast	8	1	20
1-18	-	CaMnSi+Al (2 lbs.)	N1700, T1300	Cast	7	1	21
1-19	-	CaSi+Al (.5 lb.)	N1700, T1300	Cast	2-3	1	22
1-20	-	Al (2 lbs.)	N1700, T1300	Cast	6-7	1	23
1-21	-	Carbotram (4 lbs.)	N1700, T1200	Cast	7-8	1	24
1-22	-	Al (2 lbs.)	N1700, T1300	Cast	6-7	1	25
1-23	-	Al (.5 lb.)	N1700, T1300	Cast	3-4	1	26
1-24	-	None	N1700, T1300	Cast	3-6	1	27
1-25	-	Al (.5 lb.)	N1700, T1300	Cast	4	1	28
1-26	-	CaMnSi+Al (3 lb.)	N1700, T1300	Cast	7	1	29
1-27	-	CaSi+Al (2.5 lb.)	N1700, T1200	Cast	2-3	1	30
1-28	-	CaSi+Al (2.4 lb.)	N1700, T1200	Cast	7-8	1	31
1-29a	-	Al (1 lb.)	N1800	Bar	5	2	7-6a
1-29b	-	"	N1800, T1250	"	"	"	"
1-30a	-	"	N1950, T1250	"	5	2	7-6b
1-30b	-	"	N2000, T1250	"	-	"	"
1-31a	-	-	HR, T1300F	Bar 3/4"	-	2,3	7-18
1-31b	-	-	N1750, T1200	"	-	2,3	7-18
1-31c	-	-	N1650, T1200	"	-	2,3	7-18
1-32	-	-	T1400 (4 hrs)	Tube $2\frac{1}{2}$ O.D.×.3"	-	2,3	7-19
1-33	A209	Si+Al (1.6 lb.)	A1575 → 1200, AC	Bar 3/4"	6	2,3	7-20
1-34	A209	Si	" "	Bar 3/4"	-	2,3	7-21
1-35	A209	-	CD, T1300	Tube, 2 O.D.×.344"	-	3	-
1-36	-	-	A1600	Tube	-	3	-

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

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

Table I - page 2

Code No.	Spec. No.	Deoxid. Pract.	Heat Treatment	Product Form-Size	Grain Size	Ref.	Ref. Code No.
1-37	-	-	1525 → 1200, AC	Wrought	-	3	-
1-38*	-	Si	N1650	Bar, 1"	1-3	4	-
1-39+	-	Si+Al (1.6 lb)	N1650	Bar, 1"	6-8	4	-
1-40	A204-B	-	N1650	Plate, 5 3/16"	-	4	-
1-41°	-	Si+Al (.4 lb)	N1650	Bar, 1"	1-3	4	-
1-42	-	-	T1270	Cast	-	5	-
1-43	-	-	N1650, T1250	Bar, 1"	6-8$_M$	6	1a
1-44a	-	-	N1650, Q1550, T1100	Bar, 1 1/8"	7$_M$	6	1b
1-44b	-	-	N1650, T1050	" "	3.5$_M$	6	1c
1-44c	-	-	N1650, Q1550, T1100	" "	4.5$_M$	6	1d
1-45	-	-	N1650, T1225	Bar, 1"	-	6	2
1-46**	-	Si-Al	A1550	Bar, 1"	8$_M$	6	3a
1-47	-	Si-Al	A1550	Bar, 1"	8$_M$	6	3b
1-48	-	Si-Al	A1550	Bar, 1"	4-5$_M$	6	3c
1-49	-	Si-Al	A1550	Bar, 1"	6-8$_M$	6	3d
1-50	-	-	N1650, T1200	Tube	-	6	4a
1-51	-	-	" "	"	-	6	4b
1-52	-	-	" "	"	-	6	4c
1-53	-	-	" "	"	-	6	4d
1-54	-	-	" "	"	-	6	4e
1-55	-	-	" "	"	-	6	4f
1-56	-	Killed	N1650, T1200 (1 wk.)	Bar, 1"	-	6	5a
1-57	-	Killed	N1650, T1200 (1 wk.)	Bar, 1"	-	6	5b
1-58	-	Killed	N1650, T1400 (1 wk.)	Bar, 1"	-	6	5c
1-59	-	Si-Al	N1650	Bar	-	6	6a
1-60	-	Si-Al	N1650, T1200 (5 hr)	Bar	-	6	6b
1-61	-	Si-Al	N1650, T1200 (168hr)	Bar	-	6	6c
1-62	-	Si-Al	N1650, T1300 (5 hr)	Bar	-	6	6d
1-63	-	Si-Al	N1650, T1300 (168hr)	Bar	-	6	6e
1-64	-	Si-Al	N1650, T1400 (5 hr)	Bar	-	6	6f
1-65	-	Si-Al	N1650, T1400 (168hr)	Bar	-	6	6g
1-66	-	-	N1650, T1110	Plate, 1 1/4"	-	6	7
1-67	-	-	Normalized	Bar, 1"	2$_M$	6	8a
1-68	-	Si	T1200	Plate, 1 1/2"	2-4$_M$	6	8b
1-69	-	Si	T1200	Plate, 1 1/2"	2-4$_M$	6	8c
1-70	-	-	T1200	Weld metal	-	6	9b
1-71	-	-	T1200	Weld metal	-	6	9c
1-72	-	-	As Received	Pipe	-	6	9a
1-73	A204-B	-	N1675	Plate, 5 1/4"	4-5$_M$	9	-
1-74	A204-B-C	-	N1700	Plate, 3"	-	9	-
1-75	A204-B-C	-	N1700, T1100	Plate, 3"	-	9	-
1-76	A204-B	-	N1700, T1100	Plate, 4 3/4"	-	9	-

* Identical with Code 1-6
\+ Identical with Code 1-5
° Identical with Code 1-4
** Identical with Code 1-1

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Code No.	Spec. No.	Deoxid. Pract.	Heat Treatment	Product Form-Size	Grain Size	Ref.	Ref. Code No.
1-77	A204-B	-	N1700, T1100	Plate, 4 3/4"	-	9	-
1-78	A204-A-B	-	N1675	Plate, 6"	-	9	-
1-79	A204-B	-	N1650, T1150	Plate, 3 1/4"	-	9	-
1-80	"	-	N1650, T1200	" "	-	9	-
1-81	"	-	N1650, T1250	" "	-	9	-
1-82	-	-	T1200	Weld metal	-	19	1
1-83	-	-	T1200	" "	-	19	2
1-84	-	-	T1200	" "	-	19	3
1-85	-	-	T1275	" "	-	19	4
1-86*	-	-	T1112	" "	-	19	5
1-87*	-	-	T1202	" "	-	19	5
1-88	-	-	T1200	" "	-	5	-
1-89	-	-	T1275	" "	-	5	-

Part 2 - Manganese-molybdenum and manganese-molybdenum-nickel steels (Spec. A302)

Code No.	Spec. No.	Deoxid. Pract.	Heat Treatment	Product Form-Size	Grain Size	Ref.	Ref. Code No.
2-1	A302B	-	Norm. & Temp.	Plate, 6"	-	2	7-14a,b,c
2-2	"	-	" " "	Plate, 8 1/2"	-	2	7-15a,b
2-3	"	-	" " "	Plate, 3"	-	2	7-16a,b
2-4	A302B	FG;Al	N1775F$^{(1)}$, T1125	Plate, 8 1/8"	-	7	-
2-5	A302B	FG	Spray Quenched & Tempered	Plate, 15"	-	7	-
2-6	A302B	-	N1650, T1200	Plate, 4"	-	8	-
2-7	A302C	-	N1650, T1225, T1125	Plate, 2 7/8"	-	8	-
2-8	A302C	-	N1650, T1275	Plate, 5 9/16"	-	9	-
2-9	A302B		N1600, T1100	Plate, 6"	-	9	-
2-10	A302C	-	N1650	Plate, 2"	-	9	-
2-11	"	-	N1650, T1290	Plate, 2"	-	9	-
2-12	"	-	N1650, T1300	Plate, 2"	-	9	-
2-13	"	-	N1650, T1275	Plate	-	9	-
2-14	A302B	FG	Q1575, T1225, T1150	Plate, 10 1/2"	-	7	-
2-15	"	"	" " "	" "	-	7	-
2-16	"	"	" " "	" "	-	7	-

Part 3 - Manganese-molybdenum and manganese-molybdenum-nickel steels (Spec. A533)

Code No.	Spec. No.	Deoxid. Pract.	Heat Treatment	Product Form-Size	Grain Size	Ref.	Ref. Code No.
3-1	A533B,2,3	-	01700, 01625, T1175	Plate, 6 3/8"	-	10	-
3-2	"	-	" " "	" "	-	10	-
3-3	"	-	" " "	" "	-	10	-
3-4	A533B,2	FG	Q1575, T12225, T1150	Plate, 7 7/8"	-	11	-
3-5	"	"	" " "	Plate	-	11	-
3-6	A533D,2,3	FG	Q1650, T1240	Plate, 1 3/4"	-	9	-
3-7	"	"	Quenched & Temp.	Plate, 1 3/4"	-	9	-
3-8	"	"	Q1675, T1225, T1075	Plate, 1 3/4"	-	9	-
3-9	A533D,2,3	-	01675, T1225	Plate, 1 3/4"	-	9	-

(1) Spray quench to 600F

* Data identical with Codes 1-70 and 1-71

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Code No.	Spec. No.	Deoxid. Pract.	Heat Treatment	Product Form-Size	Grain Size	Ref.	Ref. Code No.
3-10	A533A,1,2	-	Q1600, T1100, T1150	Plate, 6"	-	9	-
3-11	A533B,1	-	Q1650, T1240, T1150	Plate, 5 9/16"	-	9	-
3-12	A533B,1,2	-	Q1650, T1240, T1150	Plate	-	9	-
3-13	A533B,1	FG-Al	Q1600, T1225, T1150	Plate, 9 5/8"	-	7	-
3-14	"	"	" " "	" "	-	7	-
3-15	"	"	" " "	" "	-	7	-
3-16	A533B,3	-	Q1650, T1200	Plate, 2 3/8"	-	8	-
3-17[1]	A533A	-	Q1650, T1150	Plate, 3/4"-1"	-	12	-
3-18a[1]	A533B	-	" "	" "	-	12	-
3-18b	A533B,1	-	Q1650, T1200, T1100	Plate(2), 6"	-	13	-
3-18c	"	-	" " "	" (2), 12"	-	13	-

Part 4 - Carbon-Manganese-Molybdenum steel forgings (Spec. A372, Class IV)

Code No.	Spec. No.	Deoxid. Pract.	Heat Treatment	Product Form-Size	Grain Size	Ref.	Ref. Code No.
4-1	A372,IV	-	Q1650, T900	Pipe 24"O.D.×1.08"w	-	8	-

Part 5 - Carbon-Manganese-Molybdenum steel castings (Spec. A487, Class 2)

Code No.	Spec. No.	Deoxid. Pract.	Heat Treatment	Product Form-Size	Grain Size	Ref.	Ref. Code No.
5-1a	A487,2N	-	N1600, T1100	Casting	-	14	-
5-1b	A487,2Q	-	Q1600, T1225	"	-	14	-
5-2a	A487,2N	-	N1600, T1100	"	-	14	-
5-2b	A487,2Q	-	Q1600, T1225	"	-	14	-
5-3a	A487,2N	-	N1600, T1100	"	-	14	-
5-3b	A487,2Q	-	Q1600, T1225	"	-	14	-

Part 6 - Quenched and Tempered carbon-manganese-molybdenum steel plate (Spec. A514, Type C)

Code No.	Spec. No.	Deoxid. Pract.	Heat Treatment	Product Form-Size	Grain Size	Ref.	Ref. Code No.
6-1	A514C	-	Q1650, T1125	Plate, 1/2"	-	15	-
6-2	A514C	-	" "	" "	-	15	-

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(1) Yield and tensile strengths at room temperature exceed limits of current specification.
(2) Heat treated to simulate thickness indicated.

Table II

Chemical Composition of Steels

Code No.	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	N	
Part 1 - Carbon-Molybdenum steels												
1-35	.18	.52	.009	.022	.28	.12	.08	.54	.08			
1-36	.19	.50	.008	.018	.26	.16	.12	.59	.10			
1-37	.14	.54	.015	.015	.22	.06	.08	.52	.08			
1-38	.16	.85	.020	.019	.24	.028	.015	.51	.03	.010	.005	
1-39	.13	.52	.012	.021	.16	.058	.042	.52		.044	.005	
1-40	.23	.85			.26			.54				
1-41	.22	.51	.012	.020	.17	.046	.048	.50	.09	.004	.005	V
1-42	.18	.58	.008	.008	.36	.12	.10	.53				.001
1-43	.18	.68	.030	.019	.20	.10	.12	.51	.26			
1-44	.16	.78	.032	.015	.25	.03	.04	.48				
1-45	.17	.51	-	-	.32	-	-	.46	-			
1-46	.13	.49	.011	.010	.25	-	-	.52	-			
1-47	.16	.49	.015	.018	.30	-	-	.49	-			
1-48	.16	.47	.016	.015	.23	-	-	.42	-			
1-49	.11	.19	.010	.012	1.35	-	-	.50	-			
1-50	.17	.52	-	-	.16	.05	-	.54	-			
1-51	.21	.48	-	-	.31	.05	.11	.53	-			
1-52	.15	.47	-	-	.13	.02	-	.55	-			
1-53	.15	.41	-	-	.19	.07	.14	.58	-			
1-54	.13	.50	-	-	.13	.06	-	.52	-			
1-55	.16	.45	-	-	.14	.06	-	.58	-			
1-56	.16	-	-	-	-	-	-	.50	-			
1-57	.10	-	-	-	-	-	-	.50	-			
1-58	.10	-	-	-	-	-	-	.50	-			
1-59	.11	.47	.010	.014	.17	-	-	.54	-			
1-60	.11	.47	.010	.014	.17	-	-	.54				
1-61	.11	.47	.010	.014	.17	-	-	.54				
1-62	.11	.47	.010	.014	.17	-	-	.54				
1-63	.11	.47	.010	.014	.17			.54				
1-64	.11	.47	.010	.014	.17			.54				
1-65	.11	.47	.010	.014	.17			.54				
1-66	.17	.50	-	-	.21	-	-	.54				
1-67	.16	.66	.016	.012	-	-	-	.54				
1-68	.17	.60	.01	.02	.22	-	-	.45				
1-69	.17	.60	.01	.02	.22			.45				
1-70	.06	.48	-	-	.03	-	-	.56				
1-71	.06	.48	-	-	.03	-	-	.56				
1-72	.12	-	-	-	-	-	-	.50				
1-73	.25	.75	.007	.024	.25	.05	.09	.45	.12	.010		
1-74	.25	.75	.007	.024	.25	.05	.09	.45	.12	.010		
1-75	.25	.75	.007	.024	.25	.05	.09	.45	.12	.010		
1-76	.25	.75	.007	.024	.25	.05	.09	.45	.12	.010		

Code No.	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	N
1-77	.25	.75	.007	.024	.25	.05	.09	.45	.12	.010	
1-78	.21	.62	.015	.024	.23	.08	.21	.47	.24	.012	
1-79	.20	.70	.008	.012	.17	.10	.16	.47	.21	.02	
1-80	.20	.70	.008	.012	.17	.10	.16	.47	.21	.02	
1-81	.20	.70	.008	.012	.17	.10	.16	.47	.21	.02	
1-82	.14	.44			.12			.59			
1-83	.13	.66			.18			.46			
1-84	.12	.52			.23			.48			
1-85	.08	2.32	.020	.021	.71			.48			
1-86	.06	.48			.03			.56			
1-87	.06	.48			.03			.56			
1-88	.08	.26			.10			.55			
1-89	.20	.65	.004	.003	.51			.52			

Part 2 - Manganese-molybdenum and manganese-molybdenum-nickel steels (Spec. A302)

2-1	.25	1.36	.018	.036	.23			.49			
2-2	.25	1.36	.018	.036	.23			.49			
2-3	.25	1.36	.018	.036	.23			.49			
2-4	.20	1.27	.020	.028	.21			.48			
2-5	.22	1.45	.011	.015	.18	.29	.35	.50	.20	.037	
2-6	.18	1.26	.015	.012	.29	.09		.56			
2-7	.19	1.37	-	-	.20		.62	.55			
2-8	.21	1.27	.011	.016	.25	.10	.56	.60	.12	.014	
2-9	.20	1.28	.009	.018	.24	.07	.08	.47	.11	.031	
2-10	.22	1.30	.010	.017	.22	.07	.62	.52	.13	.029	
2-11	.23	1.30	.010	.015	.22	.06	.52	.42	.12	.039	
2-12	.23	1.30	.010	.015	.22	.06	.52	.42	.12	.039	
2-13	.24	1.32	.009	.016	.15	.11	.56	.55	.11	.019	
2-14	.20	1.46	.013	.010	.22			.48	.12		
2-15	.20	1.37	.010	.021	.19			.47	.12		
2-16	.20	1.42	.010	.014	.26			.47	.10		

Part 3 - Manganese-molybdenum and manganese-molybdenum-nickel steels (Spec. A533)

3-1	.26	1.35	.012	.021	.26	.15	.61	.46	.28		
3-2	.25	1.37	.012	.024	.33	.13	.63	.46	.23		
3-3	.25	1.37	.013	.024	.32	.13	.65	.46	.23		
3-4	.22	1.56	.005	.013	.38	.07	.57	.51	.19	.03	
3-5	.22	1.31	.008	.025	.22	.15	.51	.49	.25	.048	
3-6	.19	1.48	.012	.022	.21	.29	.35	.50	.20	.037	
3-7	.20	1.37	.009	.017	.19	.08	.25	.48	.15	.041	
3-8	.18	1.18	.010	.016	.22		.31	.48			
3-9	.22	1.30	.011	.025	.24	.14	.25	.45	.23	.03	
3-10	.20	1.28	.009	.018	.24	.07	.08	.47	.11	.031	
3-11	.21	1.27	.011	.016	.25	.10	.56	.60	.12	.014	
3-12	.24	1.32	.009	.015	.15	.08	.56	.55	.11	.019	

Table II - page 3

Code No.	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Al	N	
3-13	.22	1.29	.011	.018	.25	.16	.57	.46	.16	.062		
3-14	.22	1.30	.014	.020	.22	.10	.46	.50	.14			
3-15	.20	1.28	.010	.019	.25	.15	.58	.46	.25			
3-16	.25	1.34	.012	.023	.23	.10	.50	.53		.054		
3-17	.19	1.28	.013	.010	.22	-	-	.45				
3-18	.20	1.28	.019	.030	.21	.15	.53	.52	.27	.031		
Part 4 - Carbon-manganese-molybdenum steel (Spec. A372, Class IV)												
4-1	.44	1.56	.013	.021	.20			.21				
Part 5 - Carbon-manganese-molybdenum steel castings (Spec. A487, Class 2)												
5-1a,b	.30	1.10	.015	.015	.43	.26	.18	.18				
5-2a,b	.30	.87	.022	.018	.41	.21	.18	.19				
5-3a,b	.28	1.03	.016	.020	.38	.21	.16	.21				
Part 6 - Quenched and tempered carbon-manganese-molybdenum steel palte (A514C)												
									Ti		V	B
6-1	.18	1.17	.012	.023	.22	.03	.02	.24	.037	N.D.	.005	.002
6-2	.18	1.30	.012	.024	.25	.02	.02	.25	.04	N.D.	.005	.002

Table III

Short-Time Tensile Properties

Code No.	Test Temp. °F	1000 psi Yield Strength*	1000 psi Tensile Strength	Per Cent Elong.**	Per Cent Red. Area
Part 1 - Carbon-Molybdenum steels					
1-33	75	40.6	63.2	38.	67.
	200	38.3	60.2	32.	65.
	400	36.6	65.8	26.	61.
	600	29.5	66.8	26.	60.
	800	24.8	60.4	32.	68.
	1000	24.7	47.2	32.	72.
	1200	18.8	27.1	41.	72.
1-34	75	43.6	70.9	36.	64.
	200	41.4	69.4	27.	61.
	400	43.0	91.4	21.5	45.
	600	35.4	88.6	28.	52.
	800	29.9	75.5	29.	64.
	1000	28.5	59.4	31.	74.
	1200	24.7	33.9	36.	80.
1-38	80	42.5[+]	71.6	35.[a]	69.
1-39	80	41.3[+]	62.6	40.[a]	77.
1-40	80	49.4	72.5	30.	-
	700	35.0	69.2	30.	65.
	800	32.4	66.0	25.	68.
1-41	80	46.4[+]	72.5	32.[a]	64.
	300	41.5	82.4	22.[a]	52.
	500	35.3	86.5	23.[a]	46.
	700	35.4	73.9	29.[a]	64.
	1500	4.6	7.0	63.[a]	53.
	1700	3.2	5.1	79.[a]	78.
1-42	80		69.6	21.	35.
1-43	75	57.5[b]	74.0	33.	71.
1-45	70	47.2[b]	65.2	41.	75.
	800	26.5[b]	57.7	37.	78.
	1000	24.5[b]	46.7	36.	82.
1-46	85	36.0	62.5	37.	64.
	750	26.5	59.6	32.	63.
	900	23.9	50.5	27.	67.
	1000	21.2	42.5	32.	80.
	1100	16.1	37.5	32.	73.
	1200	13.0	27.5	37.	72.
	1300	9.2	18.7	50.	84.
	1400	5.4	12.7	77.	74.
1-48	85	32.5	64.0	37.	63.
	750	23.5	68.1	29.	62.
	900	22.2	58.2	29.	68.
	1000	22.7	50.4	32.	78.
	1100	22.6	42.1	40.	81.
	1200	15.1	28.1	56.	89.

* 0.2% offset unless noted otherwise.

** Elong. in 2 inches unless noted otherwise.

\+ .5% strain

a Elong. in 1 inch

b "yield point"

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Code No.	Test Temp. °F	1000 psi		Per Cent	
		Yield Strength	Tensile Strength	Elong.	Red. Area
	1300	10.4	19.0	68.	92.
	1400	5.9	11.6	83.	89.
1-49	85	47.6	71.7	35.	66.
	750	25.5	64.3	35.	69.
	900	24.2	52.5	37.	73.
	1000	23.4	44.5	38.	79.
	1100	19.2	35.6	45.	81.
	1200	11.7	25.6	60.	80.
	1300	8.4	16.7	69.	83.
	1400	5.1	9.7	85.	82.
1-50	85	36.2	60.8	40.	74.
	925	23.2	52.0	33.	82.
	1100	23.0	39.9	39.	84.
1-51	85	45.2	71.7	35.	69.
	925	28.0	57.0	32.	77.
	1100	26.8	43.7	38.	81.
1-52	85	35.0	58.9	40.	74.
	925	23.0	52.0	33.	83.
	1100	22.2	39.5	42.	88.
1-53	95	40.0	64.9	37.	72.
	925	26.2	56.9	29.	73.
	1100	25.6	41.5	40.	86.
1-54	85	35.0	58.0	40.	76.
	925	21.2	50.6	33.	82.
	1100	21.8	39.2	42.	86.
1-55	85	35.0	58.5	42.	76.
	925	22.0	51.1	34.	82.
	1100	22.6	38.2	41.	84.
1-56	75	37.3	53.8	44.	-
1-59	75	41.0	63.0	37.	74.
1-60	75	39.5	59.0	38.	77.
1-61	75	40.8	59.0	37.	77.
1-62	75	44.1	58.2	39.	79.
1-63	75	39.3	56.0	36.	64.
1-64	75	37.0	62.0	38.	77.
1-65	75	38.5	62.1	38.	78.
1-67	70	43.3[b]	71.8	34.	67.
	900	12.6[b]	63.5	27.	76.
1-68	70	40.7[b]	61.7	35.	59.
1-69	70	40.5[b]	64.0	33.	63.
1-70	70	58.1[b]	75.0	29.	56.
1-71	70	60.2[b]	72.4	31.	63.
1-72	70	33.9[b]	55.2	37.	-
	900	32.0[b]	48.1	27.	-
1-73	70	49.6	80.3	27.	47.
	300	46.0	84.3	23.	43.
	500	43.5	90.5	18.	37.
	600	40.0	90.5	20.	36.
	650	42.1	79.9	21.	49.

Table III - page 3

Code No.	Test Temp. °F	1000 psi Yield Stren.	1000 psi Tensile Stren.	Per Cent Elong.	Per Cent Red. Area
1-73	700	42.8	79.5	24.	48.
cont.	750	38.5	69.3	21.	52.
	800	40.3	69.5	20.	52.
	850	41.6	67.7	21.	49.
1-74	70	55.6	83.3	24.	51.
	500	57.8	97.8	21.	35.
	675	48.1	77.3	21.	54.
	850	51.5	76.7	20.	56.
	1000	46.0	62.7	20.	63.
1-75	70	51.7	78.8	28.	52.
	500	40.6	78.6	17.	41.
	675	43.5	79.6	23.	49.
	850	47.6	71.2	25.	51.
	1000	40.8	60.5	22.	54.
1-76	70	47.2	74.4	30.	51.
	500	42.8	79.7	24.	40.
	675	39.8	67.3	21.	49.
	850	41.9	70.4	20.	45.
	1000	36.3	58.2	23.	54.
1-77+	70	46.9	73.6	32.	52.
	500	44.5	78.5	21.	38.
	675	38.5	65.5	23.	49.
	850	36.8	66.7	23.	52.
	1000	42.2	57.0	24.	55.
1-78	70	46.6	73.2	31.	56.
	500	36.0	64.6	26.	52.
	675	33.5	65.3	25.	42.
	850	30.4	60.5	26.	61.
	1000	29.9	50.6	30.	68.
1-79	75	55.6	80.6	29.	61.
	750	31.4	75.8	28.	64.
1-80	75	55.1	78.6	31.	63.
	750	31.1	75.4	28.	63.
1-81	75	52.3	76.7	29.	66.
	750	31.4	69.0	31.	64.
Part 2 - Manganese-molybdenum and manganese-molybdenum-nickel steels (Spec. A302)					
2-4	75	77.0	98.5	23.	61.
	100	73.7	99.2	26.	65.
	150	70.2	96.4	21.	60.
	200	69.5	94.5	22.	66.
	300	68.1	91.0	22.	65.
	400	65.9	89.9	20.	56.

\+ Test samples from 1/2 T position.

Table III - page 4

		1000 psi		Per Cent	
Code No.	Test Temp. °F	Yield Stren.	Tensile Stren.	Elong.	Red. Area
2-4	550	67.5	92.0	17.3	52.
cont.	700	65.9	92.0	24.	54.
2-5	75	85.6	104.9(1)	20.	50.
	1000	64.5	75.4	23.	66.
	1200	42.5	46.6	27.	55.
	1400	13.6	16.6	58.	51.
	1600	7.2	10.3	51.	44.
	1800	4.0	5.4	59.	57.
2-6	80	76.4	96.1	25.	69.
	200	70.1	90.0	23.	68.
	400	66.9	88.8	23.	67.
	600	66.5	94.0	27.	65.
	800	61.0	79.9	26.	73.
	1000	53.4	61.7	29.	83.
	1200	32.0	38.7	31.	91.
	1400	12.0	17.4	79.	92.
	1600	6.6	13.4	50.	92.
	1900	3.0	5.6	-	91.
2-7	80	71.6	88.1	27.	-
	500	55.0	82.4	21.	67.
	700	58.5	84.5	28.	74.
	900	49.6	68.6	21.	76.
2-8	80	54.2	100.8	26.	50.
	750	53.2	90.5	33.	64.
	850	50.1	74.9	34.	68.
	950	47.9	64.4	34.	72.
2-9	80	69.8	94.9	22.	56.
	750	58.9	84.8	23.	62.
	850	56.3	79.8	22.	64.
	950	53.4	71.7	25.	68.
2-10(2)	75	94.4	116.3(2)	22.	60.
	400	90.7	111.0	14.	46.
	600	84.4	111.9	26.	69.
	800	82.2	103.5	22.	71.
	1000	69.6	78.4	20.	69.
2-11	75	73.3	95.0	26.	69.
	400	67.2	93.4	24.	64.
	600	70.3	96.5	25.	61.
	800	67.3	81.0	28.	72.
	1000	54.4	63.3	26.	78.
2-12	75	64.2	90.5	28.	69.
	400	60.1	84.5	23.	68.
	600	61.1	95.8	32.	64.

(1) Slightly higher than permitted by spec. A302.
(2) Exceeds limit of spec. A302C.

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		1000 psi		Per Cent	
Code No.	Test Temp. °F	Yield Stren.	Tensile Stren.	Elong.	Red. Area
2-12	800	56.2	76.7	22.	72.
cont.	1000	50.6	57.1	22.	80.
2-13	80	60.7	87.0	30.	65.
	750	47.3	79.1	30.	63.
	850	44.3	69.2	31.	69.
	950	43.7	61.2	31.	72.
2-14	75	61.7	81.4	27.	72.
	200	58.6	76.8	25.	67.
	400	53.2	74.2	22.	69.
	600	53.1	75.2	27.	65.
2-15	75	58.7	81.0	29.	70.
	200	56.5	76.4	25.	68.
	400	54.1	76.6	22.	69.
	600	51.0	74.1	27.	65.
2-16	75	62.8	83.5	29.	69.
	200	59.5	79.1	27.	67.
	400	54.6	75.7	26.	66.
	600	52.4	80.0	29.	62.
Part 3 - Manganese-molybdenum and manganese-molybdenum-nickel steels (Spec. A533)					
3-1	75	87.2	108.1	24.	67.
	200	84.5	101.9	23.	66.
	400	78.5	97.5	22.	67.
	600	76.5	100.9	19.5	51.
	800	69.2	87.3	21.	63.
3-2	75	87.0	107.5	25.	66.
	200	82.0	101.0	24.	66.
	400	78.6	98.1	22.	63.
	600	78.0	101.3	21.	55.
	800	71.2	86.1	21.	69.
3-3	75	91.5	110.4	25.	67.
	200	86.1	102.9	24.	67.
	400	81.2	99.0	21.	63.
	600	81.8	103.5	21.	54.
	800	72.8	89.1	22.	66.
3-4	75	72.6	94.5	24.	65.
	300	65.4	85.5	23.	65.
	500	62.9	85.9	21.	64.
	700	60.9	84.6	25.	67.
	900	54.6	67.1	22.	74.
3-5	75	69.4	91.3	25.	66.
	550	61.8	88.0	23.	60.
	650	60.1	84.9	25.	61.
3-6	75	88.3	105.7	26.	-
	200	91.8	107.7	23.	71.
	400	88.4	105.3	22.	65.

Table III - page 6

	Test	1000 psi		Per Cent	
Code No.	Temp. °F	Yield Stren.	Tensile Stren.	Elong.	Red. Area
3-6	600	84.8	111.1	20.	62.
cont.	800	78.1	97.7	22.	69.
	1000	66.7	74.4	24.	79.
3-7	75	82.8	100.5	25.	-
	200	81.0	98.3	23.	70.
	400	76.0	96.5	19.	70.
	600	74.7	106.5	24.	56.
	800	68.5	91.5	22.	64.
	1000	61.6	72.9	22.	79.
3-8	75	89.1	107.1	23.	64.
	700	76.4	100.6	18.7	60.
	800	71.9	92.2	19.0	63.
	900	68.5	83.2	18.5	67.
	1000	62.9	74.5	20.	72.
3-9	75	86.7	107.6	21.	64.
	300	77.3	97.0	22.	65.
	500	73.1	102.5	28.	63.
	700	71.7	100.0	27.	70.
	800	69.1	90.4	25.	66.
3-10	80	62.1	83.1	30.(1)	69.
	750	57.8	82.5	30.(1)	71.
	850	54.5	71.4	30.(1)	75.
	950	50.7	64.1	29.(1)	80.
3-11	80	64.5	87.0	29.	67.
	750	54.2	73.1	29.	66.
	850	50.9	67.0	33.	71.
	950	47.9	58.9	32.	79.
3-12	75	70.8	95.1	27.	63.
	750	59.5	79.7	31.	67.
	850	56.0	71.4	43.	72.
	950	53.0	62.7	31.	76.
3-13	75	65.3	87.3	26.	67.
	200	67.7	89.0	22.	66.
	400	56.7	78.3	22.	66.
	600	58.1	85.2	25.	66.
3-14	75	64.6	87.1	27.	70.
	200	63.4	84.1	25.	69.
	400	52.2	75.5	23.	68.
	600	54.1	80.1	23.	66.
3-15	75	67.2	88.8	25.	67.
	200	64.8	84.6	24.	68.
	400	58.8	81.0	22.	66.
	600	57.3	83.2	22.	64.
3-16	80	100.0	117.0	21.	66.
	200	99.4	114.0	20.	65.
	400	91.4	111.0	20.	62.

(1) 1" gage length.

		1000 psi		Per Cent	
Code No.	Test Temp. °F	Yield Stren.	Tensile Stren.	Elong.	Red. Area
3-16 cont.	600	90.0	117.0	25.	66.
	800	79.0	98.8	23.	72.
	1000	69.8	79.8	22.	82.
3-17	75	121.3	138.0	22.	70.
3-18a	75	121.5	130.5	20.	63.
3-18b	75	70.0	88.7	28.	69.
	200	64.8	82.5	25.	69.
	600	58.1	83.6	21.	60.
	900	51.7	64.6	22.	74.
	1100	44.2	45.5	26.	81.
3-18c	75	64.1	84.6	29.	69.
	200	56.7	77.5	28.	68.
	600	48.5	78.9	23.	58.
	900	41.4	58.4	28.	75.
	1100	36.1	39.8	38.	82.
Part 4 - Carbon-manganese-molybdenum steel forgings (Spec. A372, Class IV)					
4-1	75	95.9	125.9	19.	54.
	200	91.8	120.3	18.5	53.
	300	86.9	118.1	17.0	54.
	400	85.5	119.3	18.0	55.
	500	87.1	123.7	22.0	60.
	600	85.9	127.4	29.0	71.
	700	81.4	117.5	28.0	74.
	800	77.6	101.4	24.0	78.
	900	72.5	88.6	27.0	84.
	1000	63.3	74.4	25.5	85.
Part 5 - Carbon-manganese-molybdenum steel castings (Spec. A487, Class 2)					
5-1a	75	65.0	98.5	23.	41.
	300	62.5	90.0	28.	46.
	500	56.5	89.5	20.	39.
	700	55.0	91.2	22.	39.
5-1b	75	88.0	107.0	22.	48.
	300	85.0	101.5	18.0	48.
	500	78.0	101.0	18.0	44.
	700	78.0	103.7	24.0	46.
5-2a	75	59.0	88.5	24.0	43.
	300	50.0	80.0	26.0	51.
	500	41.0	80.0	23.0	41.
	700	40.0	81.0	24.0	42.
5-2b	75	77.0	98.0	24.0	57.
	300	71.0	92.0	22.0	56.
	500	65.0	89.0	21.0	53.
	700	65.0	97.0	27.0	59.

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Code No.	Test Temp. °F	1000 psi Yield Stren.	 Tensile Stren.	Per Cent Elong.	 Red. Area
5-3a	75	63.0	93.0	23.0	45.
	300	58.0	84.6	24.0	50.
	500	52.5	84.0	22.0	40.
	700	46.0	85.0	23.0	51.
5-3b	75	80.0	101.0	22.0	52.
	300	71.0	91.3	21.0	50.
	500	68.0	96.0	22.0	53.
	700	67.5	95.0	31.0	62.
Part 6 - Quenched and tempered carbon-manganese-molybdenum steel plate					
6-1	70	115.0	120.3	19.	66.
	300	106.0	114.7	18.	62.
	600	101.0	115.1	24.	70.
	700	91.0	103.2	25.	72.
	750	92.0	99.8	20.	73.
	800	90.0	97.3	18.5	72.
	850	88.0	93.2	18.0	74.
	900	85.0	88.9	19.0	79.
	950	82.0	85.1	21.0	83.
	1000	77.0	80.5	21.0	82.
	1100	63.0	65.2	27.	86.
6-2	70	122.2	128.3	19.0	66.
	300	112.0	122.2	16.5	63.
	600	106.8	121.3	24.	71.
	700	102.9	114.1	22.	70.
	750	97.8	107.1	20.	72.
	800	95.7	103.7	18.5	72.
	850	92.7	99.8	18.5	71.
	900	88.7	94.0	18.0	75.
	950	87.6	90.6	20.5	79.
	1000	81.0	84.5	21.0	82.
	1100	64.6	68.5	29.0	88.

Table IV

Creep and Rupture Data

Code No.	Temp. °F	Stress, ksi	Test[1] Duration-Hours	Min. creep Rate-%/hr.	At Rupture	
					% Elong.[2]	% Red. Area
Part 1 - Carbon-Molybdenum steels						
1-31a	950	40.0	841.	-	5.5	8.5
		37.0	1518.	-	4.0	5.4
		34.5	2108	-	4.0	5.5
		31.5	3528	-	4.0	7.3
		30.0	5739.	-	5.0	4.4
1-31b	950	37.5	1064.	.00522	13.5	13.2
		36.0	1375.	.00375	11.0	11.5
		34.5	2099.	-	12.5	12.6
		31.5	3053.	-	8.5	10.9
		29.0	3372.	-	9.5	13.2
1-31c	950	36.0	1055.	.0062	16.0	16.7
		34.0	1630.	.0035	12.0	15.6
		31.0	2512.	-	12.0	9.7
		27.0	3950.	-	7.0	14.4
		22.0	8120.	-	10.5	17.2
1-32	950	33.0	2382.	.0015	5.0	8.6
		30.0	4568.	.00102	8.0	13.8
	1050	17.0	1426.	.00178	13.5	20.2
		15.0	2526.	-	14.0	15.3
		12.5	3369.	.00098	16.0	19.5
		10.0	6407.	.00045	4.0	17.4
1-33	850	50.0	1879.	-	23.0	23.0
		45.0	6040.	-	18.0	39.
		42.0	8991.	-	14.0	10.9
		37.5	20,171.	.000322	10.5	7.9
	950	36.0	375.	-	12.5	15.7
		30.0	944.	-	8.0	6.7
		22.0	5310.	-	5.5	6.1
		19.5	12,274.	-	8.0	10.4
	1050	15.0	487.	-	21.5	38.
		12.5	1208.	-	19.5	32.
		9.5	5197.	-	17.0	34.
		8.4	6101.	.00137	17.5	26.
		8.0	10,075.	.00072	17.0	28.

(1) All tests continued to rupture except those designated c, which were terminated before rupture.

(2) Elongation measured in 2 inches, unless otherwise noted.

Table 1V - page 2

					At Rupture	
Code No.	Temp. °F	Stress, ksi	Test Duration-Hours	Min. creep Rate-%/hr.	% Elong.	% Red. Area
1-34	850	50.0	3575.	-	13.0	13.8
		48.0	5217.	-	11.0	12.7
		45.0	9791.	-	10.0	9.2
	950	40.0	370.	-	9.5	9.1
		36.0	1565.	-	7.0	14.4
		30.0	3153.	-	3.5	9.7
		22.5	8750.	-	4.5	6.8
	1050	18.0	536.	-	5.0	11.5
		15.0	955.	-	6.0	11.5
		12.5	1688.	-	7.5	5.5
		9.5	5924.	-	9.0	13.9
		7.0	13,845.	-	7.3	7.3
1-35	850	65.0	1.0	-	25.	72.
		62.0	Ruptured during loading		28.	73.
		60.0	1211.	.00157	28.	56.
		56.0	7160.	.000858	19.	38.
		52.0	12,850.	.00028	15.0	11.6
1-36	850	55.0	830.	.0111	31.5	49.
		50.0	3138.	.00193	23.	30.
		47.0	5970.	.00112	21.	22.4
		44.0	12,890.	.00079	14.	11.5
	950	35.0	754.	.0072	9.0	15.0
		32.0	1023.	.00525	10.0	10.9
		28.5	1587.	.00295	4.5	10.3
		25.0	3967.	.000987	7.5	9.8
		21.0	7286.	.00063	8.5	7.4
1-37	850	55.0	766.	.006	22.	27.
		53.0	2395.	.0015	18.0	16.7
		50.0	3906.	.00079	14.5	15.6
	950	38.0	624.	.00368	9.0	13.8
		35.0	1579.	.00088	6.5	9.1
		31.0	2321.	.00078	7.5	6.1
	1050	18.0	403.	.0080	7.5	9.1
		15.0	1006.	.00194	9.0	41.
		12.0	1178.	-	8.5	14.3
1-38	900	62.0	1.9	-	35.	-
		58.0	22.3	-	39.	-
		56.0	148.	-	40.	-
		53.0	1063.	-	30.	-
	1050	40.0	6.2	-	50.	-
		34.2	51.	-	39.	-
		28.8	183.	-	28.	-
		25.0	361.	-	25.	-
		20.0	873.	-	34.	-
1-39	900	58.0	19.	-	35.	-
		54.0	668.	-	40.	-
		53.0	1227.	-	27.	-
		52.0	1561.	-	30.	-

Table IV - page 3

Code No.	Temp. °F	Stress, ksi	Test Duration-Hours	Min. creep Rate-%/hr.	At Rupture	
					% Elong.	% Red. Area
1-39 cont.	1050	40.0	6.5	-	44.	-
		35.0	51.	-	25.	-
		30.0	119.	-	15.	-
		25.0	334.	-	12.	-
		20.0	850.	-	12.	-
1-41	900	59.0	1.8	-	30.	-
		55.0	183.	-	28.	-
		54.0	445.	-	22.	-
		53.0	600.	-	15.	-
	1050	40.0	9.0	-	39.	-
		35.0	65.	-	20.	-
		30.0	186.	-	10.	-
		25.0	315.	-	10.	-
		23.0	517.	-	10.	-
		20.0	813.	-	10.	-
1-42	950	40.0	41.8	-	11.7	35.
	1000	30.0	195.	-	5.3	17.
	1050	20.0	412.	-	3.8	12.
1-43	800	25.0	1500. c	.000020	-	-
	900	18.0	2000. c	.000009	-	-
1-44a	900	17.0	2000. c	.000006	-	-
1-44b	850	20.0	2000. c	.000012	-	-
	900	17.0	2000. c	.000012	-	-
1-44c	850	20.0	2000. c	.000008	-	-
	900	17.0	2000. c	.000006	-	-
	1000	9.0	2000. c	.000036	-	-
1-45	1000	3.0	1000. c	.000010*	-	-
		10.0	1000. c	.000026	-	-
	1100	3.0	1000. c	.000023	-	-
1-46	900	13.0	1000. c	.000013	-	-
		15.0	1000. c	.000024	-	-
		17.5	1000. c	.000082	-	-
		20.0	1230. c	.00014	-	-
	1000	8.0	1000. c	.000025	-	-
		10.0	1000. c	.000097	-	-
		12.0	1100. c	.000122	-	-
		15.0	1000. c	.000505	-	-
	1100	3.0	1000. c	.000042	-	-
		4.0	1240. c	.000094	-	-
		5.0	1000. c	.000256	-	-
		6.0	1000. c	.000488	-	-
	1200	0.8	1000. c	.000007	-	-
		1.5	1200. c	.00004	-	-
		2.0	1000. c	.000067	-	-
		3.0	1150. c	.00037	-	-

* Result appears unreasonable.

Table IV - page 4

Code No.	Temp. °F	Stress, ksi	Test Duration-Hours	Min. creep Rate-%/hr.	At Rupture	
					% Elong.	% Red. Area
1-47	800	22.5	575. c	.000016	-	-
		27.0	575. c	.000122	-	-
	1000	10.0	500. c	.000012	-	-
		12.5	500. c	.000038	-	-
		15.0	500. c	.000081	-	-
	1200	.58	1000. c	.000030	-	-
		.95	1000. c	.000095	-	-
		1.0	500. c	.000070	-	-
		1.5	550. c	.000086	-	-
		2.0	550. c	.000167	-	-
		3.1	500. c	.000754	-	-
1-48	800	15.0	570. c	.000008	-	-
		17.5	635. c	.000016	-	-
		24.25	560. c	.000074	-	-
		30.0	500. c	.000172	-	-
	1000	10.0	550. c	0	-	-
		15.0	500. c	.000041	-	-
		20.0	500. c	.000214	-	-
		30.0	500. c	.0010	-	-
	1200	0.95	750. c	.000030	-	-
		1.2	615. c	.000046	-	-
		1.5	600. c	.000066	-	-
		2.0	500. c	.00012	-	-
		3.0	500. c	.00024	-	-
		4.0	600. c	.00092	-	-
1-49	800	20.0	1000. c	.000015	-	-
		25.0	1000. c	.000046	-	-
		32.5	1000. c	.00015	-	-
	1000	6.0	1000. c	.000019	-	-
		7.0	1000. c	.0000325	-	-
		9.0	1000. c	.000106	-	-
		12.5	1000. c	.000267	-	-
		17.5	1000. c	.0011	-	-
	1200	1.0	1000. c	.000022	-	-
		1.5	1000. c	.000063	-	-
		2.0	1000. c	.000120	-	-
		3.0	1000. c	.00070	-	-
1-50	925	15.0	1140. c	.000011	-	-
1-51	925	15.0	1140. c	.000020	-	-
1-52	925	15.0	1130. c	.000012	-	-
1-53	925	15.0	1140. c	.000003	-	-
1-54	925	15.0	1120. c	.0000225	-	-
1-55	925	15.0	1110. c	.000029	-	-
1-56	1000	5.0	500. c	.000022	-	-
		7.5	500. c	.000052	-	-
		9.22	500. c	.000128	-	-
		11.7	500. c	.000288	-	-

Table IV - page 5

Code No.	Temp. °F	Stress, ksi	Test Duration-Hours	Min. creep Rate-%/hr.	At Rupture	
					% Elong.	% Red. Area
1-57	1200	2.0	500. c	.000116	-	-
		3.0	500. c	.000261	-	-
1-58	1200	1.0	500. c	.000116	-	-
		4.0	500. c	.00449	-	-
1-59	1100	2.5	2360. c	.000090	-	-
		4.5	2450. c	.000258	-	-
		5.0	3530. c	.000446	-	-
1-60	1100	2.5	3210. c	.00005	-	-
		3.5	3000. c	.00018	-	-
		5.0	2670. c	.000424	-	-
1-61	1100	2.5	3080. c	.000047	-	-
		3.5	5140. c	.000144	-	-
		5.0	3000. c	.000608	-	-
1-62	1100	2.5	3020. c	.000036	-	-
		3.5	3120. c	.000098	-	-
		5.0	3120. c	.000358	-	-
1-63	1100	2.5	3030. c	.000103	-	-
		3.0	3140. c	.000138	-	-
		3.5	3070. c	.000246	-	-
1-64	1100	1.5	3000. c	.000066	-	-
		2.5	3050. c	.000105	-	-
		5.0	3340. c	.000941	-	-
1-65	1100	1.5	3000. c	.000022	-	-
		2.5	3000. c	.000080	-	-
		3.5	3020. c	.000210	-	-
1-66	1000	15.0	958. c	.000056	-	-
	1100	10.0	301. c	.00156	-	-
1-67	800	26.0	1000. c	.00002	-	-
		35.0	1000. c	.00013	-	-
	900	21.5	1500. c	.000036	-	-
		27.5	1000. c	.000156	-	-
	1000	7.5	1000. c	.00004	-	-
		10.0	1000. c	.000052	-	-
		15.0	1000. c	.000092	-	-
1-68	950	11.0	2250. c	.000003	-	-
		12.0	2250. c	.000015	-	-
1-69	900	16.0	2250. c	.000003	-	-
		25.0	2250. c	.000015	-	-
	950	11.0	2250. c	.000001	-	-
		20.0	2250. c	.000009	-	-
1-70	842	20.0	1000. c	.0000292	-	-
		15.0	1000. c	.000010	-	-
	932	13.0	1020. c	.0000196	-	-
		10.0	1025. c	.0000079	-	-
1-71	932	10.0	1030. c	.0000134	-	-
		13.0	1030. c	.0000368	-	-
	1022	6.0	1250. c	.0000368	-	-
		8.0	1250. c	.0000492	-	-

Table IV - page 6

Code No.	Temp. °F	Stress, ksi	Test Duration-Hours	Min. creep Rate-%/hr.	At Rupture % Elong.	At Rupture % Red. Area
1-72	932	20.0	1030. c	.0000194		-
	932	20.0	1030. c	.0000248		-
1-88	900	58.0	1.5	-	11.6	62.
		52.0	33.	-	5.7	18.
		46.0	136.	-	5.9	17.
		42.0	871.	-	3.0	10.
		38.0	343.	-	2.0	13.
		38.0	1035.	-	2.3	11.
1-89	1150	7.0	648.	-	15.6	44.
	1050	17.0	331.	-	14.5	33.
	1000	27.0	132.	-	25.4	48.
	900	27.0	10,046.	-	10.2	24.
	800	38.0	38,307.	-	13.3	58.
Part 2 - Manganese-molybdenum and manganese-molybdenum-nickel steels (spec. A302)						
2-8	830	57.5	219.	.01319	31.	70.
	850	65.0	0.5	8.4	29.	64.
		62.5	1.9	6.2	29.	65
		57.5	48.6	.253	34.	66.
		55.0	445.	.0268	30.	64.
		52.5	2667. c	.00426	-	-
		50.0	1438. c	.00217	-	-
		45.0	5000. c	.0004	-	-
	900	32.5	171. c	.00125	-	-
	950	60.0	during loading	-	30.	70.
		47.5	10.3	1.76	42.	74.
		45.0	26.9	1.12	41.	73.
		40.0	101.	.077	37.	57.
		35.0	321.	.0218	17.8	35.
		30.0	1281.	.00651	19.5	25.
2-9	950	53.0	183.	-	11.4	13.8
		45.0	727.	-	7.5	10.0
		42.5	476.	-	8.6	11.6
Part 3 - Manganese-molybdenum and manganese-molybdenum-nickel steels (spec. A533)						
3-10	850	60.0	61.	.249	31.	68.
		57.5	95.	.154	34.	62.
	950	50.0	19.4	.870	39.	77.
		47.5	630.	.01165	22.	39.
		40.0	288.	.0337	35.	54.
		37.5	1198.	-	22.	25.
		35.0	1017.	.0033	16.5	25.
		32.5	1938. c	.00159		

Table IV - page 7

Code No.	Temp. °F	Stress, ksi	Test Duration-Hours	Min. creep Rate-%/hr.	At Rupture	
					% Elong.	% Red. Area
3-11	850	60.0	2.25	3.21	30.	71.
		55.0	18.6	.371	26.	69.
		52.5	21.	.423	29.	71.
		50.0	253.	.0326	31.	70.
		47.5	160.	.0358	30.	64.
		45.0	907.	.0034	31.	71.
		40.0	1000. c	.000679	-	-
	950	50.0	0.7	9.14	36.	74.
		45.0	7.0	.864	37.	78.
		40.0	54.	.1095	35.	76.
		35.0	188.	.0399	32.	61.
		30.0	657.	.0161	24.	38.
3-17	900	80.0	110.	-	33.	44.
		70.0	265.	-	-	-
		60.0	905.	-	-	7.
	1000	57.0	15.	-	-	27.
		50.0	0.6	-	16.	66.
		45.0	10.7	-	21.	42.
		40.0	39.0	-	24.	42.
		33.5	53.	-	8.	-
		30.0	108.	-	-	10.
		25.0	271.	-	33.	21.
		20.0	740.	-	-	29.
	1100	20.0	23.3	-	-	41.
		15.0	103.	-	-	-
3-18a	900	80.0	14.	-	-	72.
		70.0	186.	-	15.	21.
		60.0	283.	-	-	-
		50.0	535.	-	41.	11.
	1000	57.0	12.1	-	21.	35.
		50.0	19.2	-	19.	24.
		45.0	29.7	-	20.	22.
		40.0	27.5	-	38.	53.
		33.5	96.	-	23.	27.
		30.0	171.	-	14.	13.
		25.0	320.	-	27.	33.
		20.0	712.	-	-	29.
	1100	15.0	106.	-	70.	60.

Part 6 - Quenched and tempered carbon-manganese-molybdenum steel plate (A514 C)

6-1	700	100.0	2.5	-	11.1	-
		95.0	650.	-	-	-
		92.0	717.	-	10.2	-
		90.0	526.	-	-	-
	800	90.0	5.3	-	-	-
		85.0	23.5	-	13.4	-

Table IV - page 8

Code No.	Temp. °F	Stress, ksi	Test Duration-Hours	Min. creep Rate-%/hr.	At Rupture % Elong.	At Rupture % Red. Area
6-1	800	82.0	26.7	-	12.3	-
cont.		80.0	78.0	-	15.0	-
		75.0	592.	-	-	-
		72.0	933.	-	-	-
	900	70.0	7.0	-	14.0	-
		65.0	15.7	-	16.0	-
		60.0	61.	-	-	-
		55.0	154.	-	30.	-
		50.0	317.	-	21.	-
		47.5	1000. c	.0116	-	-
		45.0	1000. c	.00334	-	-
		30.0	1814. c	.00135	-	-
	1000	45.0	21.5	-	28.	-
		42.0	27.5	-	30.	-
		40.0	63.	-	-	-
		35.0	212.	-	41.	-
		32.0	98.	-	40.	-
		30.0	274.	-	-	-
		27.0	362.	-	46.	-
		25.0	373.	.0226	38.	-
		20.0	1174. c	-	-	-
		18.0	1000. c	.00467	-	-
6-2	700	100.0	68.	-	10.1	-
		95.0	1995. c	-	-	-
	800	85.0	144.	-	17.	-
		80.0	366.	-	14.2	-
		80.0	439.	-	-	-
		70.0	2000. c	.00207	-	-
		68.0	1300. c	.000836	-	-
	900	55.0	422.	-	14.0	-
		50.0	1216. c	-	-	-
		42.5	1000. c	.00101	-	-
		40.0	1000. c	.00100	-	-
		37.5	1000. c	.000786	-	-
	1000	40.0	30.5	-	22.	-
		40.0	86.	-	24.	-
		35.0	212.	-	-	-
		30.0	211.	-	28.	-
		30.0	377.	-	31.	-
		16.0	1000. c	.00245	-	-

Table Va

Ratio of Elevated Temperature Yield Strength to Room Temperature Yield Strength

Temp. °F	C-1/2 Mo	A302	A533	Combined A302-A533	A372,IV	A487,2N	A487,2O	A514C
75	1.000	1.000	1.000	1.000	1.00	1.0	1.0	1.0
100	.988	.983	.990	.988	.990	.986	.990	.980
200	.940	.938	.951	.950	.947	.945	.959	.942
300	.902	.914	.923	.922	.917	.904	.925	.918
400	.870	.903	.903	.903	.902	.860	.890	.901
500	.845	.898	.887	.890	.896	.820	.860	.881
600	.818	.893	.870	.877	.886	.775	.859	.857
700	.788	.880	.848	.861	.862	.738	.858	.829
800	.749	.853	.817	.833	.815	-	-	.788
900	.698	.805	.770	.788	.746	-	-	.732
1000	.631	.729	.705	.718	.663	-	-	.654
1100	.545	.615	.617	.613		-		.549
1200	.435	.466	-	.463				
1300	.297							
1400	.140							

Table Vb

Ratio of Elevated Temperature Tensile Strength to Room Temperature Tensile Strength

Temp. °F	C-1/2 Mo	A302	A533	Combined A302-A533	A372,IV	A487,2N	A487,2O	A514C
75	1.000	1.000	1.000	1.000	1.00	1.0	1.00	1.00
100	.990	.981	.980	.983	.990	.980	.990	.990
200	.965	.928	.944	.937	.951	.930	.959	.970
300	1.035	.928	.935	.933	.939	.909	.935	.952
400	1.118	.948	.942	.946	.958	.902	.923	.942
500	1.125	.967	.947	.958	.986	.905	.928	.938
600	1.075	.966	.938	.952	.989	.909	.941	.922
700	1.010	.934	.908	.920	.939	.918	.968	.878
800	.935	.868	.850	.857	.828	-	-	.815
900	.840	.771	.764	.766	.686	-	-	.738
1000	.735	.653	.652	.653	.596	-	-	.650
1100	.590	.545	.518	.531				.545
1200	.440	.425		.417				-
1300	.295							
1400	.175							

Table VI

Summary of Rupture Strengths (ksi)
Individual Lots

	Temperature °F							
Code No.	800	850	900	950	1000	1050	1100	1200
1000 hours								
1-1				32.0	23.0	-	8.4	5.1
1-3				38.0	30.0	20.5	11.1	
1-4			52.0			19.0		
1-5			53.0			20.0		
1-6			53.0			19.5		
1-8					22.0			
1-14			36.0					
1-29b			55.0				13.4	
1-30a			54.0					
1-30b			54.0					
1-31a				38.5				
1-31b				38.0				
1-31c				39.0				
1-32				38.0		19.8		
1-33		56.0		30.0		13.0		
1-34		58.0		42.0		14.5		
1-35		62.0						
1-36		56.0		32.5				
1-37		57.0		37.0		14.0		
2-8		53.0		30.5				
2-9		-		42.0				
3-10		-		37.0				
3-11		44.0		28.5				
3-17		-	58.0	-	19.0			
3-18		-	44.0	-	18.5			
							700°F	
6-1	71.0	-	44.0	-	27.0		92.0	
6-2	74.0	-			20.0		-	
10,000 hours								
1-1				20.0	12.4	-	5.0	3.2
1-3							**6.6**	
1-4			49.0			11.0		
1-5			49.0			13.0		
1-6			49.0			11.5		
1-8					14.5			
1-14			25.7					

Table VI - page 2

	Temperature °F							
Code No.	800	850	900	950	1000	1050	1100	1200
1-29b			43.0				7.2	
1-30b			45.0					
1-31a				27.0				
1-31b				24.0				
1-31c				21.0				
1-32				26.5		9.0		
1-33		41.0		20.0		8.0		
1-34		44.0		21.5		7.9		
1-35		53.0						
1-36		44.0		19.5				
1-37		46.0		24.0		7.6		
2-8		51.0	-	24.0				
3-10		-	-	31.0				
3-11		40.0	-	22.0				
3-17		-	43.0	-	12.0			
3-18			-	-	10.4			
6-1	64.0	-						
6-2	62.0							
100,000 hours								
1-1				12.1	6.8	-	3.0	1.95
1-3							3.8	
1-5			41.0			-		
1-14			18.0					
1-31a				19.0				
1-31b				15.0				
1-31c				12.5				
1-32				18.0		4.0		
1-33		30.0		13.1		5.0		
1-34		34.0		11.0		4.1		
1-35		40.0						
1-36		35.0		11.7				
1-37		37.0		15.5				
2-8		-	-	18.8				
3-10				26.5				
3-11		35.0						
3-17			32.0					

Table VII

Summary of Creep Strengths (ksi)

Individual Lots

Code No.	700	750	800	850	900	950	1000	1100	1200
0.1 percent per 1000 hours									
1-1					18.8	-	10.8	4.0	2.2
1-2	-	-	-	-	-	23.0			
1-7							9.5		
1-9							9.0		
1-10							11.5		
1-11							10.0		
1-12							11.8		
1-13							10.1		
1-22							12.7		
1-26							11.5		
1-36				30.0		15.5			
1-37				40.0		26.0			
1-47			26.0				15.4		1.2
1-48			26.0				17.7		1.8
1-49			29.9				9.5		1.85
1-56							8.6		1.87
1-58									.95
1-59								2.9	
1-60								3.0	
1-61								3.1	
1-62								3.4	
1-63								2.6	
1-64								2.4	
1-65								2.7	
1-67			33.0		25.0		14.0		
1-68						13.2			
1-70				28.0 (842°F)		21.0 (932°F)			
1-71						17.0 (932°F)			
2-8				41.0					
3-10						23.0			
3-11				38.0					
0.01 percent per 1000 hours									
1-1				14.5	12.5	-	6.6	1.8	.97
1-2		29.5	22.0	22.5	21.7	13.2			
1-7							6.7		
1-8							8.5		
1-10							5.2		
1-11							6.3		
1-12							7.5		
1-22							7.7		

Tabel VII - page 2

Code No.	700	750	800	850	900	950	1000	1100	1200
1-43					18.0				
1-44b				19.0	16.0				
1-47			21.0				9.6		0.36
1-48			15.7				10.7		0.51
1-49			18.2				5.2		0.72
1-50					14.7 (925F)				
1-52					14.5 (925F)				
1-56							4.7		
1-59								1.2	
1-60								1.4	
1-61								1.6	
1-62								1.8	
1-65								1.18	
1-67			23.0		17.0				
1-68						11.8			
1-69					22.0	20.5			
1-70				15.0 (842F)		10.6 (932F)			
1-71						9.3 (932F)			

Table VIII

Regression Analyses of Isothermal Rupture Scatter Bands - C-Mo

Temp. °F	Order of Regress. Eq.	Variance (log psi vs log hours)	Stress (ksi) for rupture in 1000 hrs.	10,000 hrs.	100,000 hrs.*
850	1	.00121	55.4	45.6	37.5
	2	.00119	55.0	45.4	30.3
900	1	.00528	47.9	37.2	28.8
	3	.00361	51.8	14.9	0.14
950	1	.00193	35.0	23.2	15.5
	2	.00156	36.0	21.2	8.4
1000	1	.00492	23.1	15.4	10.2
1050	1	.00342	16.2	8.25	4.2
	2	.00337	16.5	7.9	3.4
1100	1	.00950	9.9	4.3	1.87
1200	Too few data to warrant evaluation				

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* By extrapolation of regression line

Table IX

Summary - Rupture Strengths (ksi) - C-Mo Steel

Temp. °F	Isothermal Scatter* Band Regress.	Individ. Lots: Strength vs Temp. Scatter Regress.	Parameter Scatter Regress.	
			Larson-Miller (c=20)	Manson Compromise
Aver. Stress for Rupture 1000 hours				
800	-	-	58.0	-
850	55.4	58.5	52.5	52.2
900	47.9	49.1	45.5	44.1
950	35.0	36.9	35.6	34.5
1000	23.1	25.6	25.4	24.7
1050	16.2	16.9	16.2	16.3
1100	9.9	11.0	10.0	9.7
1150	-	7.2	6.2	6.1
1200	-	5.10	(4.6)	-
Minimum Stress for Rupture in 1000 hours (90% confidence)				
800	-	-	46.0	-
850	-	46.2	41.3	40.8
900	-	38.8	35.5	34.8
950	-	29.1	27.7	26.9
1000	-	20.2	19.7	19.2
1050	-	13.3	12.6	12.5
1100	-	8.7	7.8	7.7
1150	-	5.7	4.8	4.7
1200	-	4.1	(3.6)	-
Average Stress for Rupture 10,000 hours				
800	-	-	52.0	52.5
850	45.6	48.6	44.5	44.0
900	37.2	36.3	34.0	33.1
950	23.2	24.1	23.5	22.9
1000	15.4	15.0	14.4	14.1
1050	8.25	9.2	8.6	8.0
1100	4.3	5.9	-	-
1150	-	4.2	-	-
1200	-	3.4	-	-

* Assuming log stress to vary linearly with log rupture time

Table IX - page 2

			Parameter Scatter Regress.	
Temp. °F	Isothermal Scatter Band Regress.	Individ. Lots: Strength vs Temp. Scatter Regress.	Larson-Miller (c=20)	Manson Compromise
Minimum Stress for Rupture in 10,000 hours (90% confidence)				
800	-	-	40.8	40.8
850	-	35.4	34.7	34.3
900	-	26.5	26.4	25.9
950	-	17.6	18.2	17.8
1000	-	10.9	11.3	10.9
1050	-	6.7	6.7	6.2
1100	-	4.3	-	-
1150	-	3.1	-	-
1200	-	2.5	-	-
Average Stress for Rupture in 100,000 hours				
800	-	-	43.8	43.8
850	-	36.0	32.5	32.2
900	-	23.7	22.0	21.0
950	-	14.0	13.3	12.1
1000	-	7.95	7.7	6.7
1050	-	4.63	-	-
1100	-	2.95	-	-
1150	-	2.30	-	-
1200	-	2.05	-	-
Minimum Stress for Rupture in 100,000 hours (90% confidence)				
800	-	-	34.2	34.1
850	-	25.3	25.3	25.1
900	-	16.7	17.1	16.3
950	-	9.86	10.3	9.4
1000	-	5.60	6.0	5.1
1050	-	3.26	-	-
1100	-	2.08	-	-
1150	-	1.64	-	-
1200	-	1.44	-	-

Table X

Summary - Creep Strength (ksi) - C-Mo Steel

	0.1%/1000 hrs.		0.01/1000 hrs.	
Temp. °F	Aver.	Min.*	Aver.	Min.*
750	-	-	27.6	18.5
800	27.9	19.1	20.3	13.6
850	33.4	22.9	18.9	12.7
900	28.4	19.5	17.1	11.4
950	18.9	12.9	12.7	8.5
1000	10.7	7.35	7.28	4.88
1050	5.8	4.00	3.26	2.20
1100	3.17	2.17	1.43	.96
1150	2.07	1.42	.86	.58
1200	1.56	1.07	.60	.40

* 90% confidence

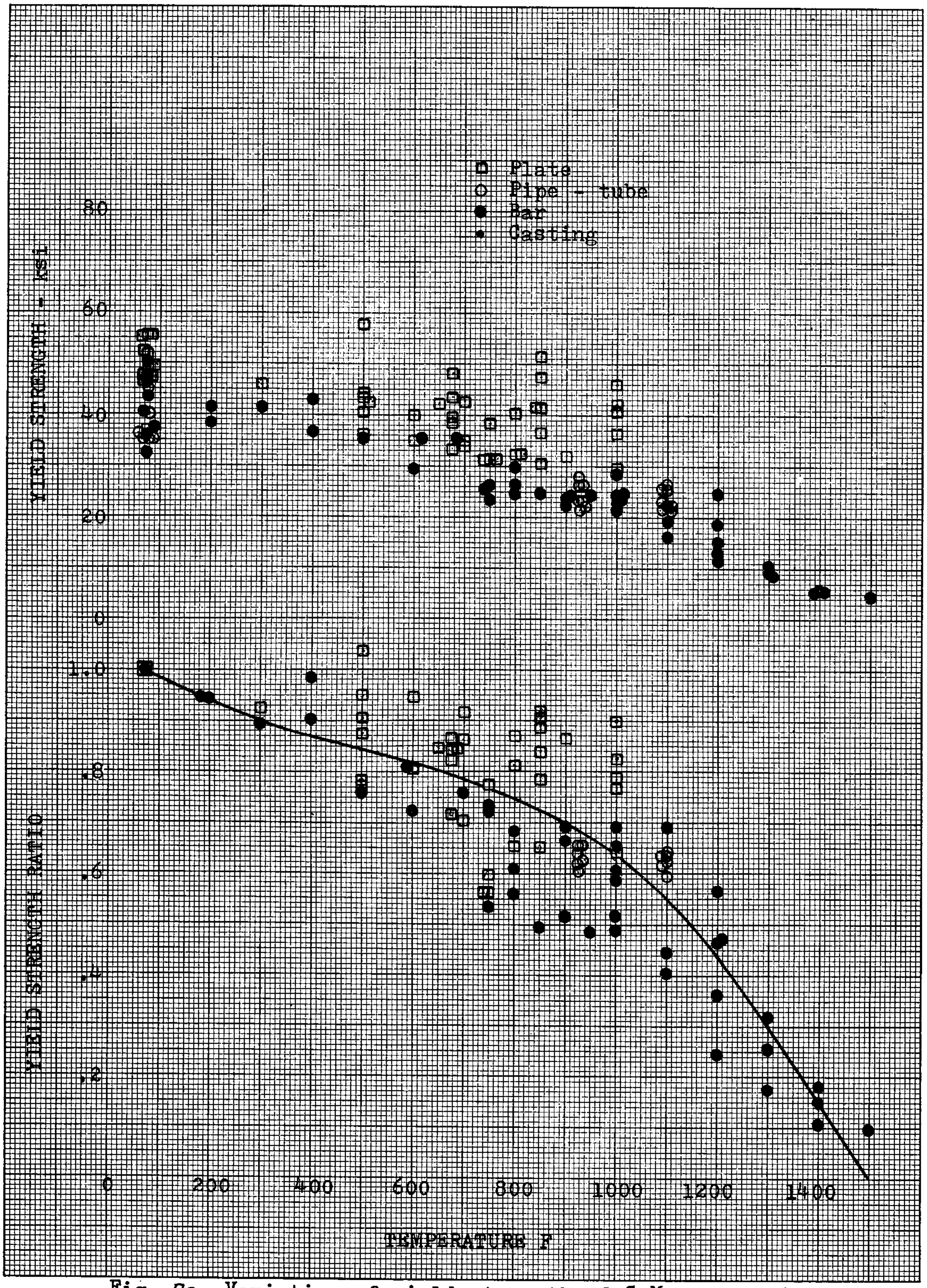

Fig. 7a Variation of yield strength of C-Mo steel with temperature.

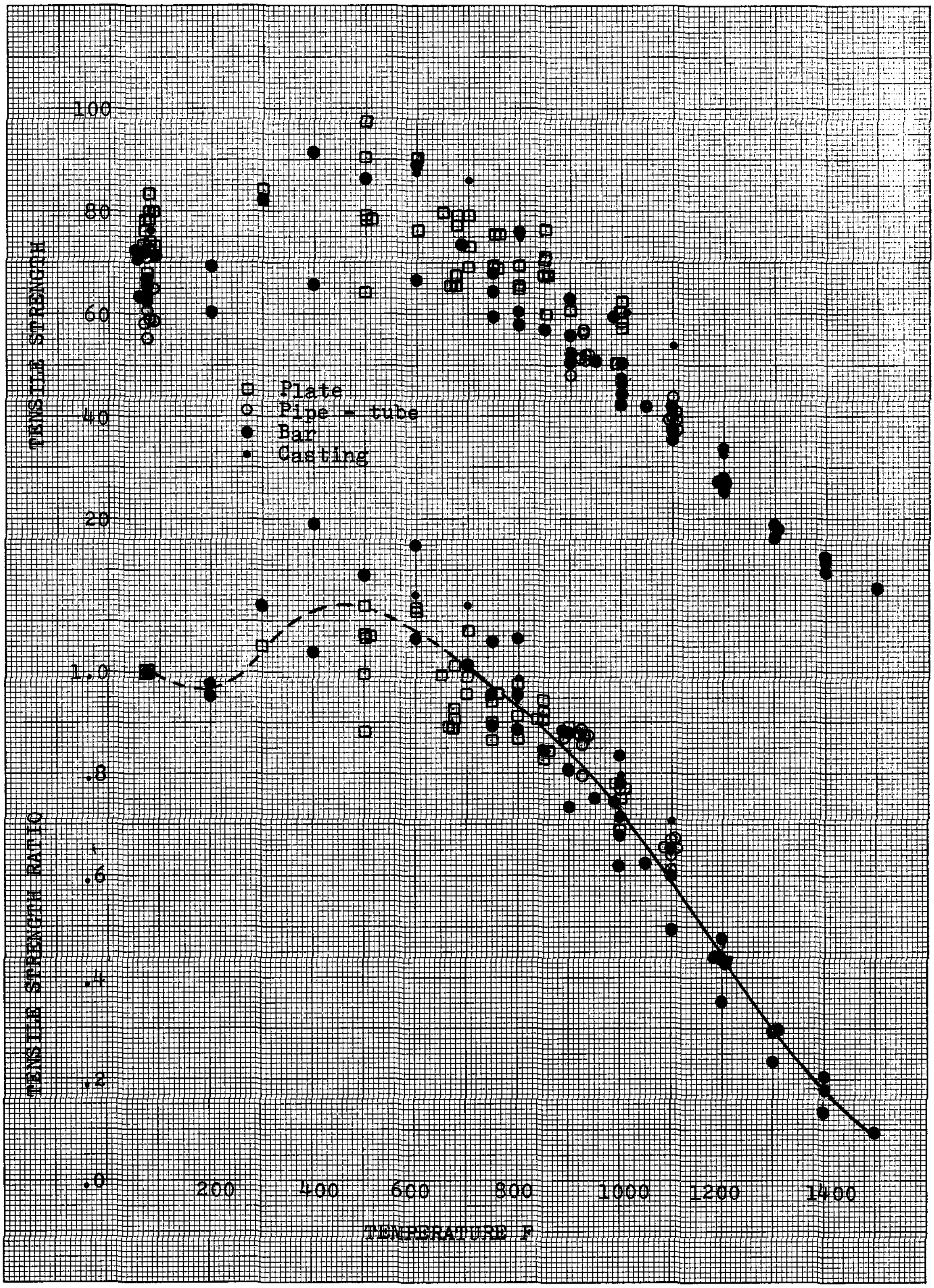

Fig. 7b Variation of tensile strength of C-Mo steel with temperature.

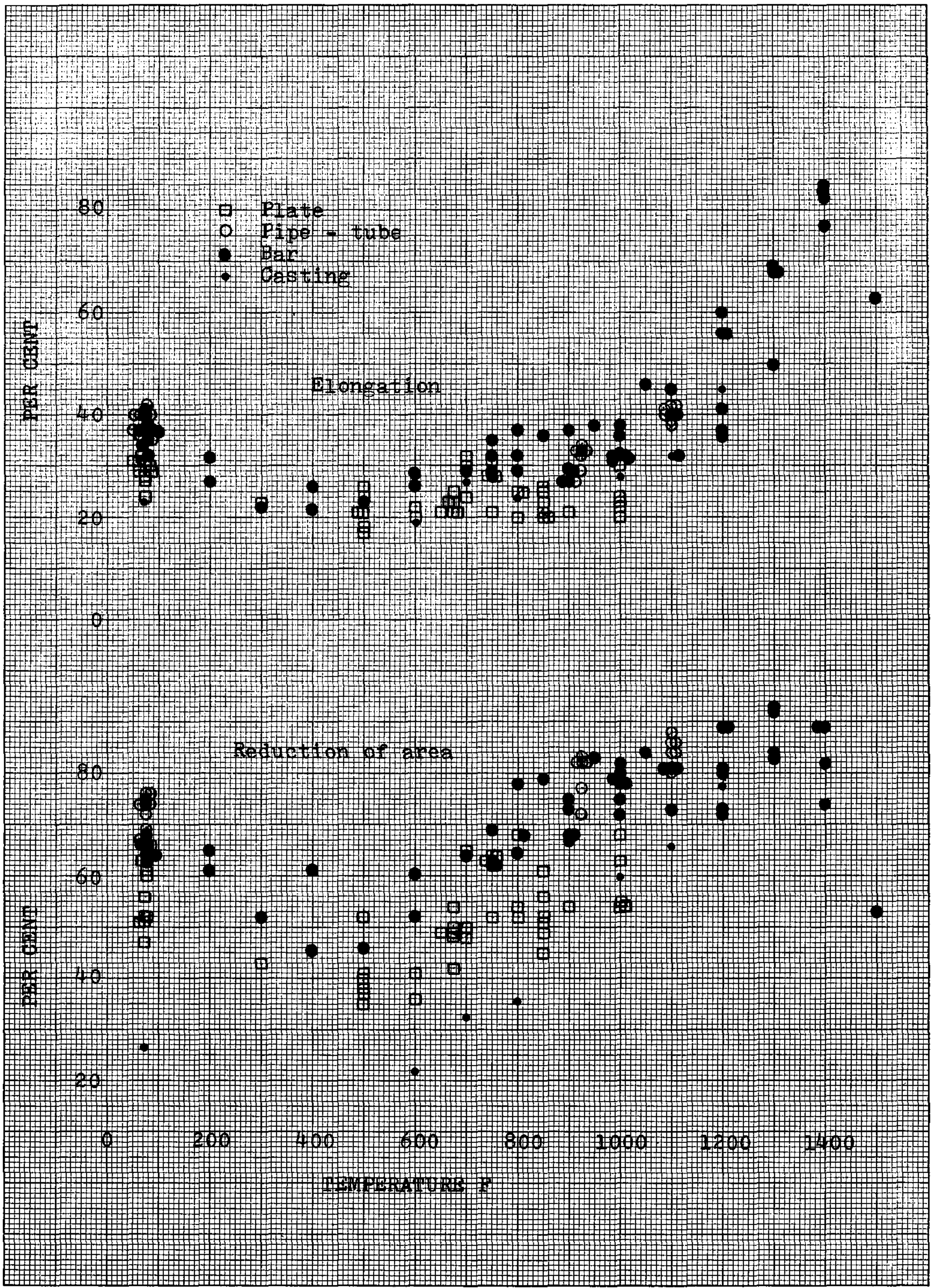

Fig. 7c Variation of elongation and reduction of area of C-Mo steel with temperature.

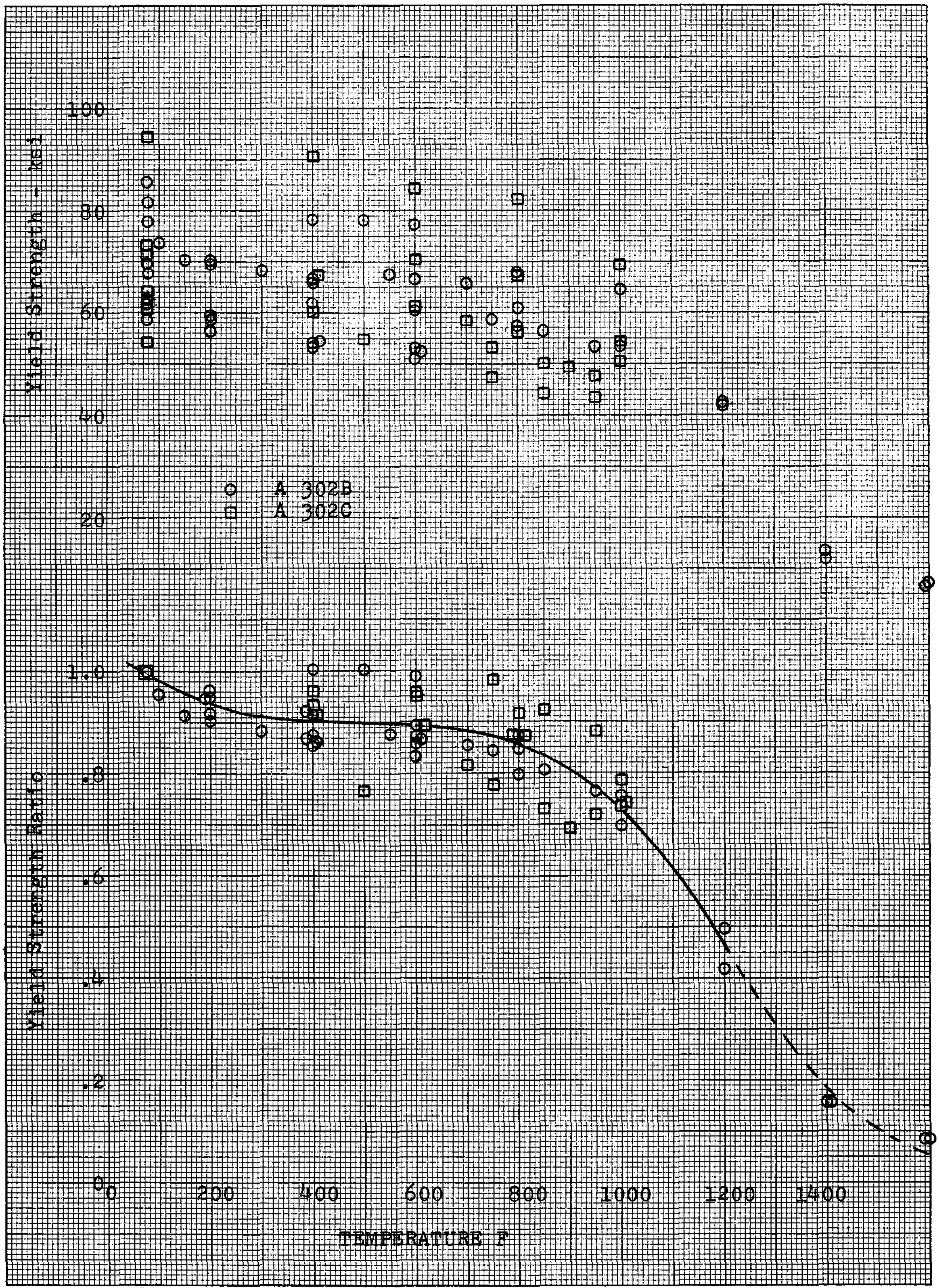

Fig. 8a Variation of yield strength of Mn-Mo-(Ni) steel, A 302, with temperature.

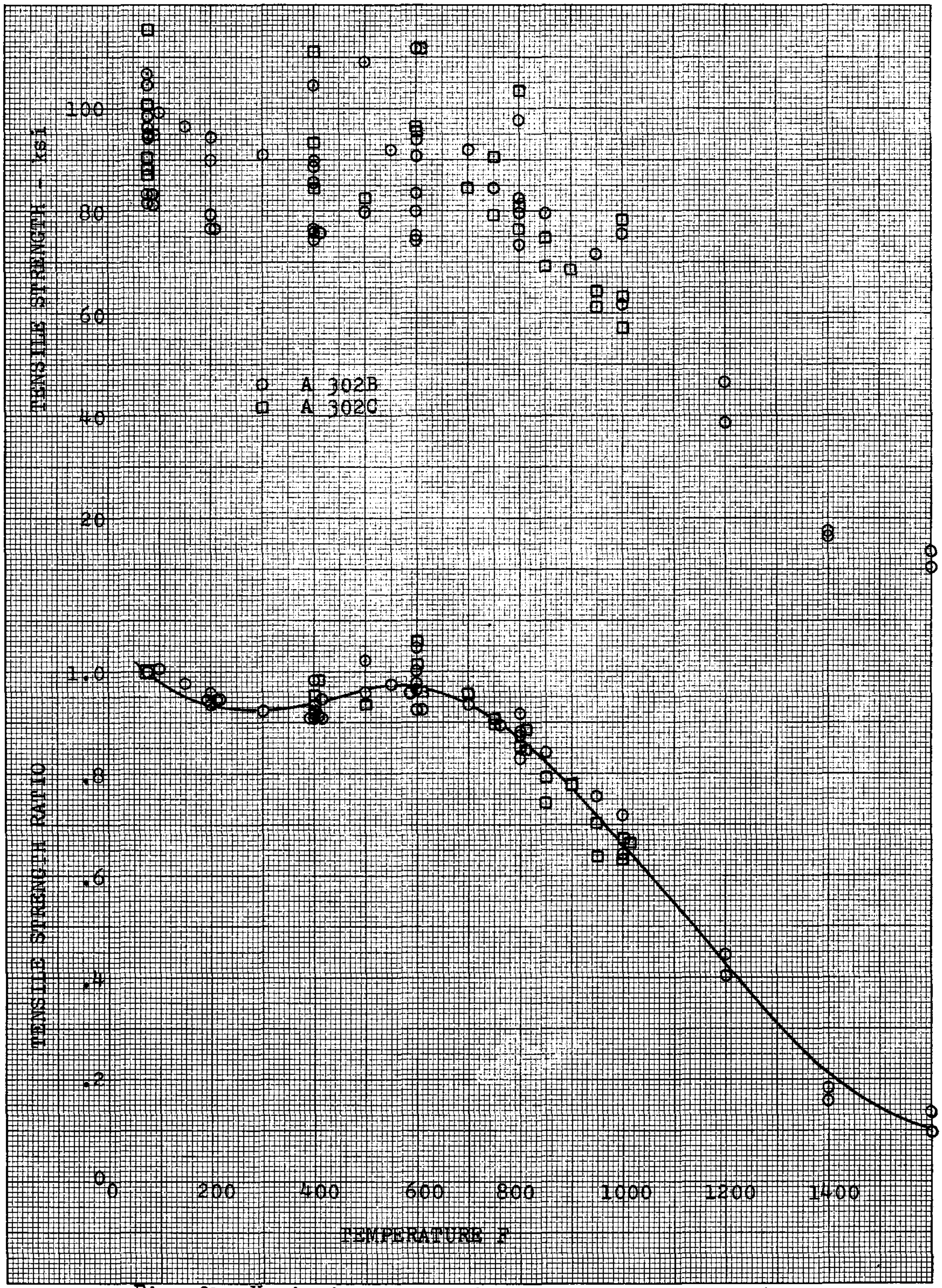

Fig. 8b Variation of tensile strength of Mn-Mo-(Ni) steel, A 302, with temperature.

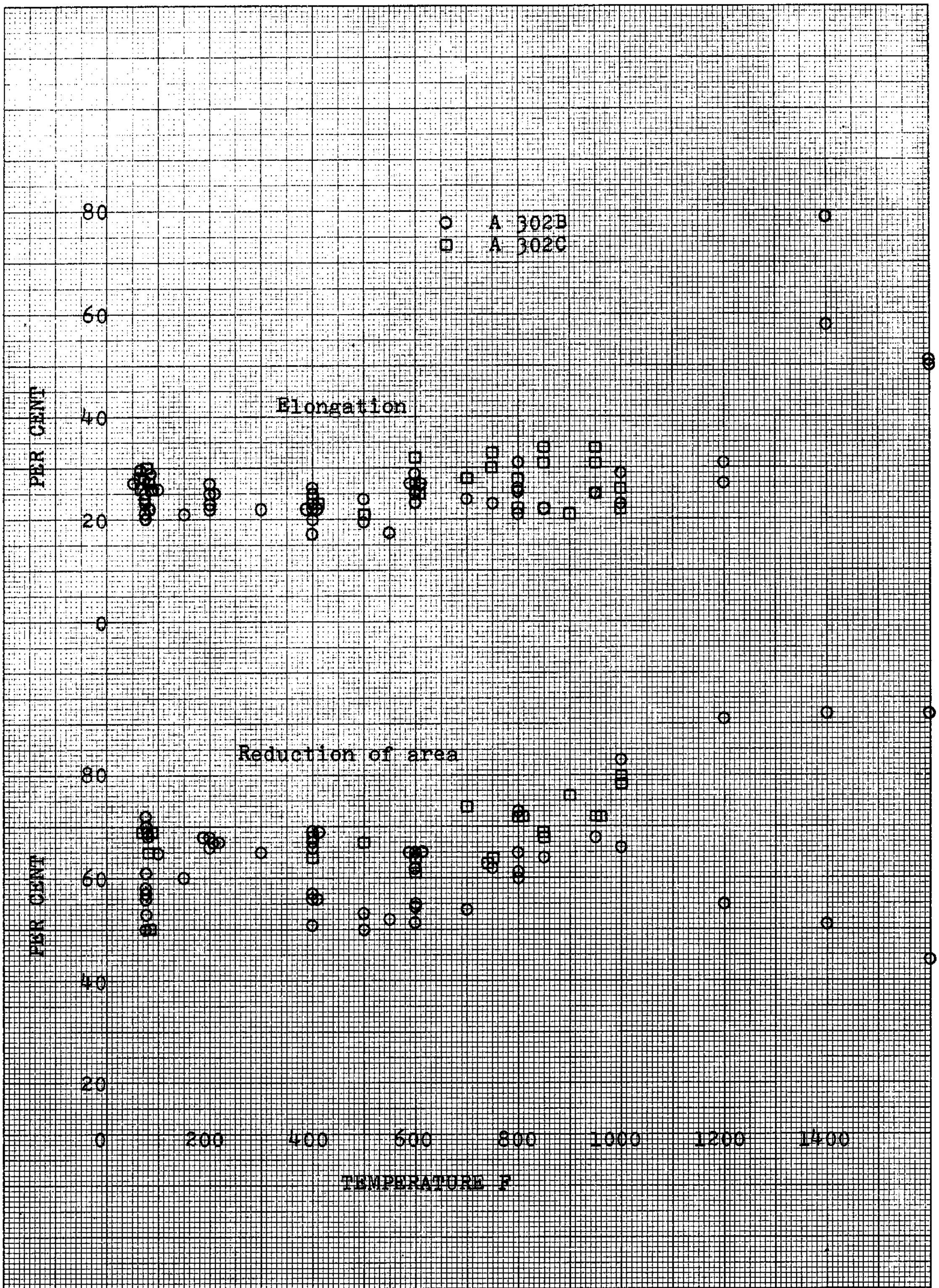

Fig. 8c Variation of elongation and reduction of area of Mn-Mo-(Ni) steel. A 302, with temperature.

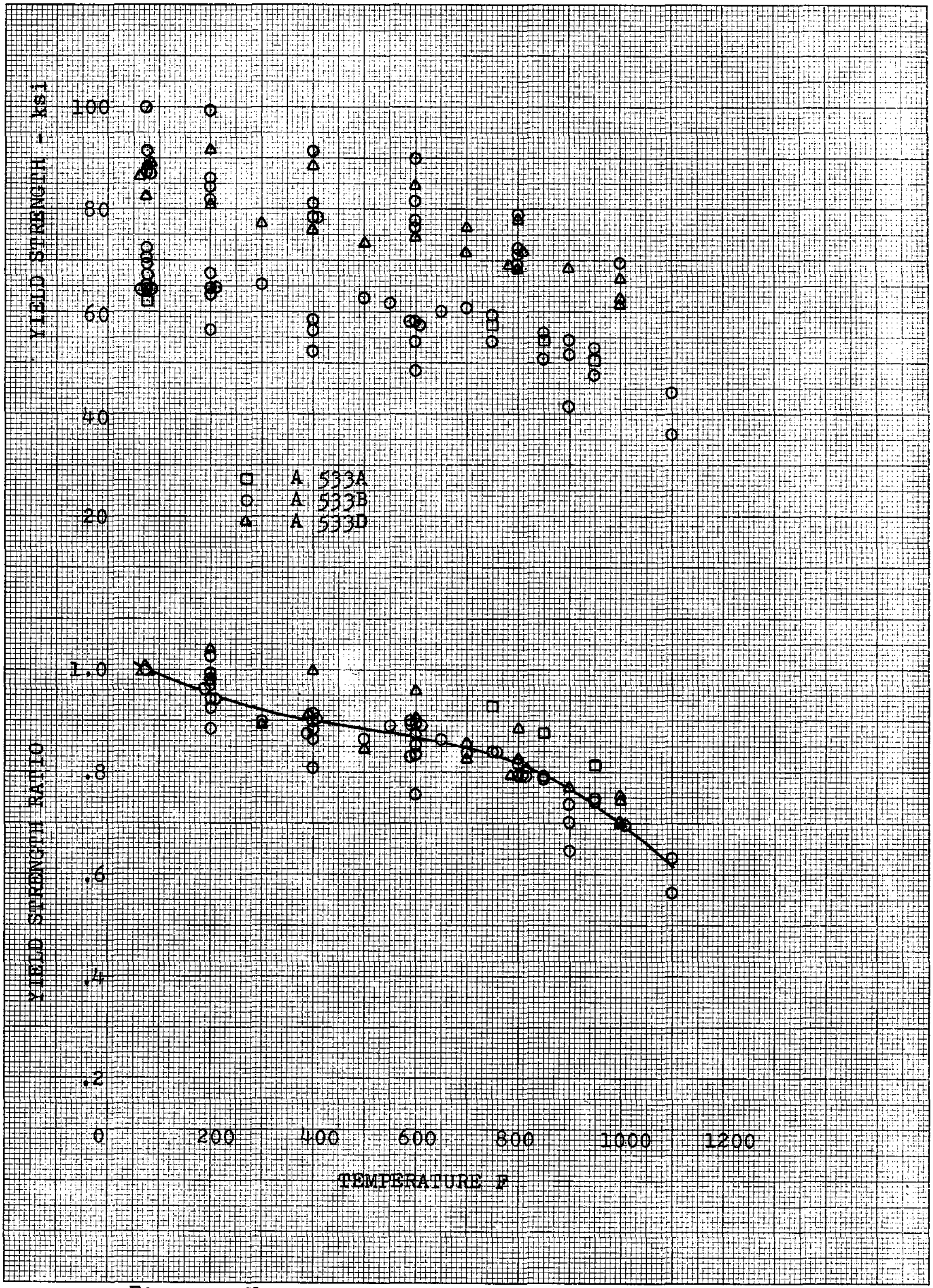

Fig. 9a Variation of yield strength of Mn-Mo-(Ni) steel, A 533, with temperature.

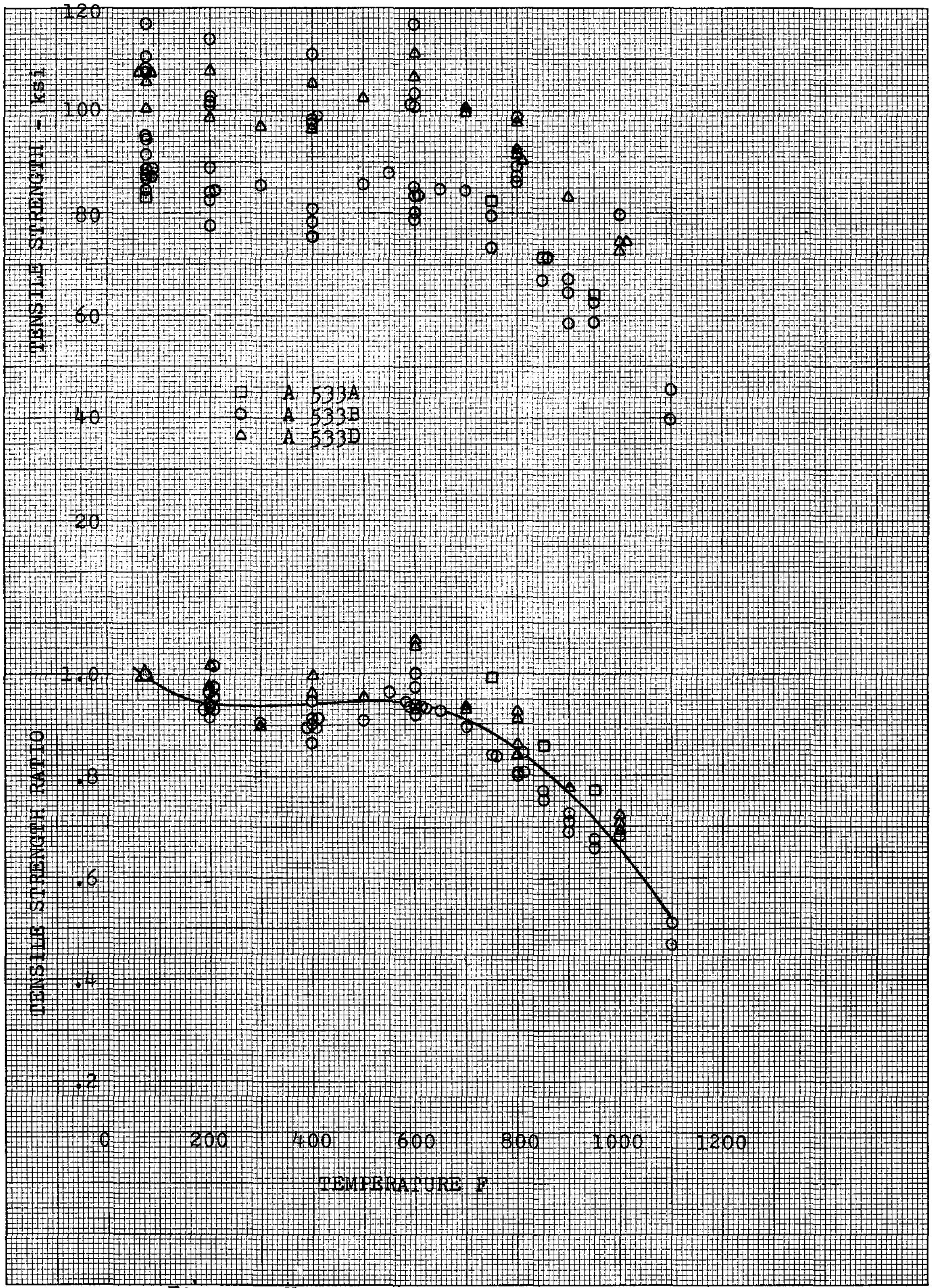

Fig. 9b Variation of tensile strength of Mn-Mo-(Ni) steel with temperature.

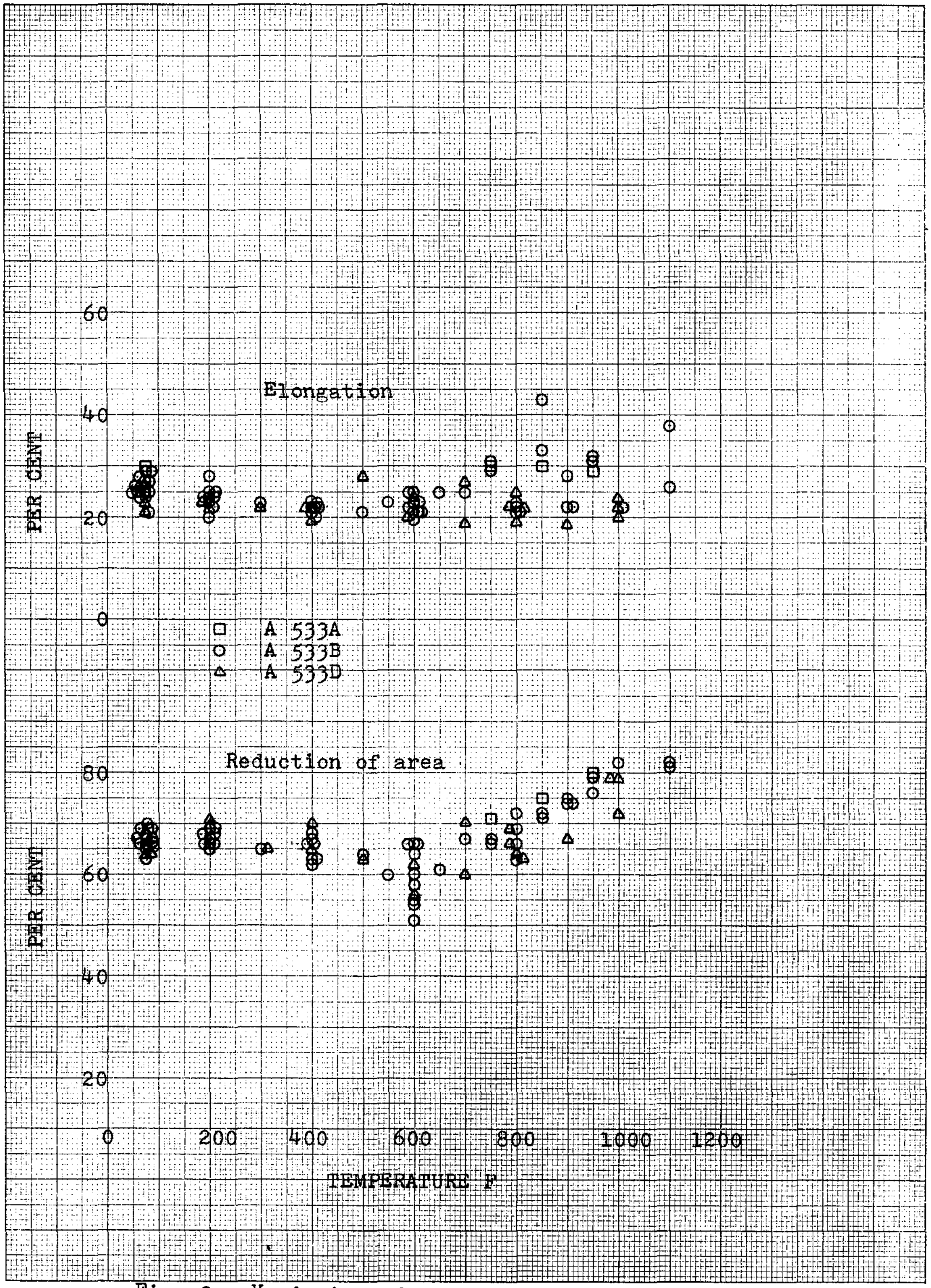

Fig. 9c Variation of elongation and reduction of area of Mn-Mo-(Ni) steel, A 533, with temperature.

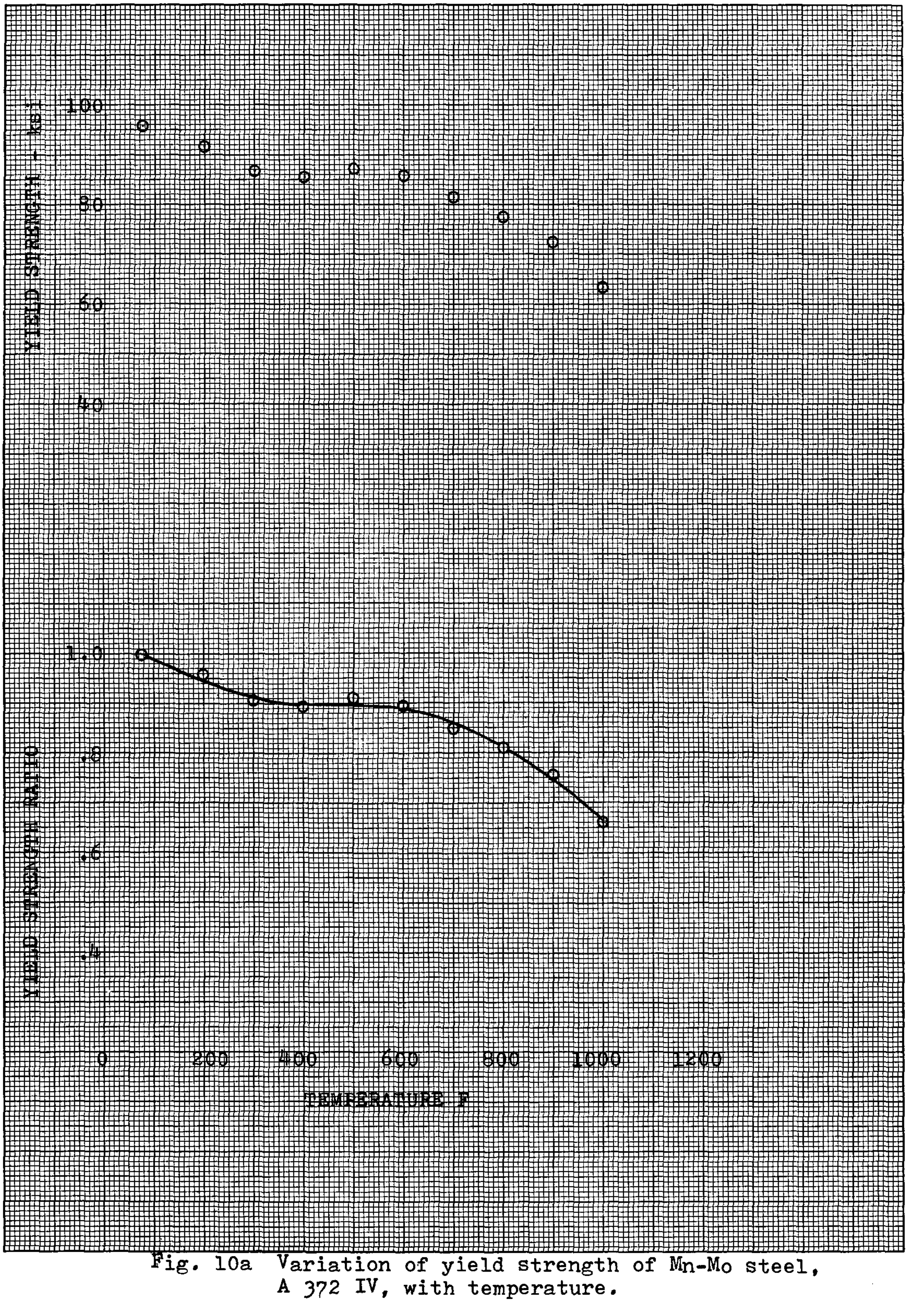

Fig. 10a Variation of yield strength of Mn-Mo steel, A 372 IV, with temperature.

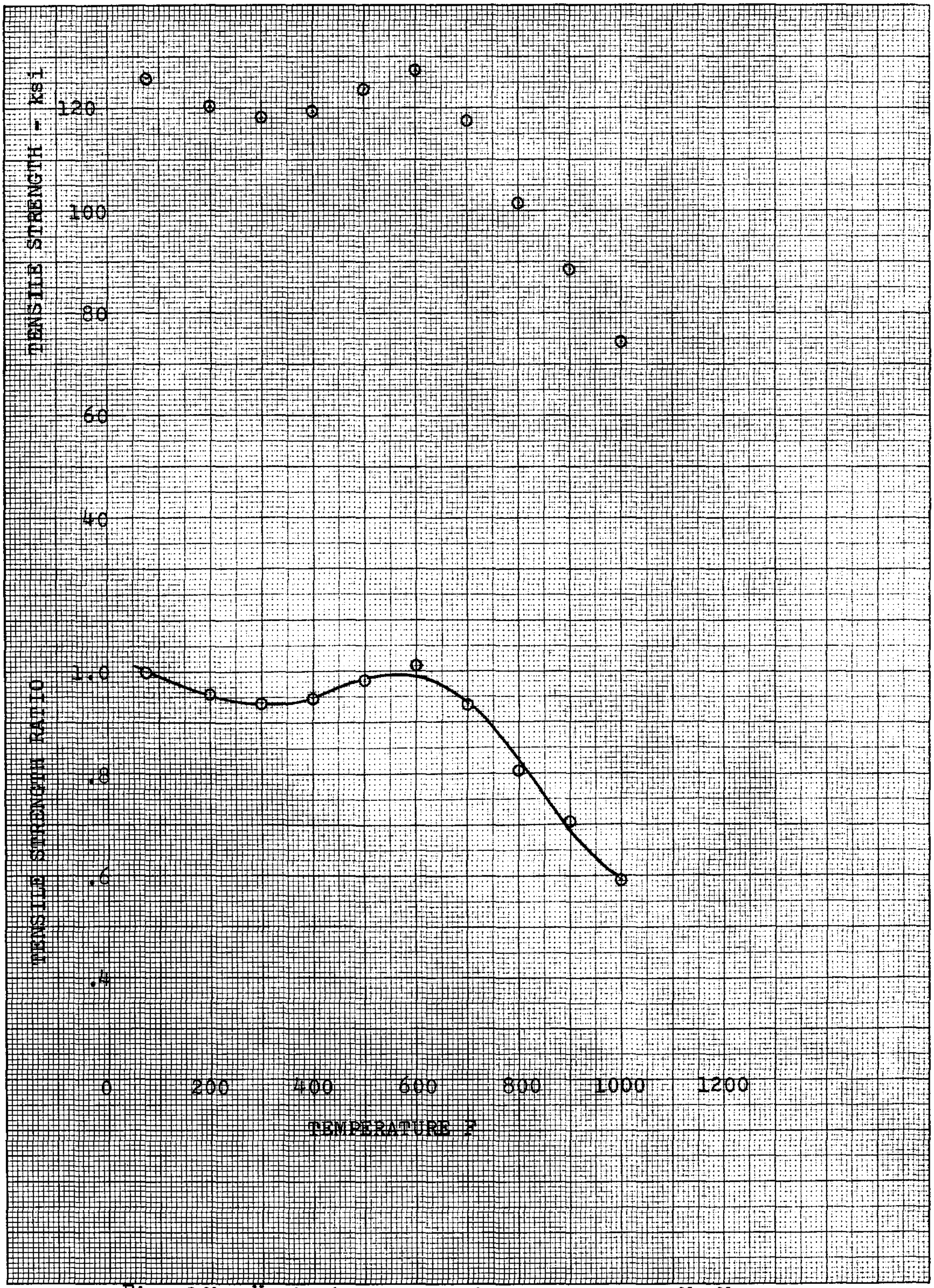

Fig. 10b Variation of tensile strength of Mn-Mo steel, A 372, IV, with temperature.

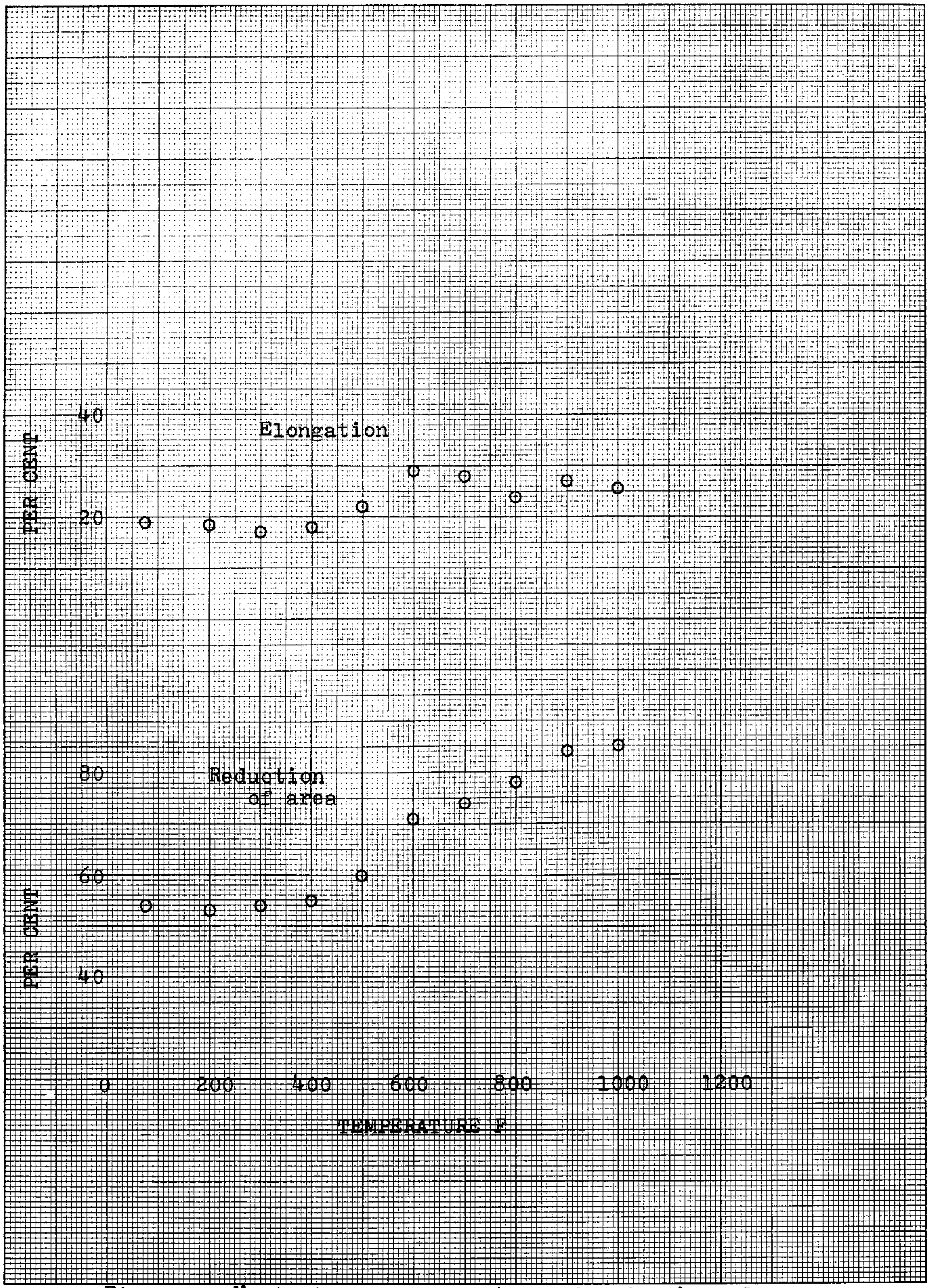

Fig. 10c Variation of elongation and reduction of area of Mn-Mo steel, A 372 IV, with temperature.

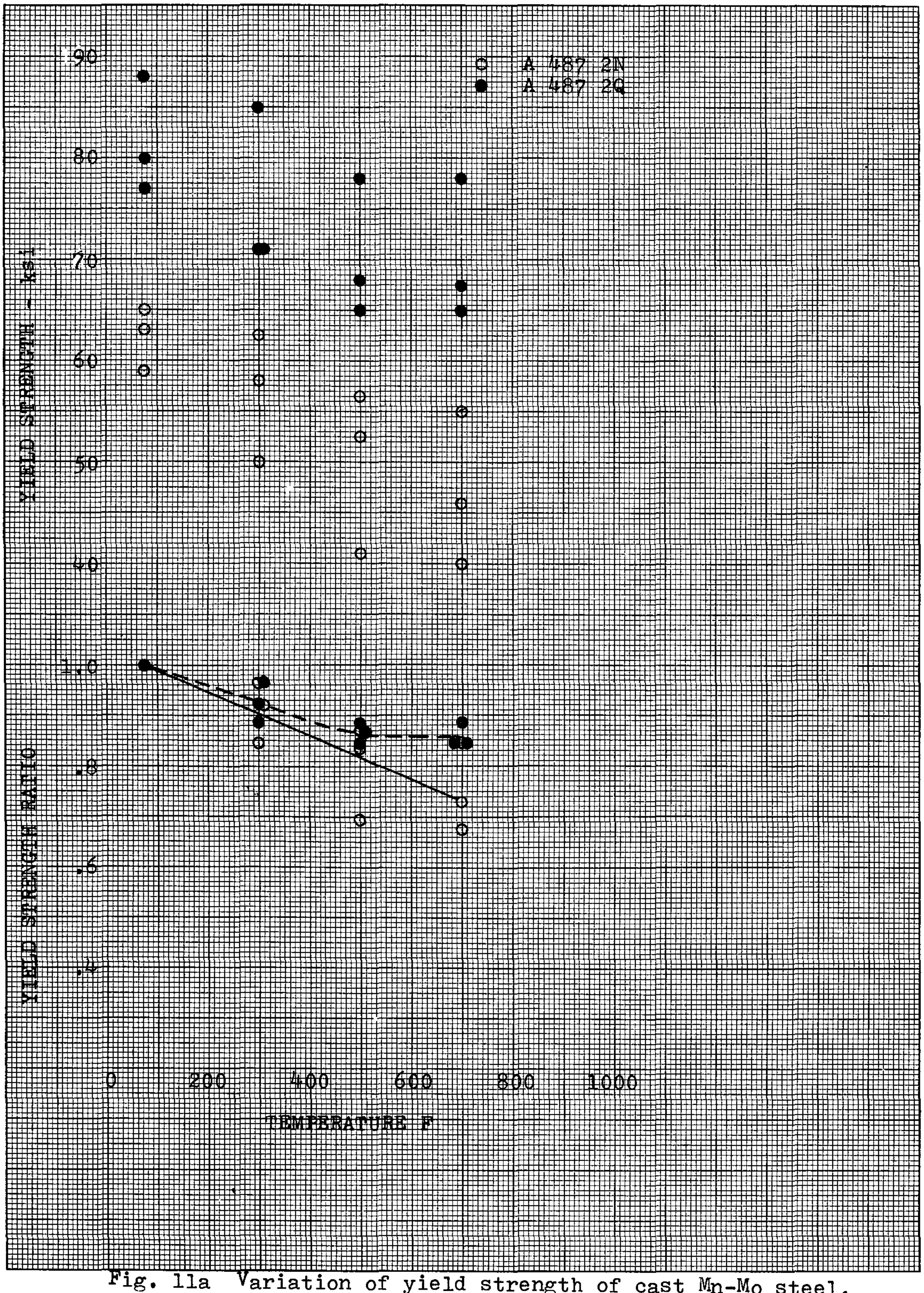

Fig. 11a Variation of yield strength of cast Mn-Mo steel, A 487, Grades 2N and 2Q, with temperature.

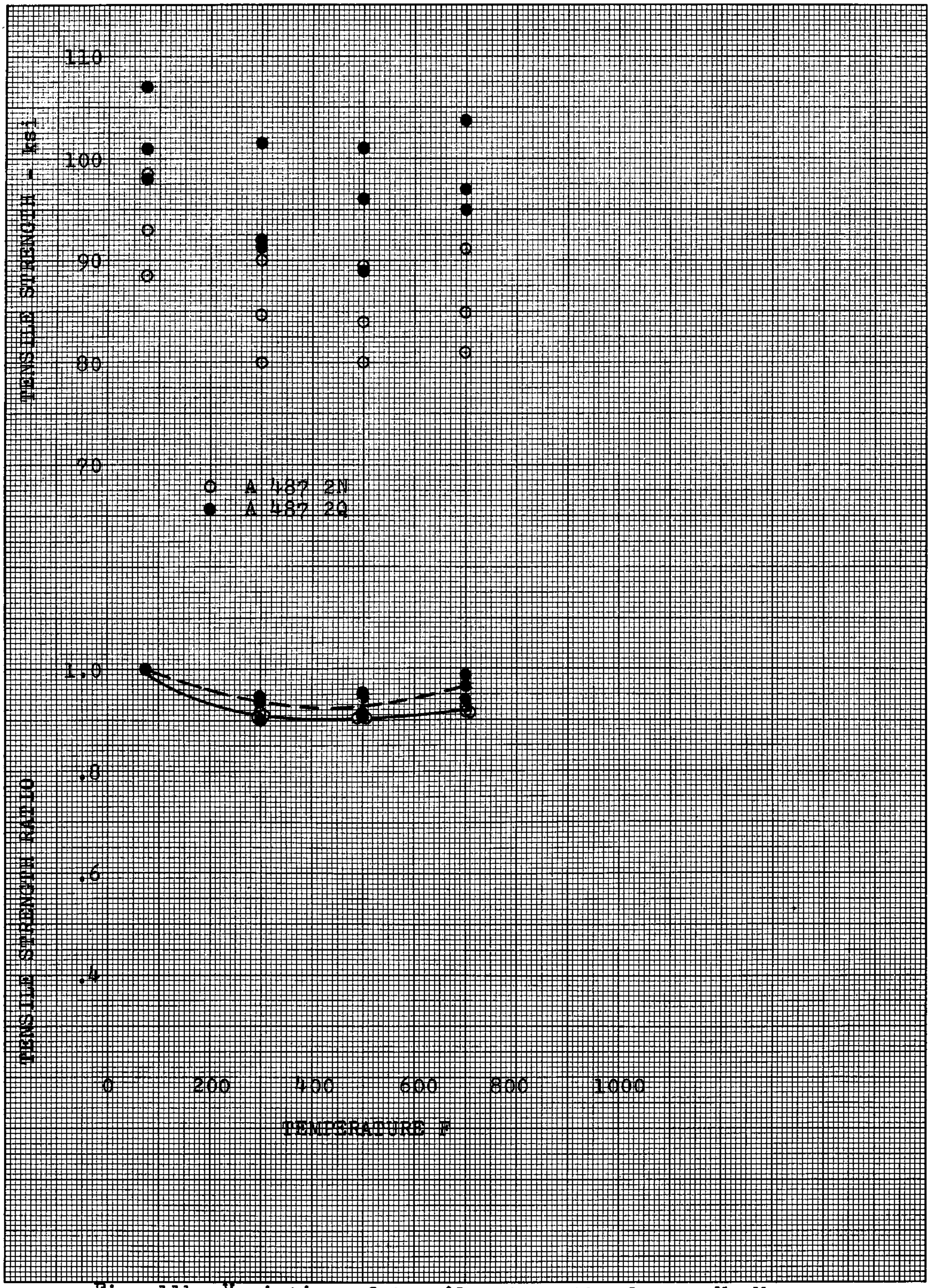

Fig. 11b Variation of tensile strength of cast Mn-Mo steel, A 487, Grades 2N and 2Q, with temperature.

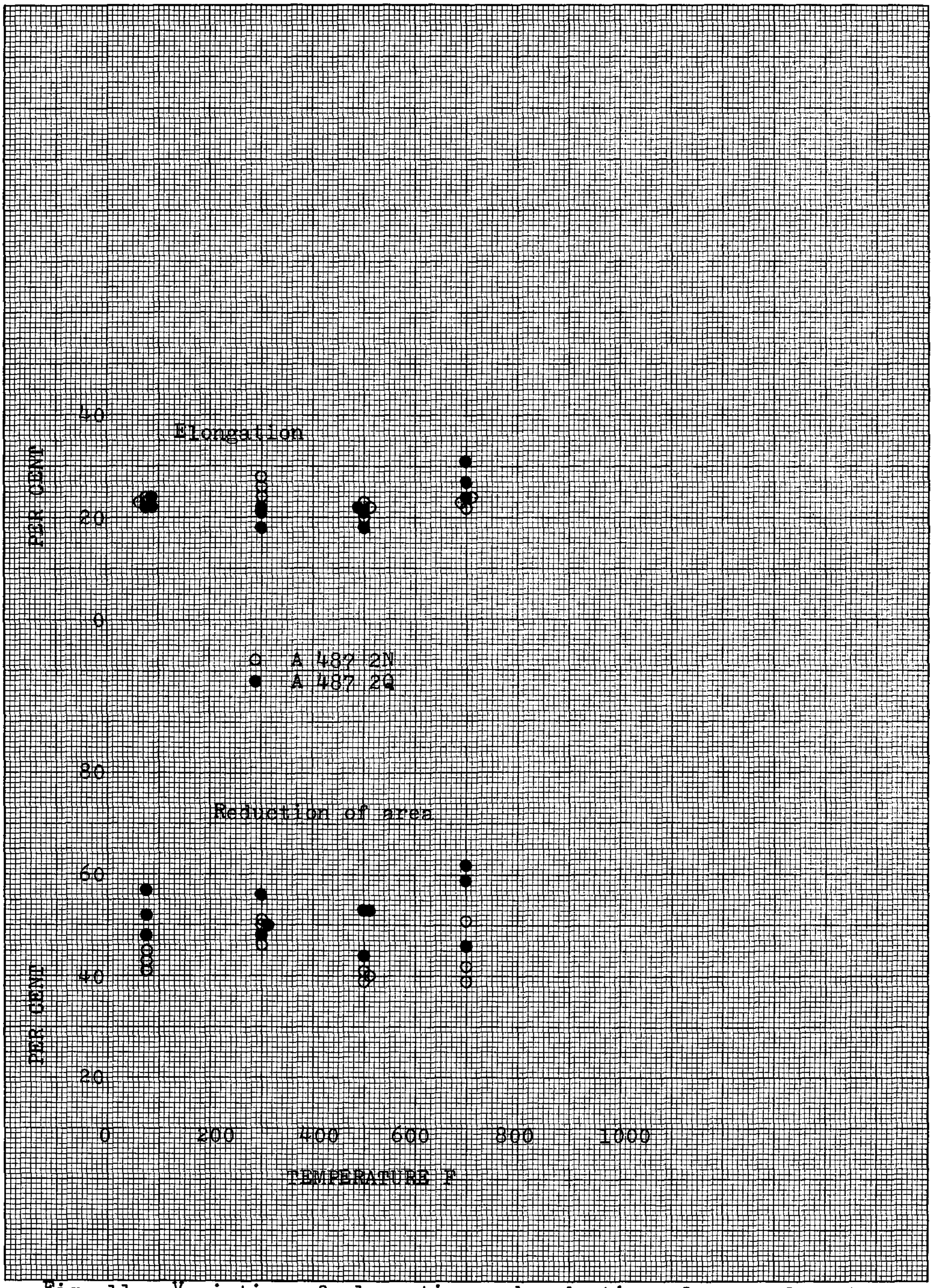

Fig. 11c Variation of elongation and reduction of area of cast Mn-Mo steel, A 487, Grades 2N and 2Q, with temperature.

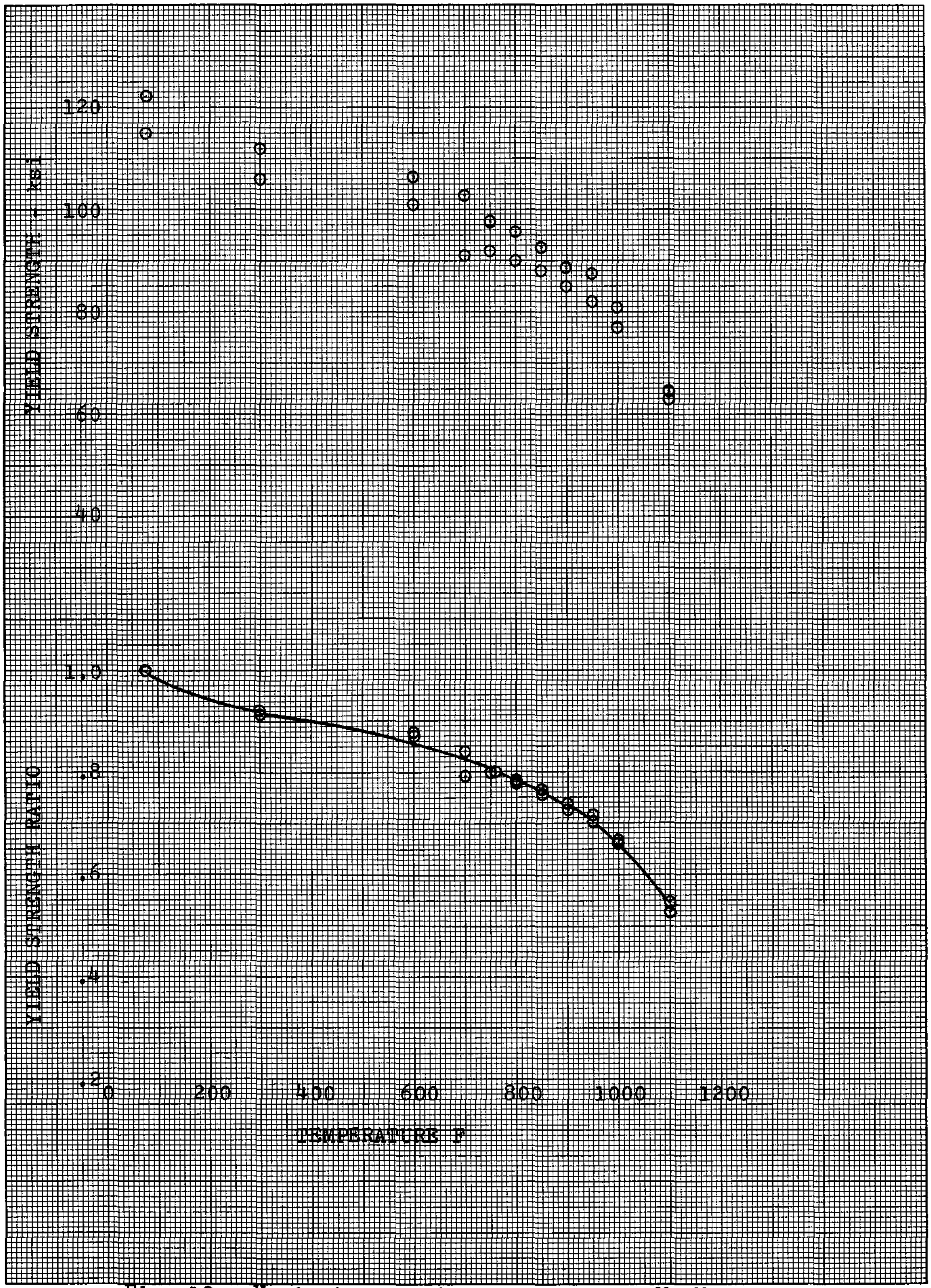

Fig. 12a Variation of yield strength of Mn-Mo steel, A 514C, with temperature.

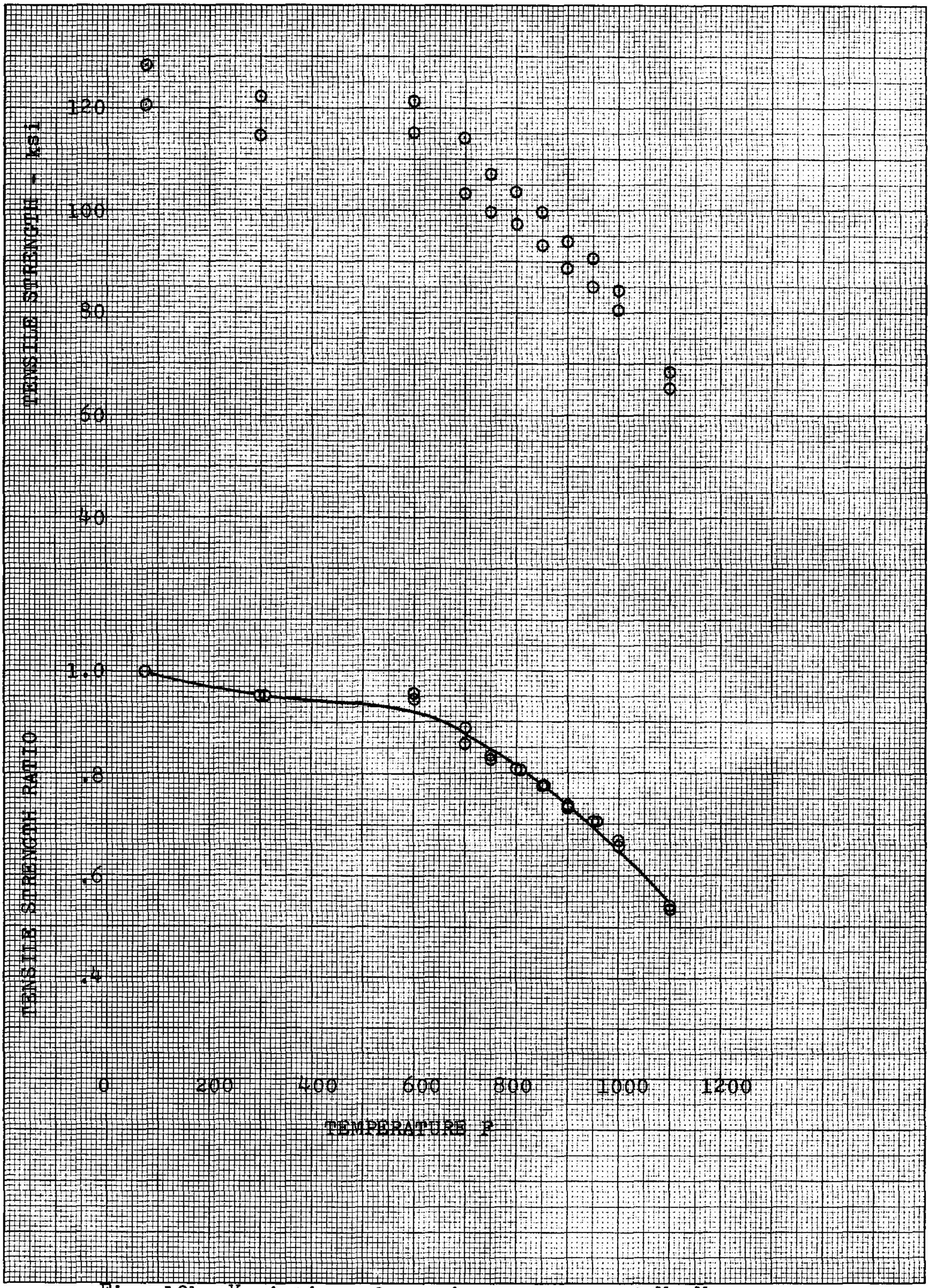

Fig. 12b Variation of tensile strength of Mn-Mo steel, A 514C, with temperature.

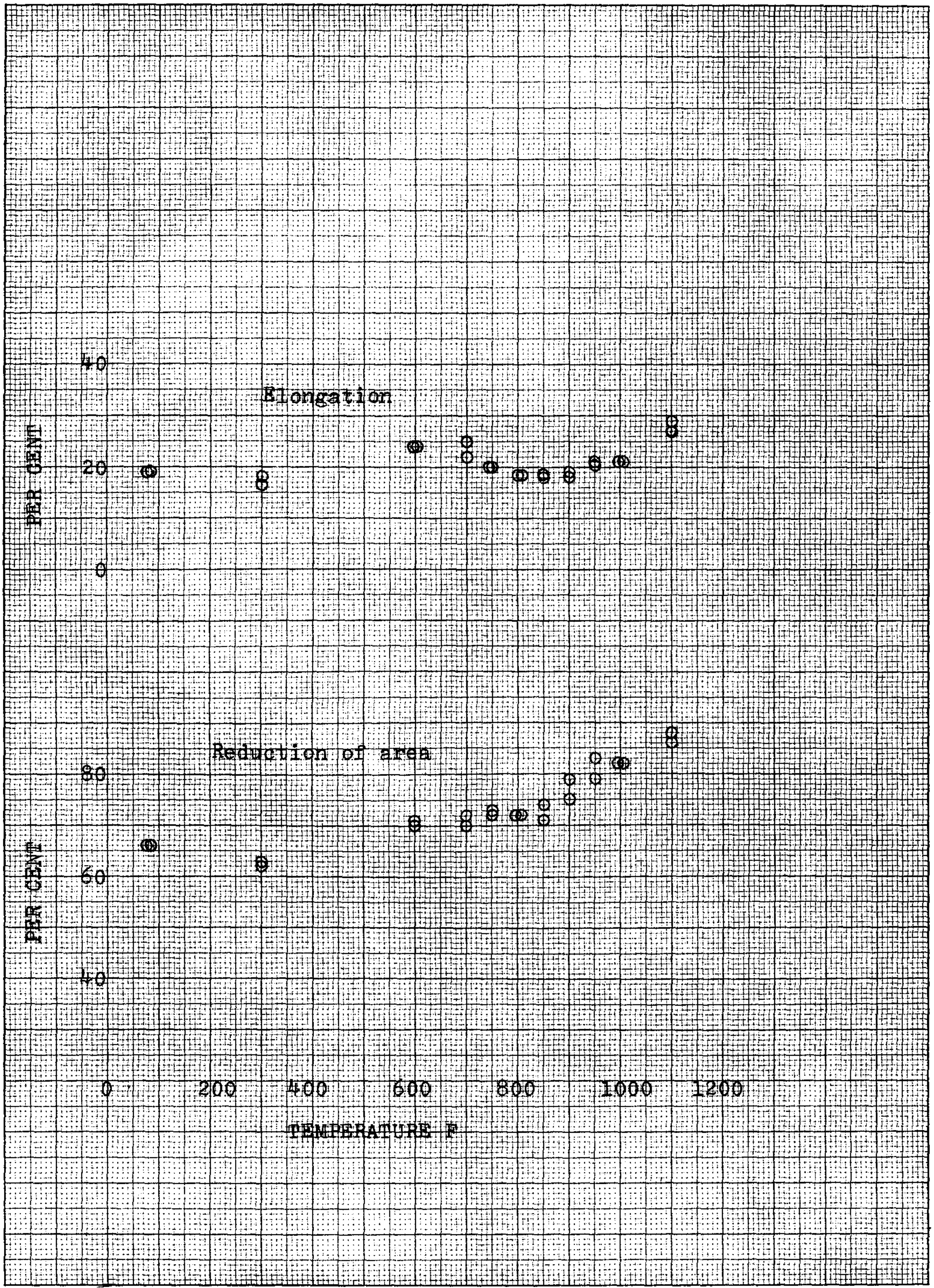

Fig. 12c Variation of elongation and reduction of area of Mn-Mo steel, A 514C, with temperature.

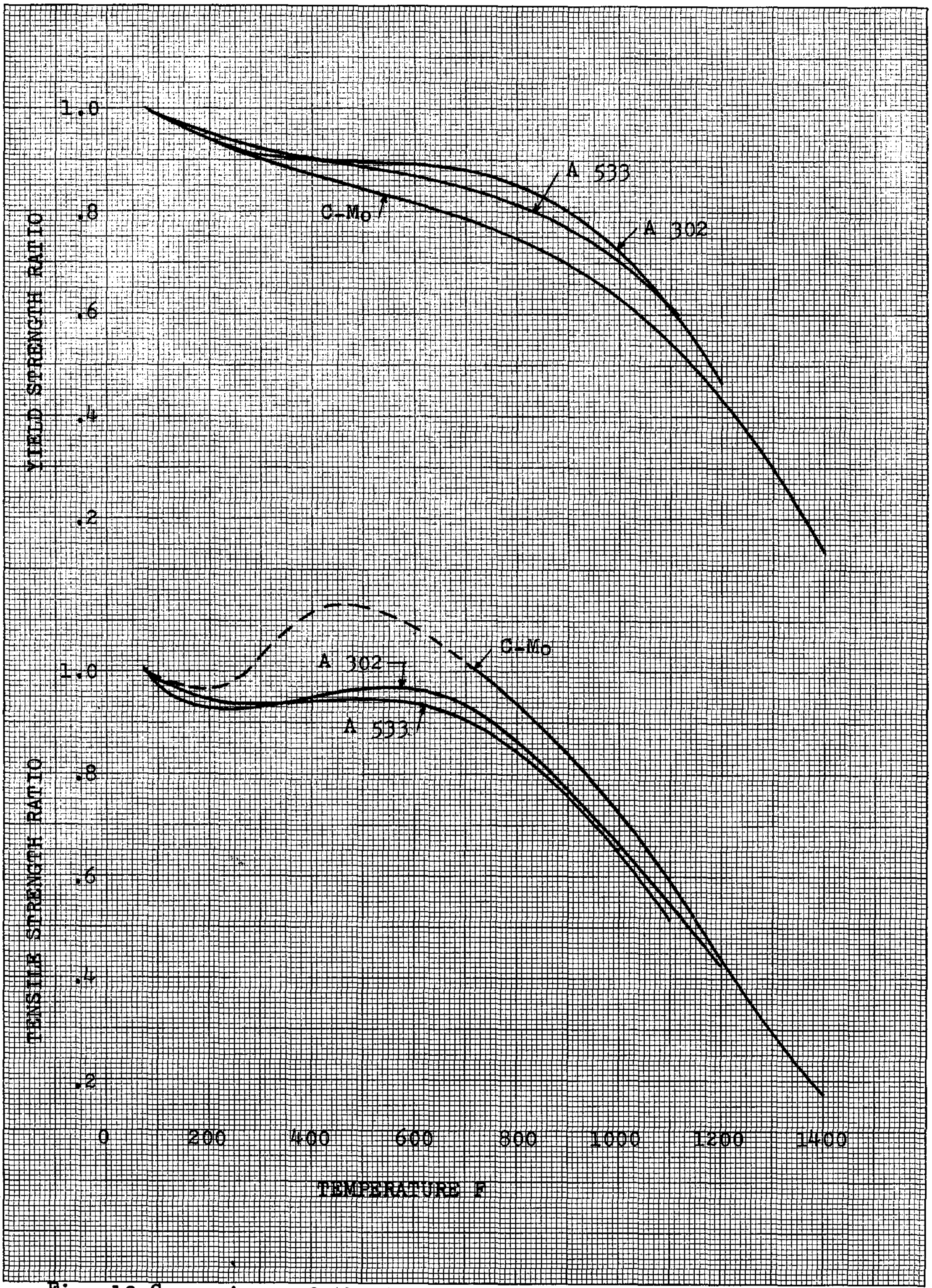

Fig. 13 Comparison of the temperature dependencies of yield and tensile strength ratios for C-Mo and Mn-Mo-(Ni), A 302 and A 533, steels.

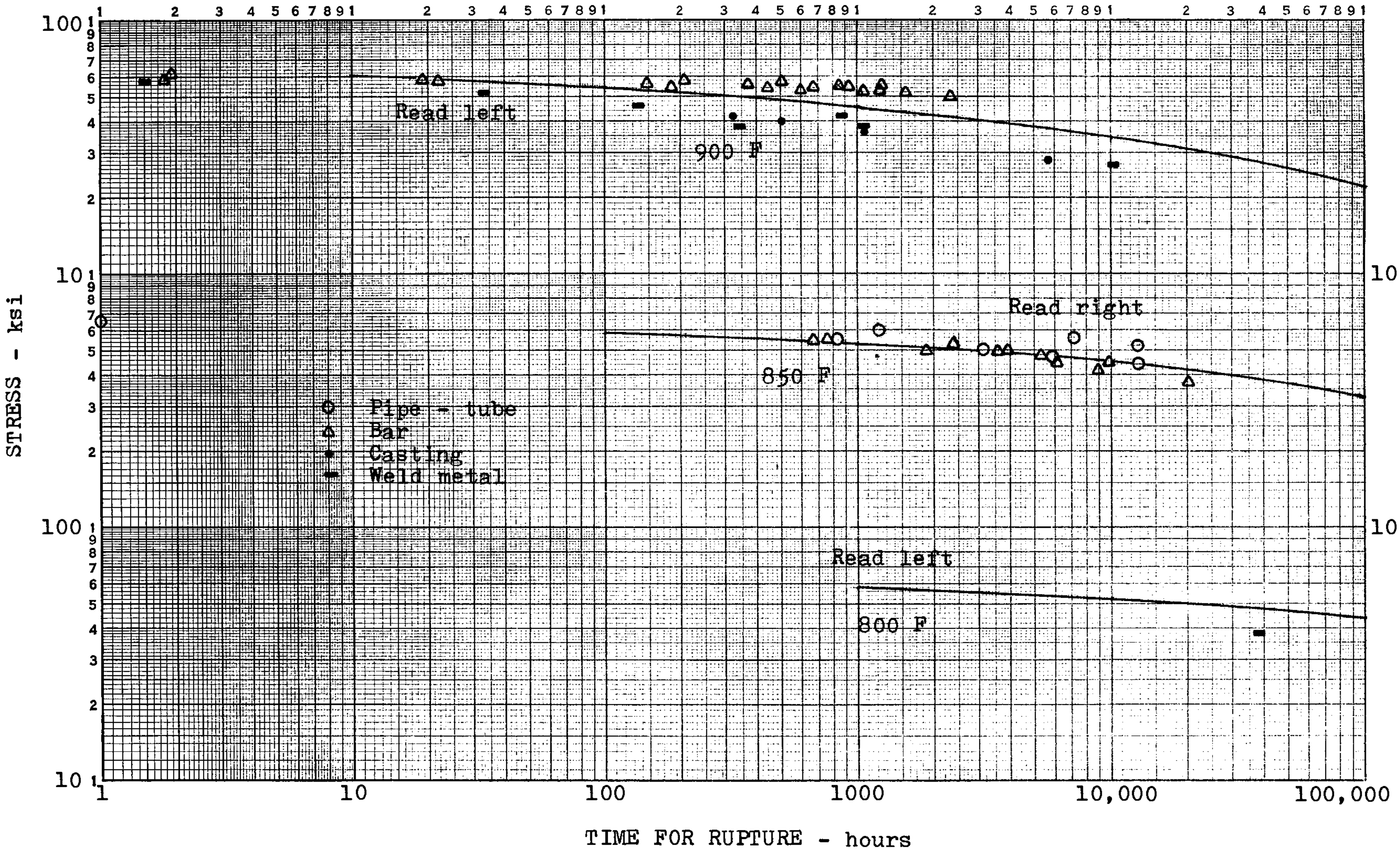

Fig. 14a Stress vs time for rupture of C - Mo steel. The superimposed curves were computed from the Larson -Miller master curve, Fig. 18a.

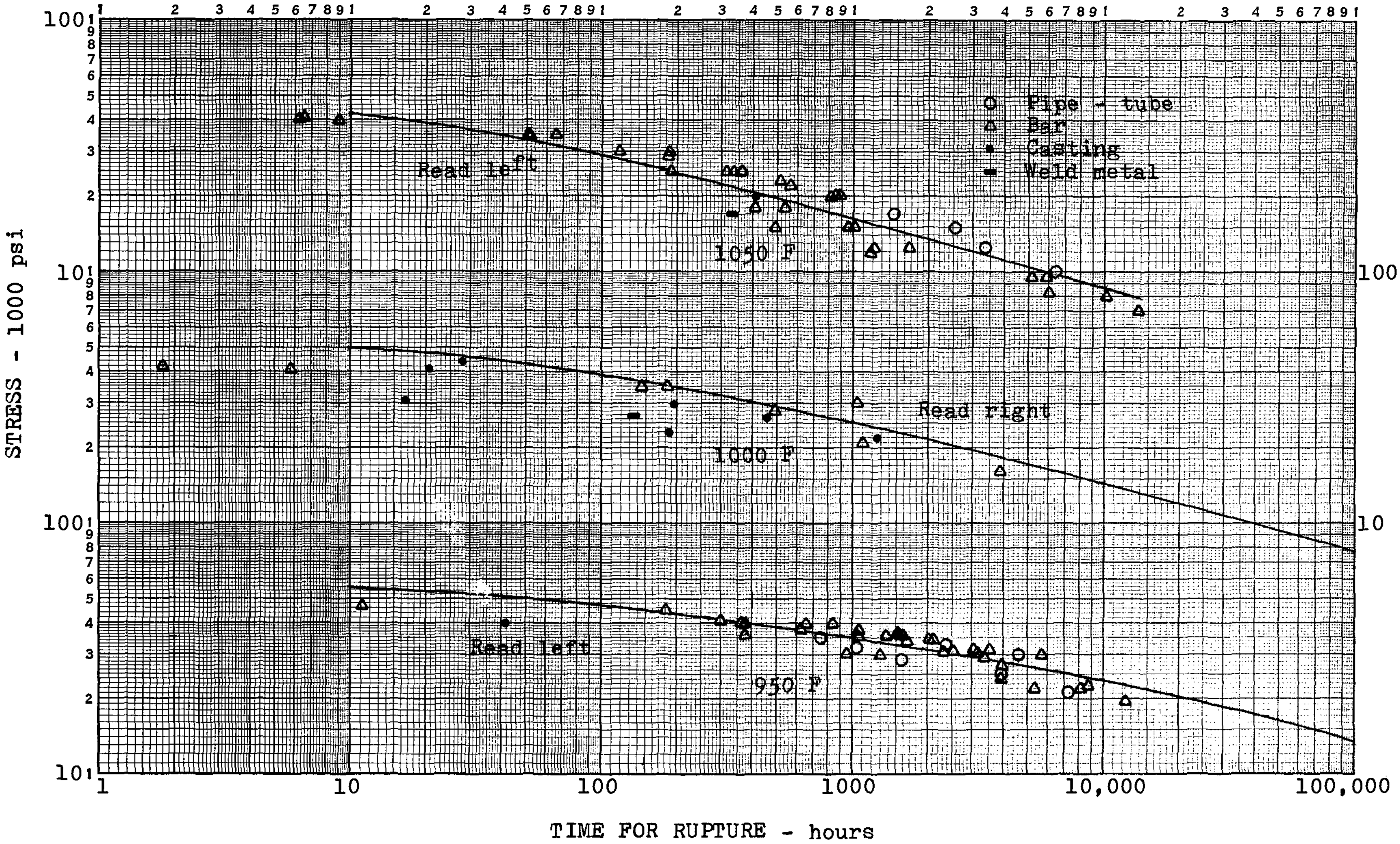

Fig. 14b Stress vs time for rupture of C-Mo steel. The superimposed curves were computed from the Larson - Miller master curve, Fig. 18a.

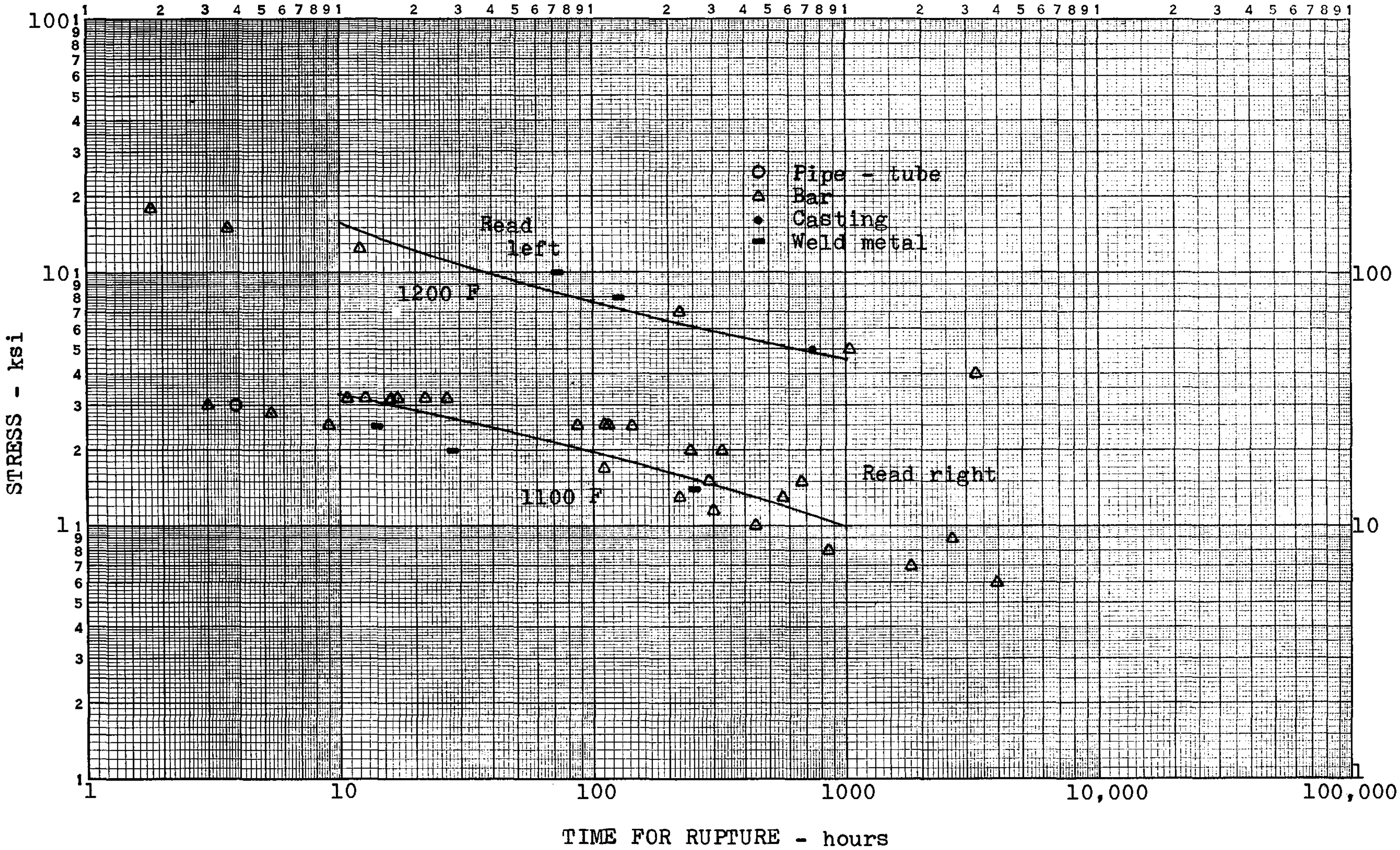

Fig. 14c Stress vs time for rupture of C-Mo steel. The superimposed curves were computed from the Larson - Miller master curve, Fig. 18a.

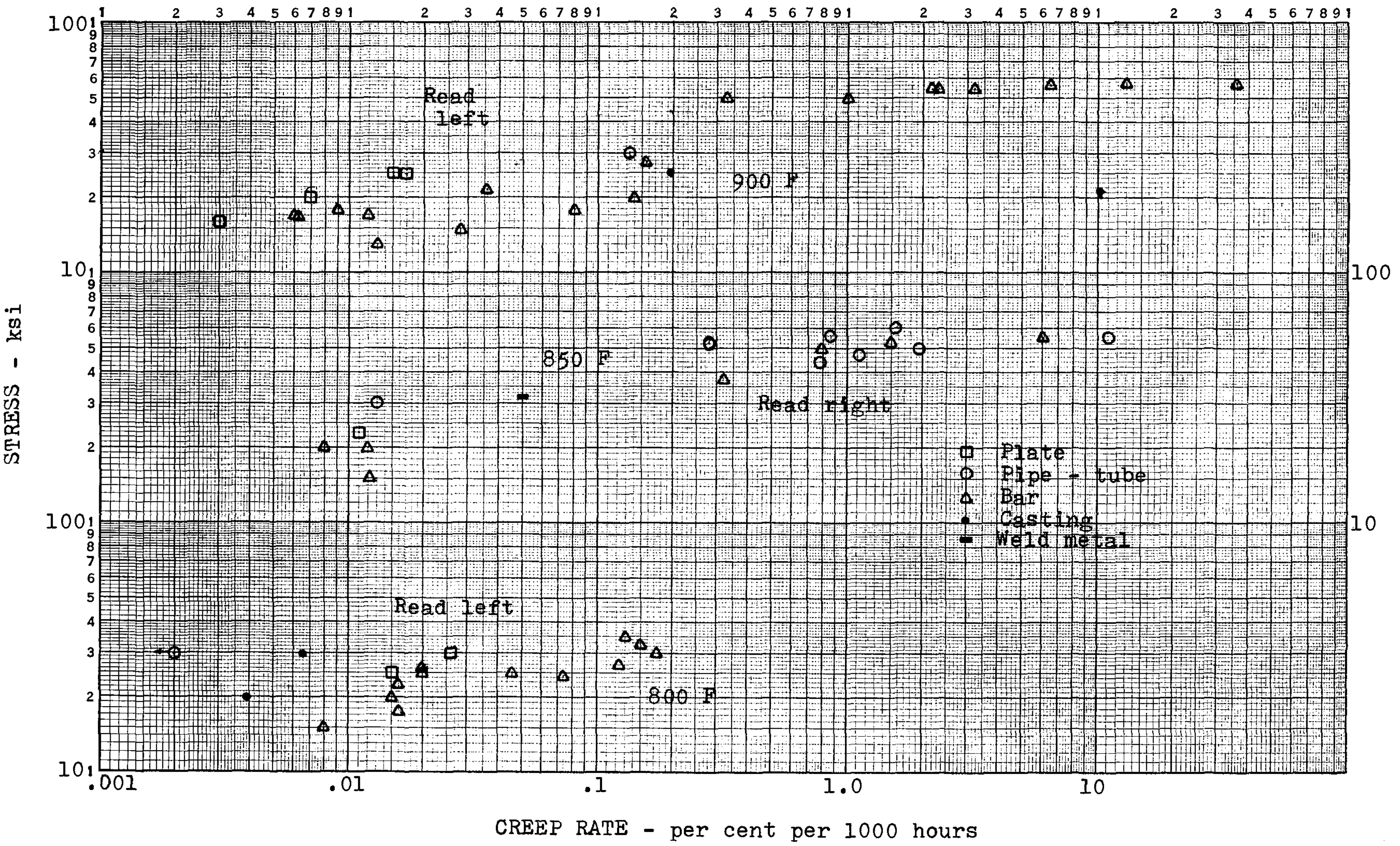

Fig. 15a Stress vs secondary creep rate of C-Mo steel.

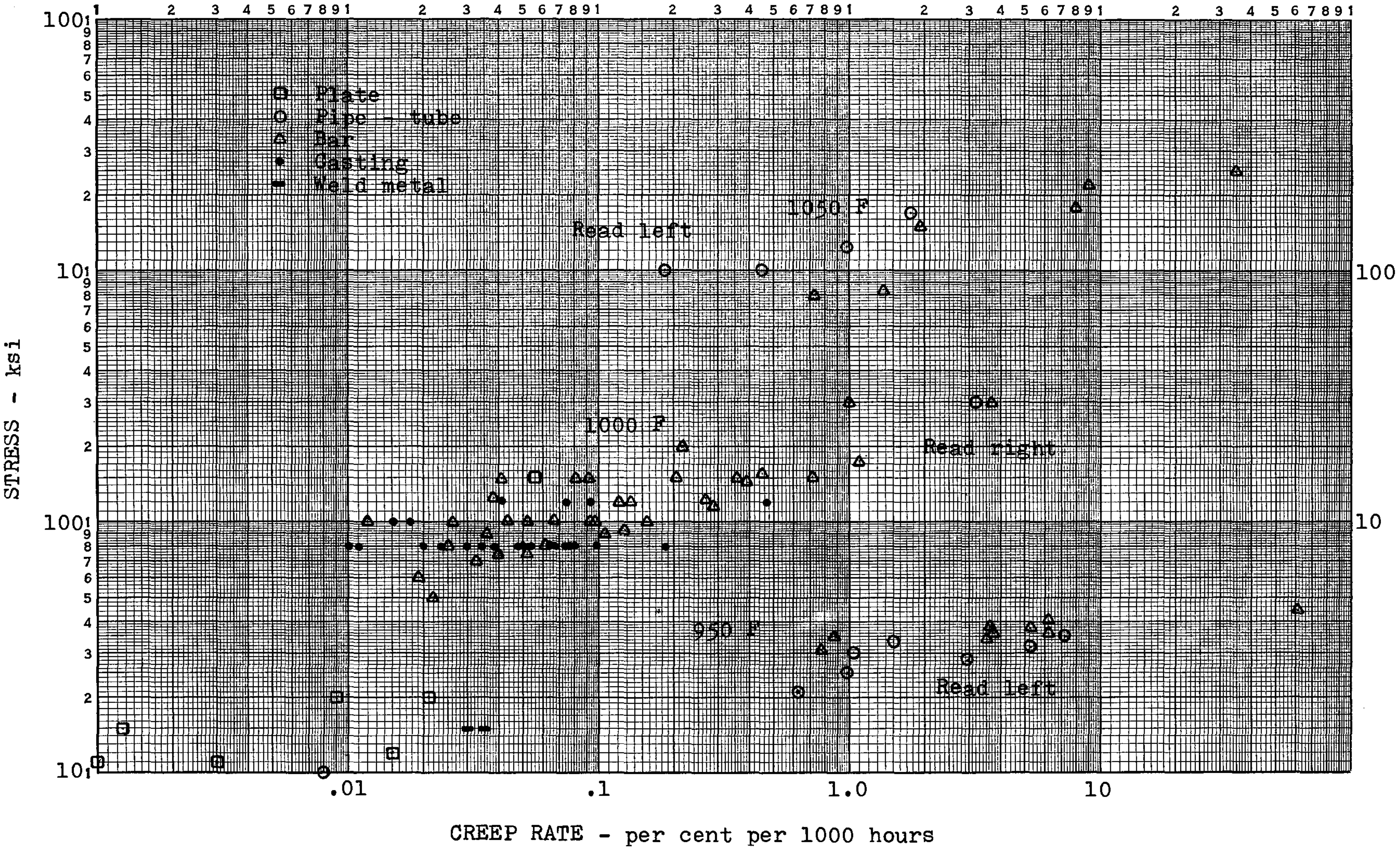

Fig. 15b Stress vs secondary creep rate of C-Mo steel.

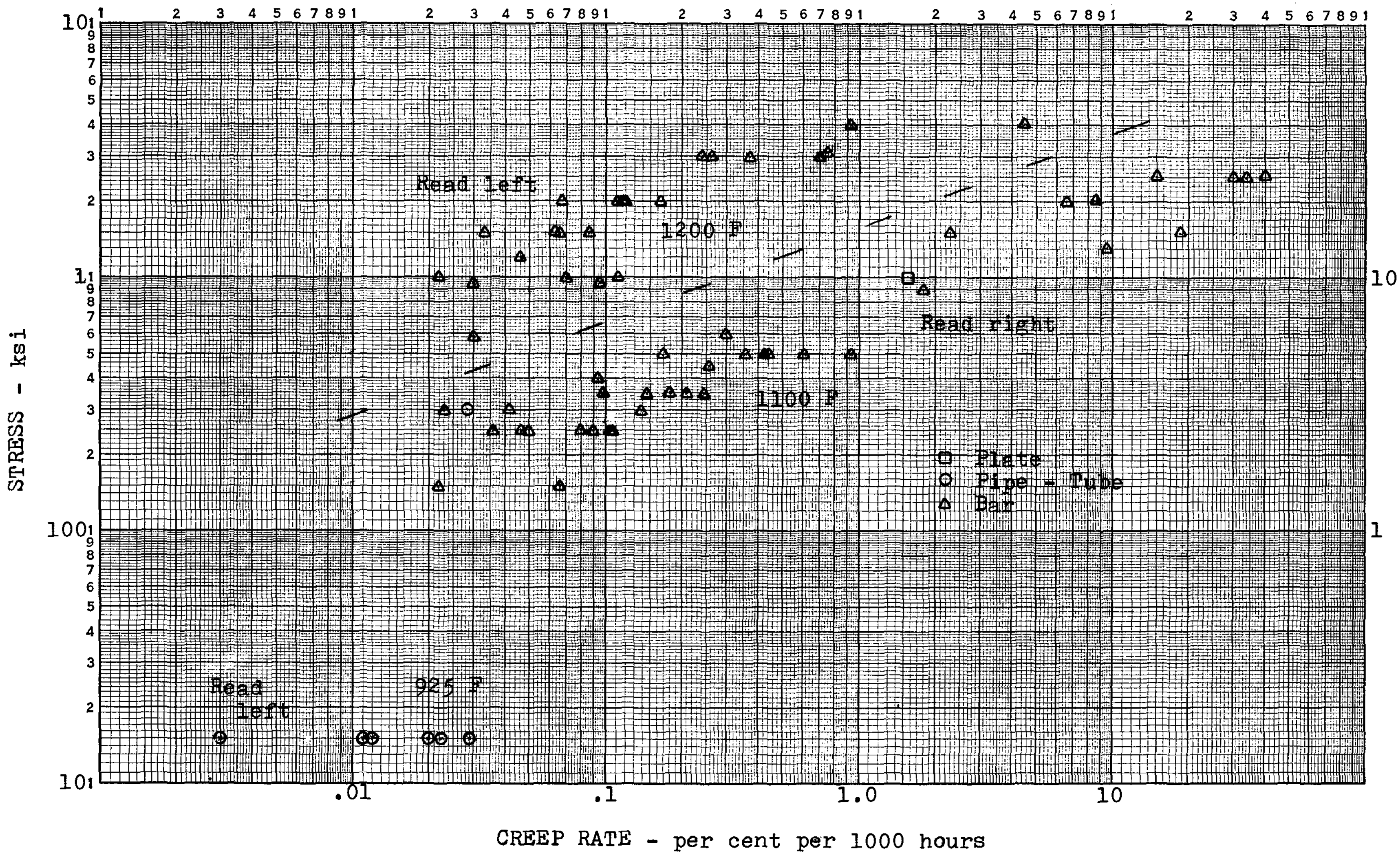

Fig. 15c Stress vs secondary creep rate of C-Mo steel.

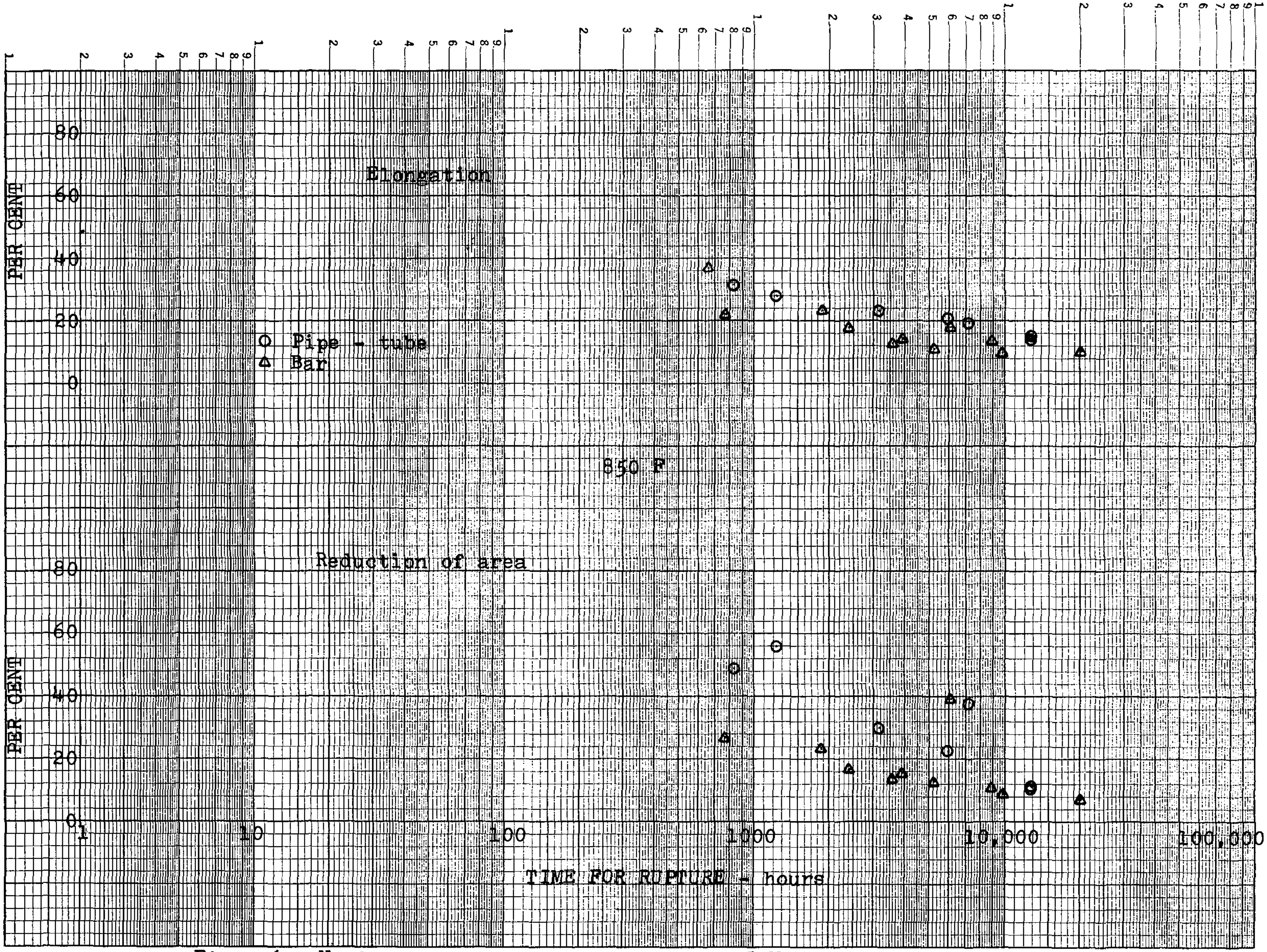

Fig. 16a Variation of rupture ductility of C-Mo steel with time for rupture.

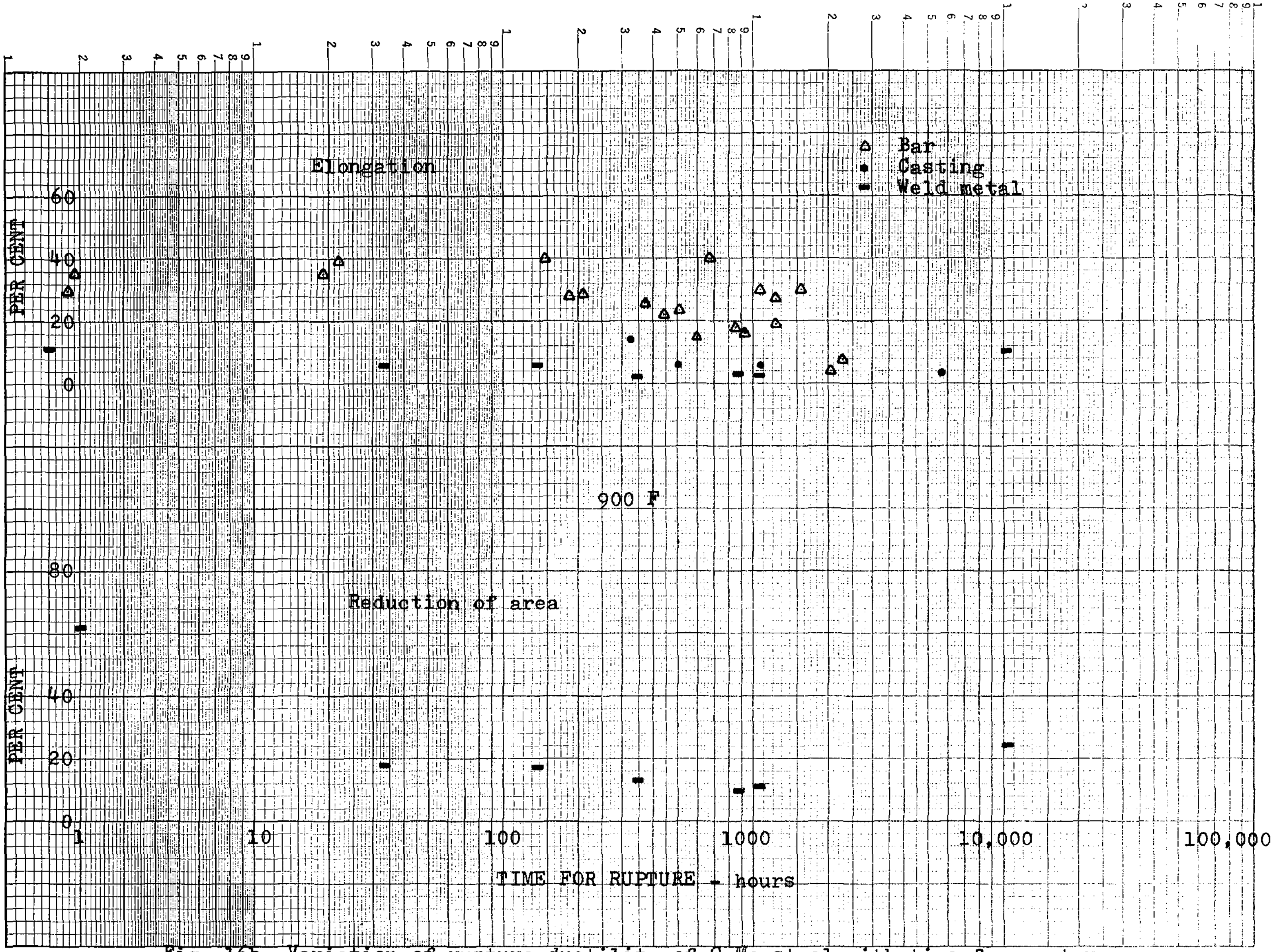

Fig. 16b Variation of rupture ductility of C-Mo steel with time for rupture.

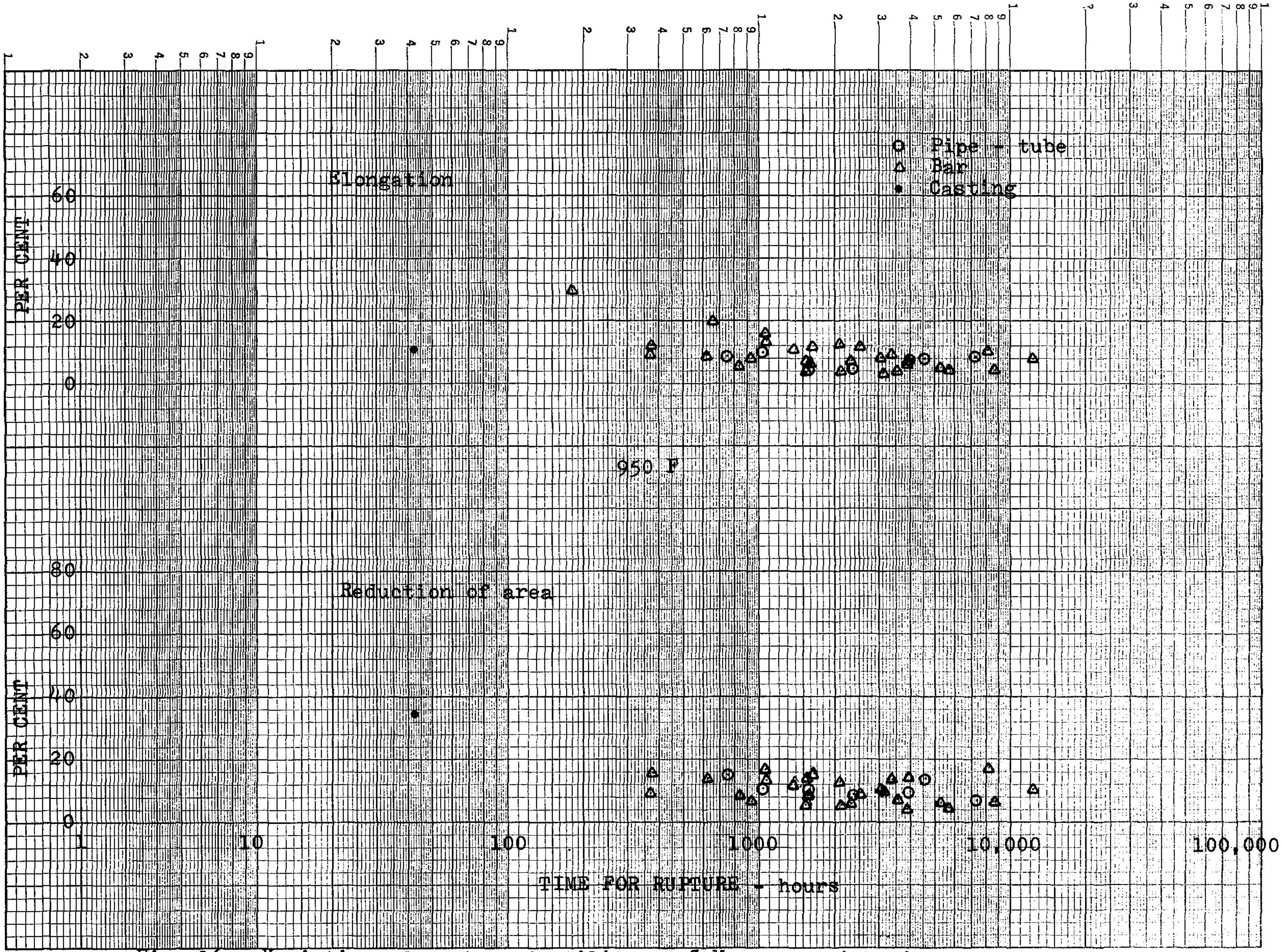

Fig. 16c Variation of rupture ductility of C-Mo steel with time for rupture.

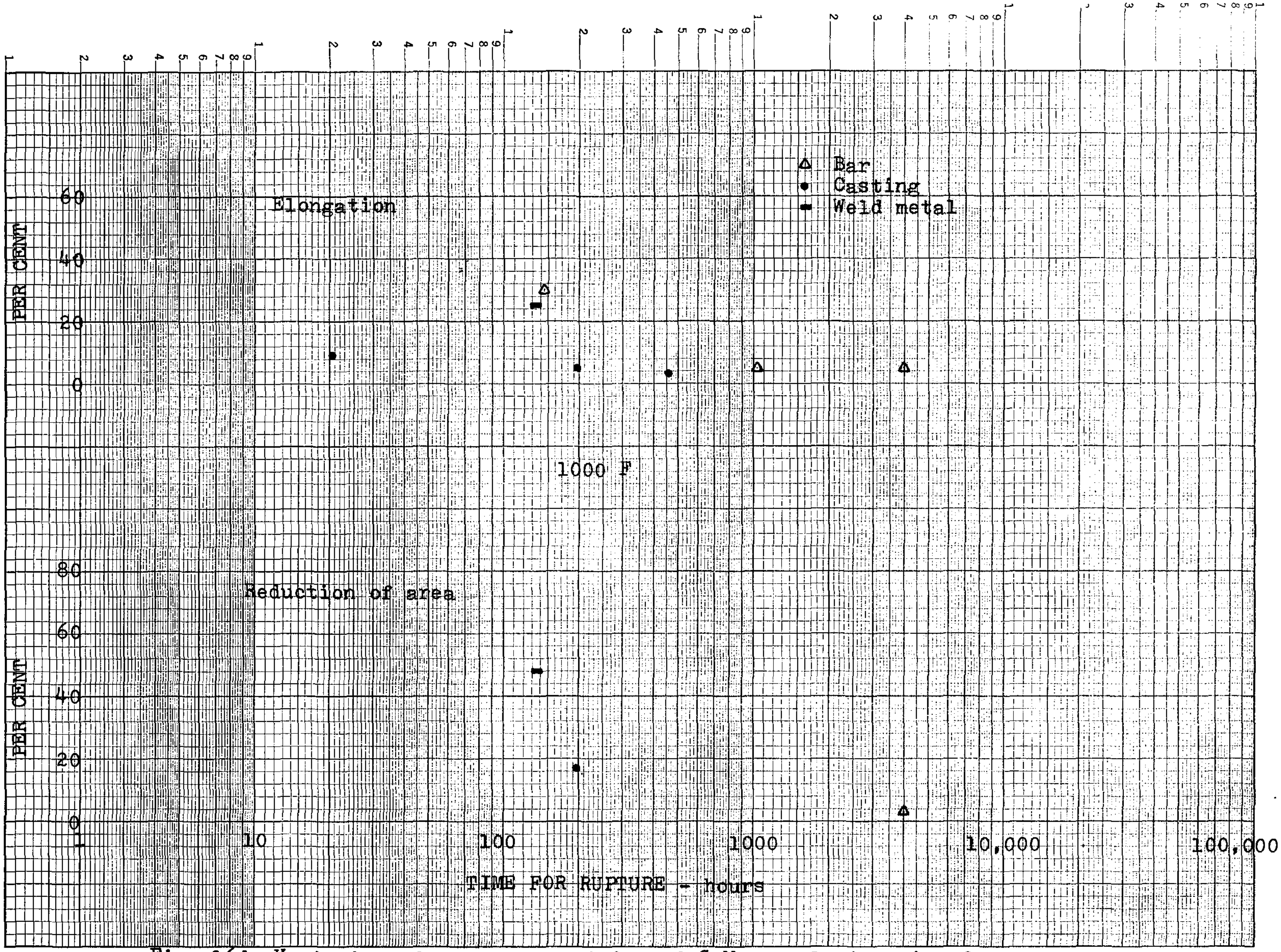

Fig. 16d Variation of rupture ductility of C-Mo steel with time for rupture.

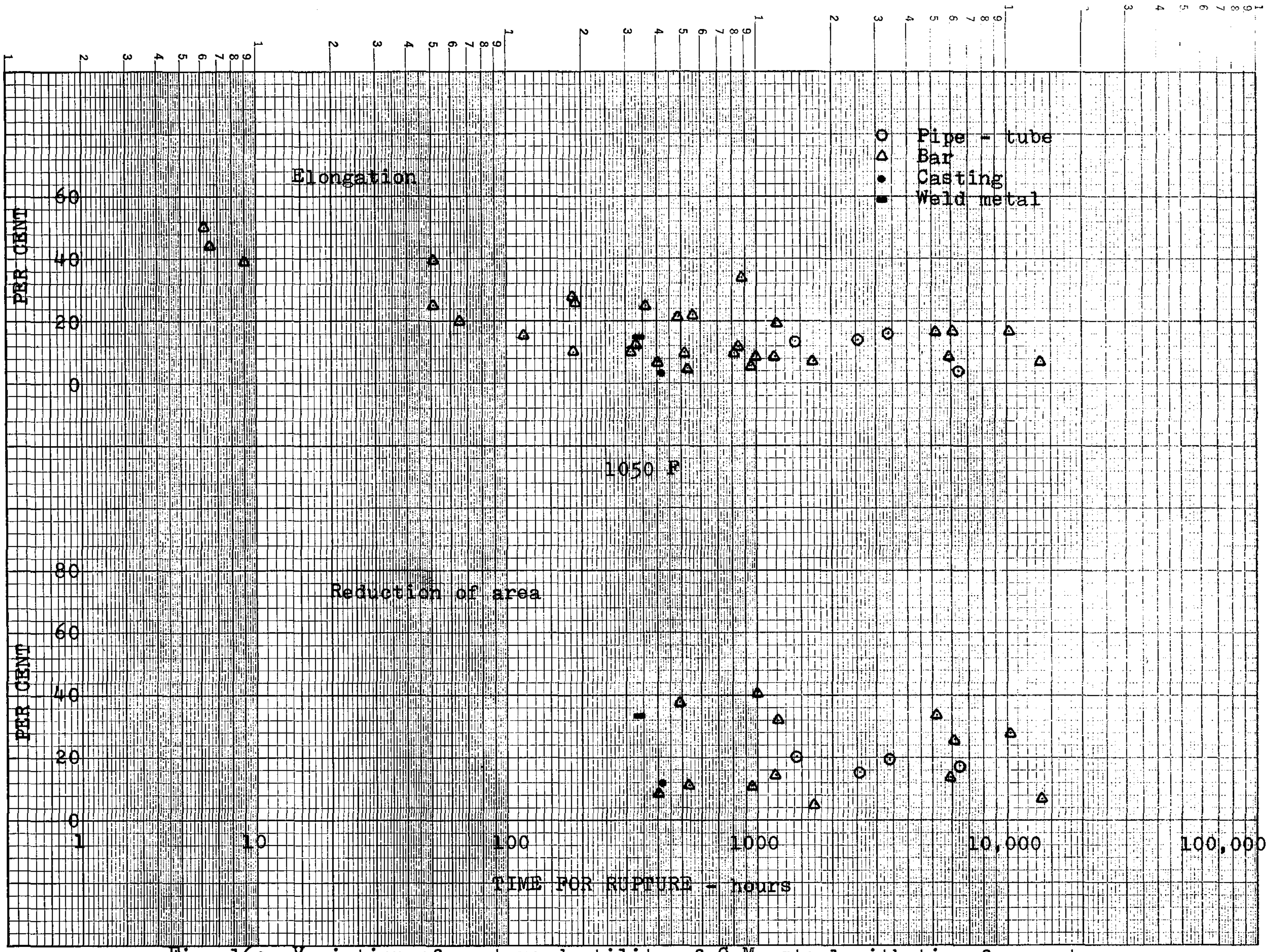

Fig. 16e Variation of rupture ductility of C-Mo steel with time for rupture.

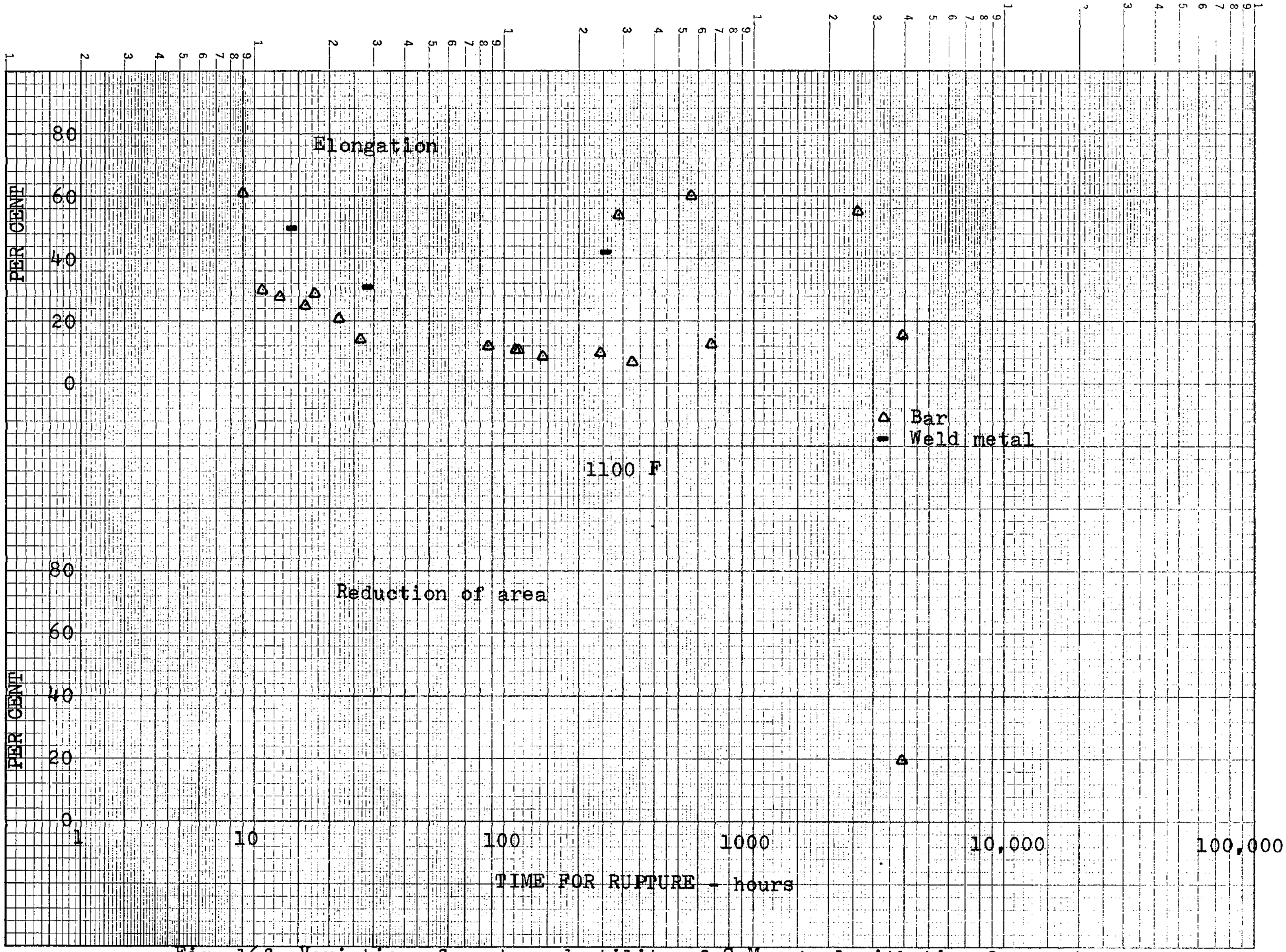

Fig. 16f Variation of rupture ductility of C-Mo steel with time for rupture.

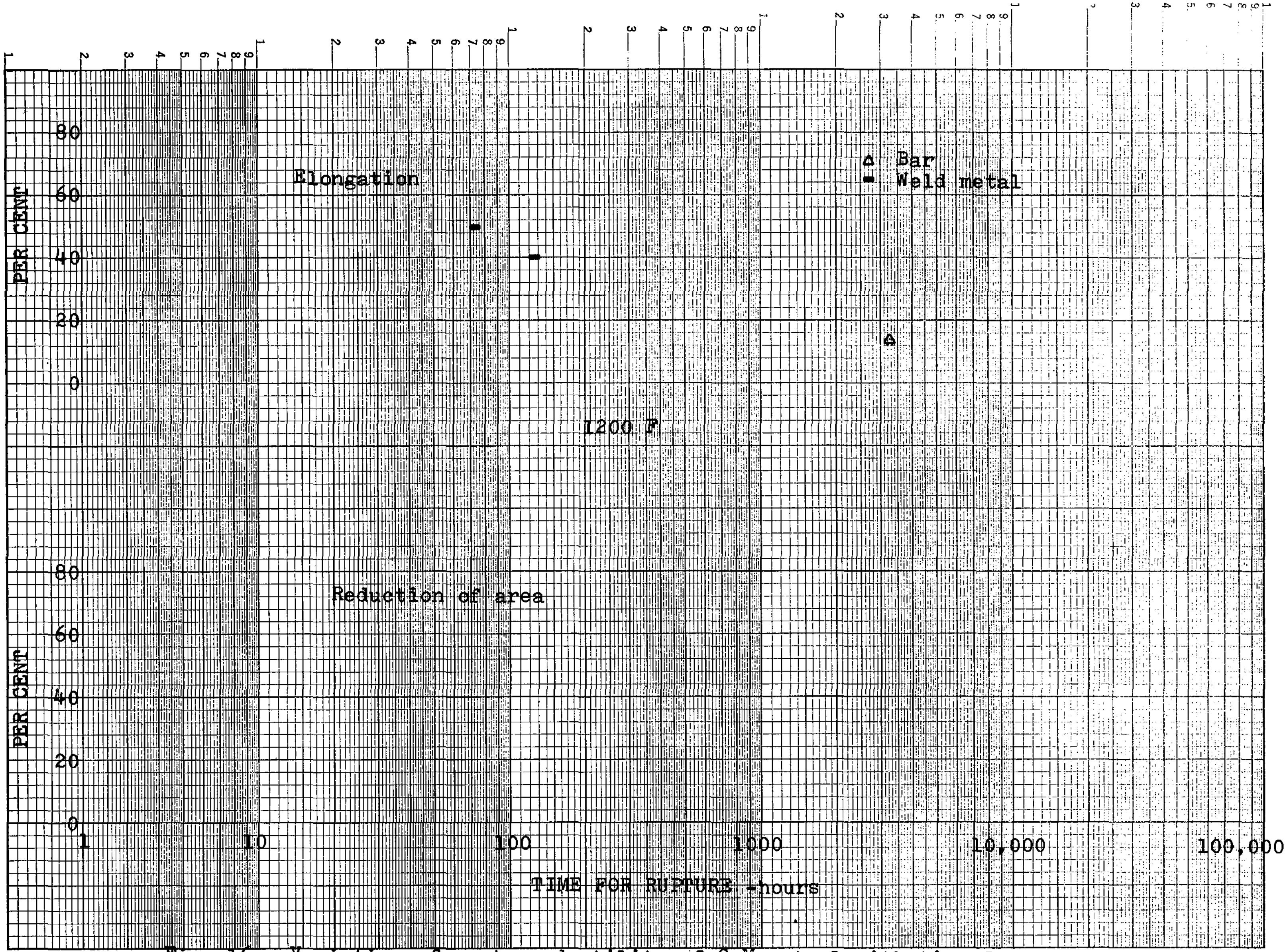

Fig. 16g Variation of rupture ductility of C-Mo steel with time for rupture.

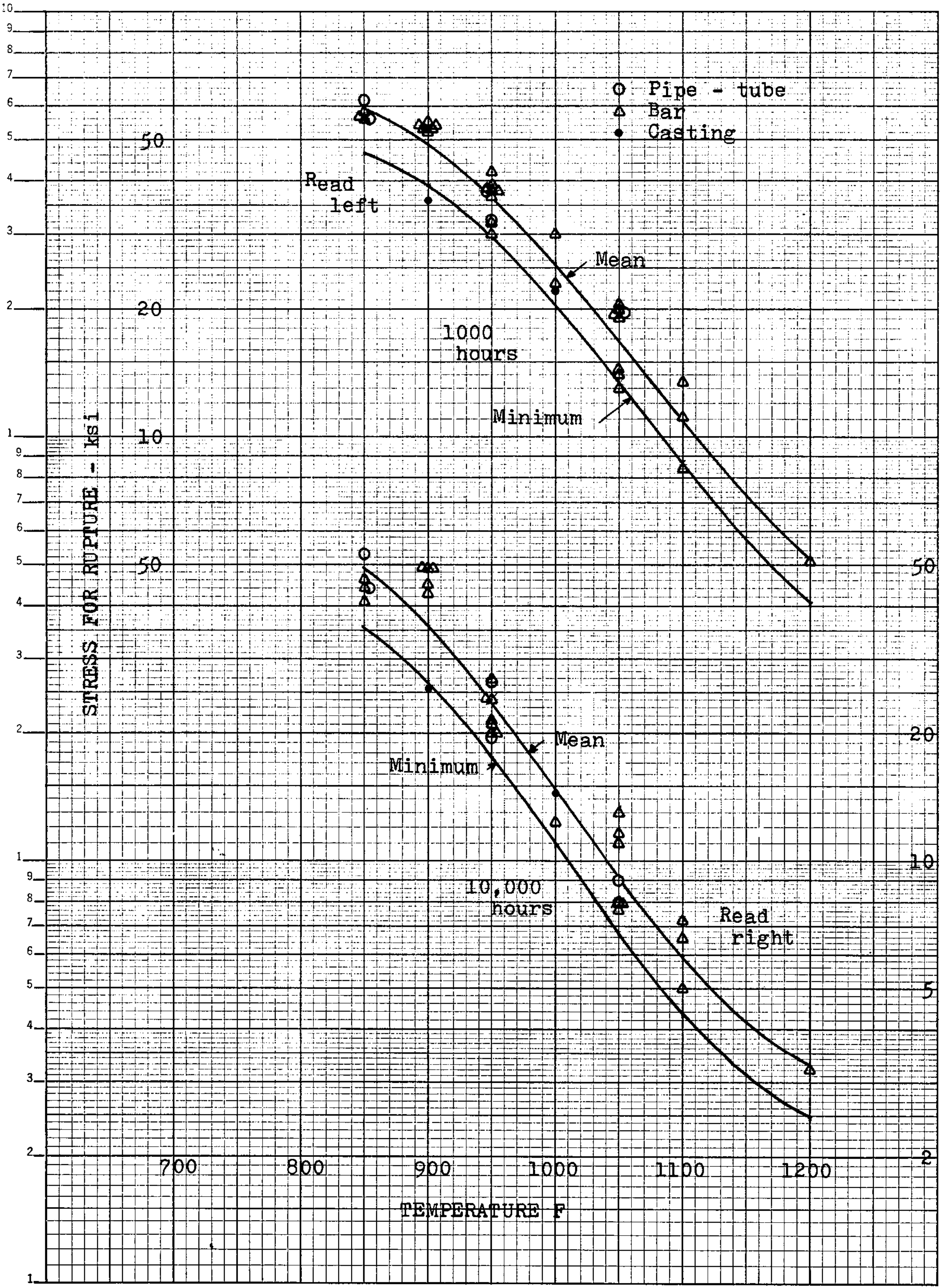

Fig. 17a Variation of rupture strength of C-Mo steel with temperature.

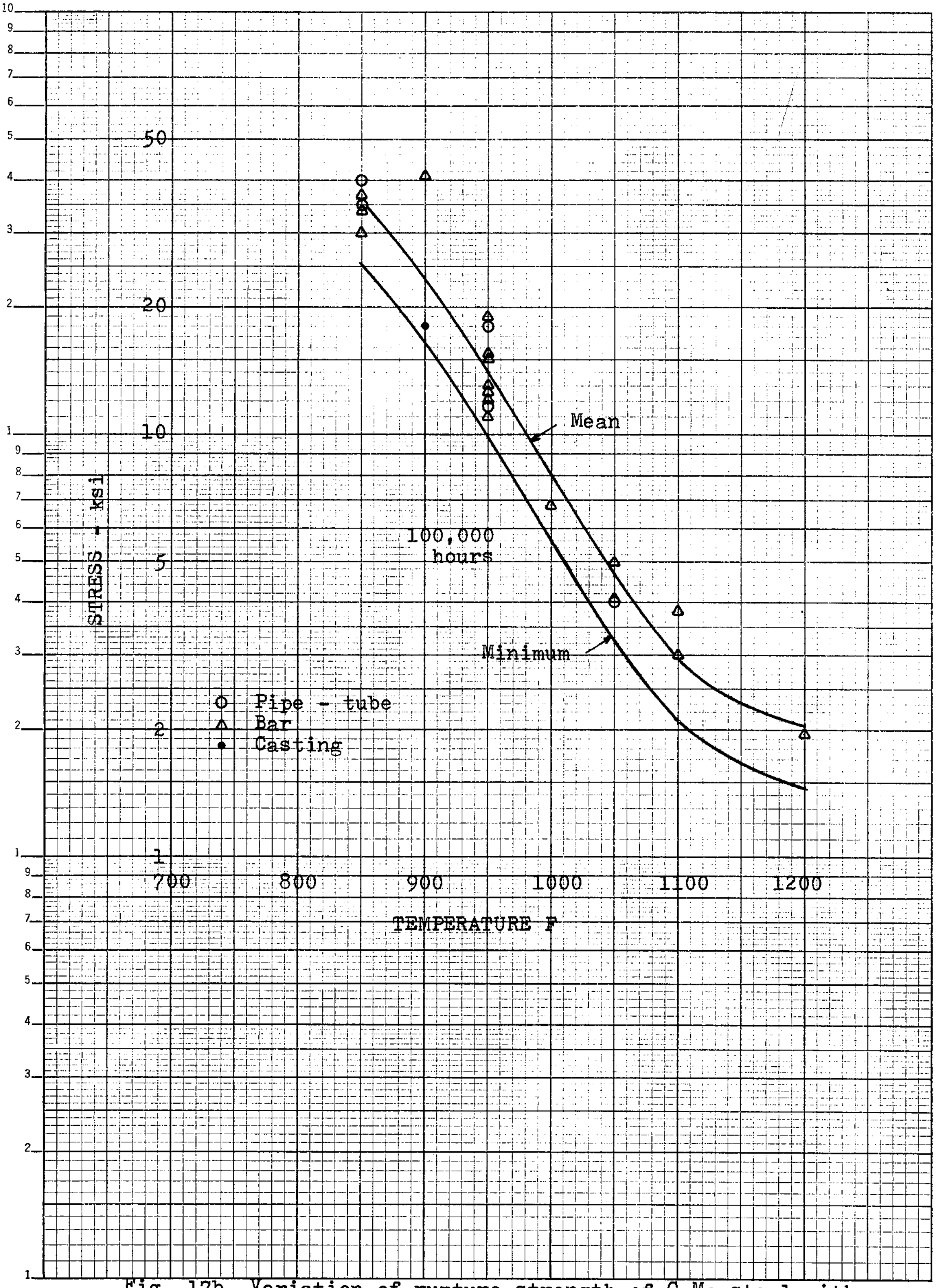

Fig. 17b Variation of rupture strength of C-Mo steel with temperature.

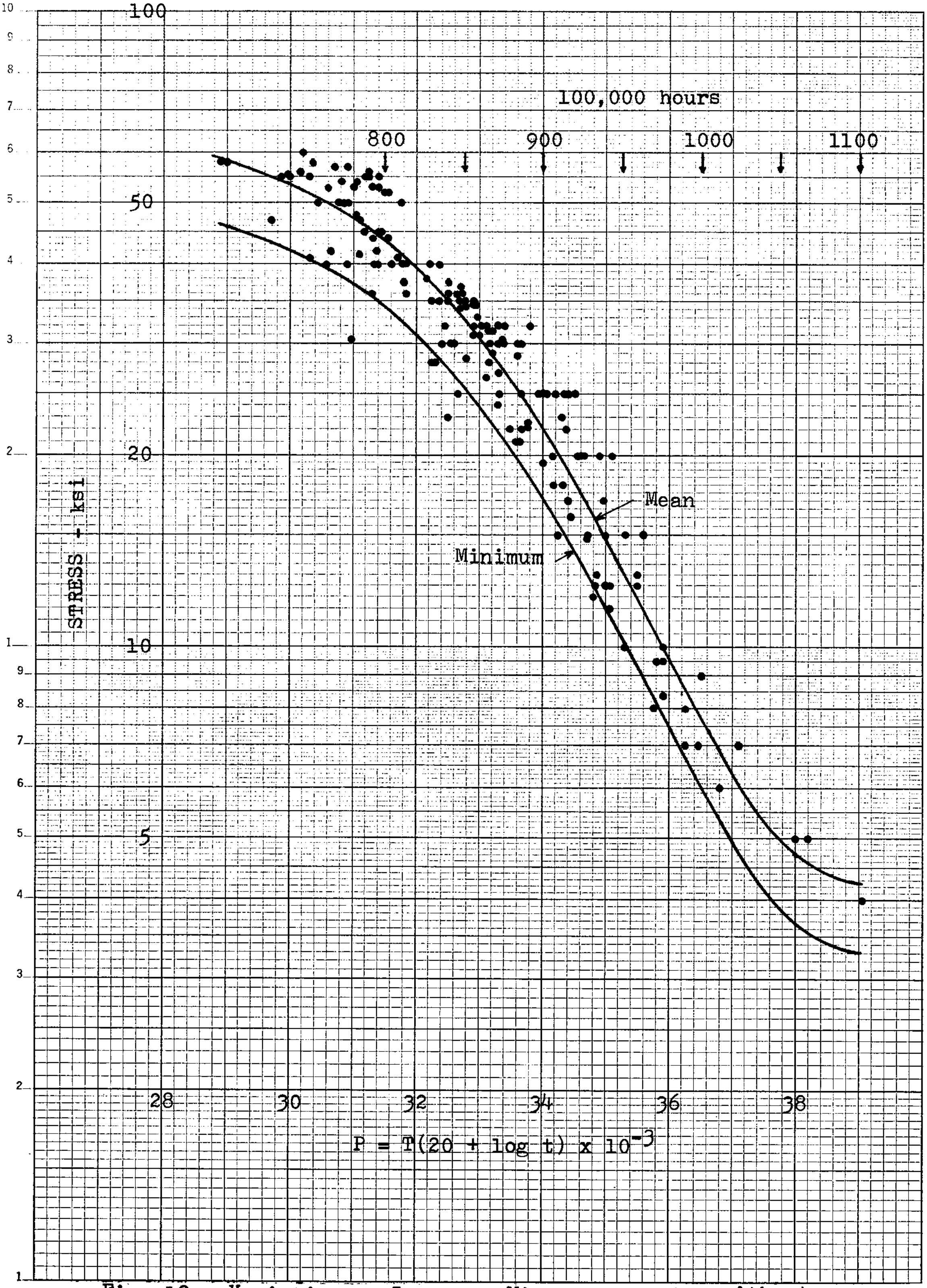

Fig. 18a Variation of Larson - Miller parameter with stress for rupture of C-Mo steel.

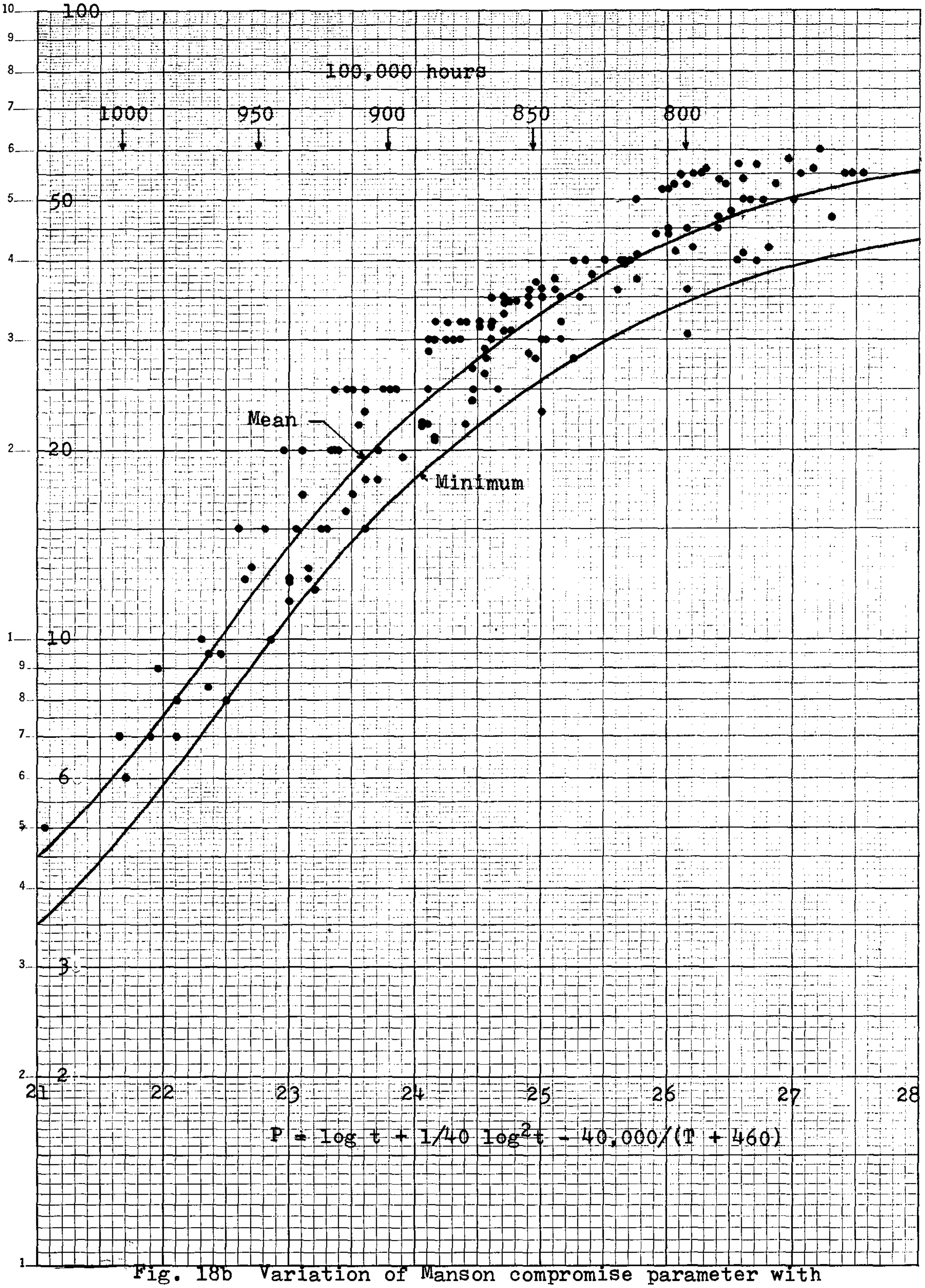

Fig. 18b Variation of Manson compromise parameter with stress for rupture of C-Mo steel.

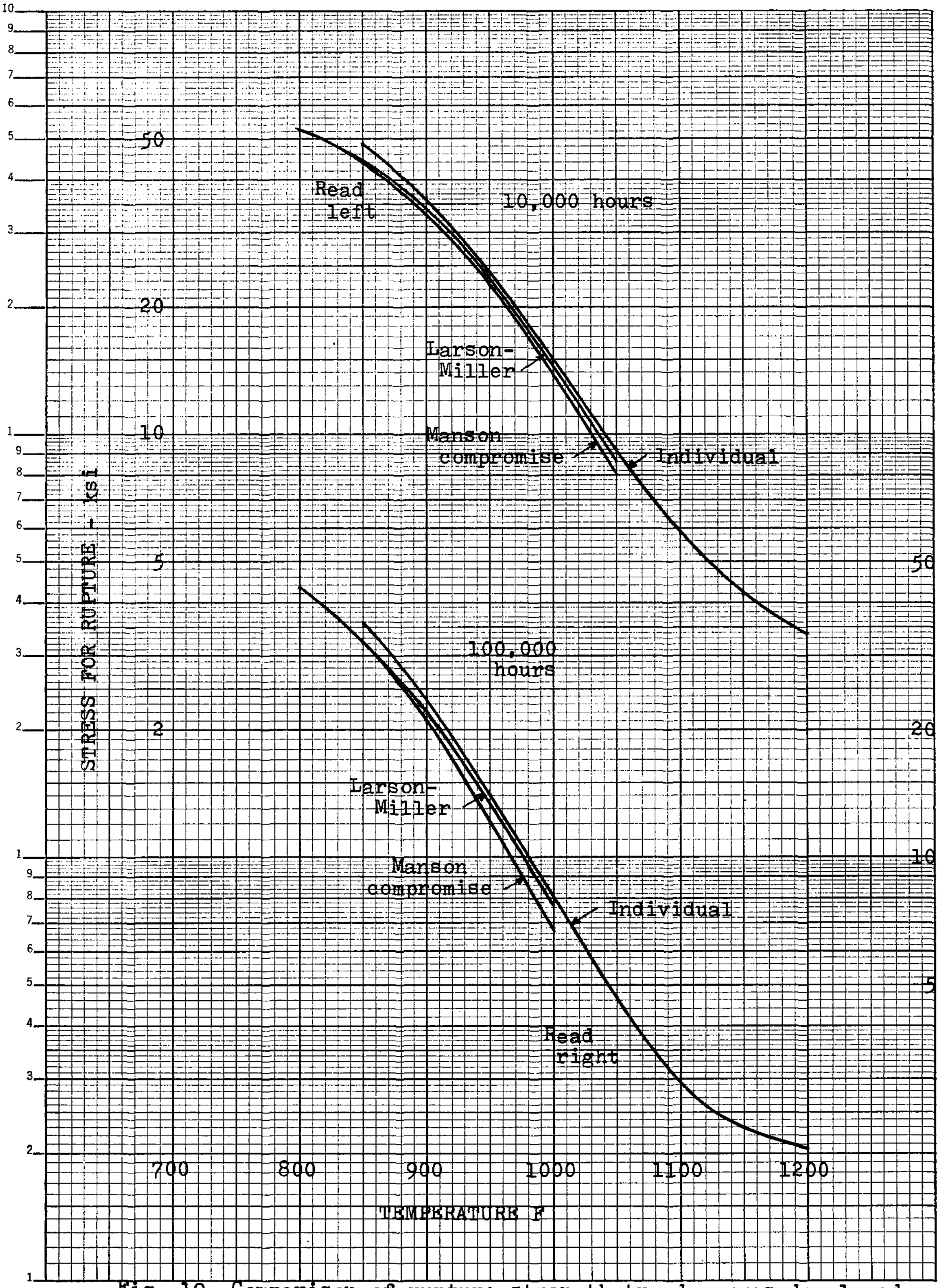

Fig. 19 Comparison of rupture strength trend curves developed for C-Mo steel by various evaluation procedures.

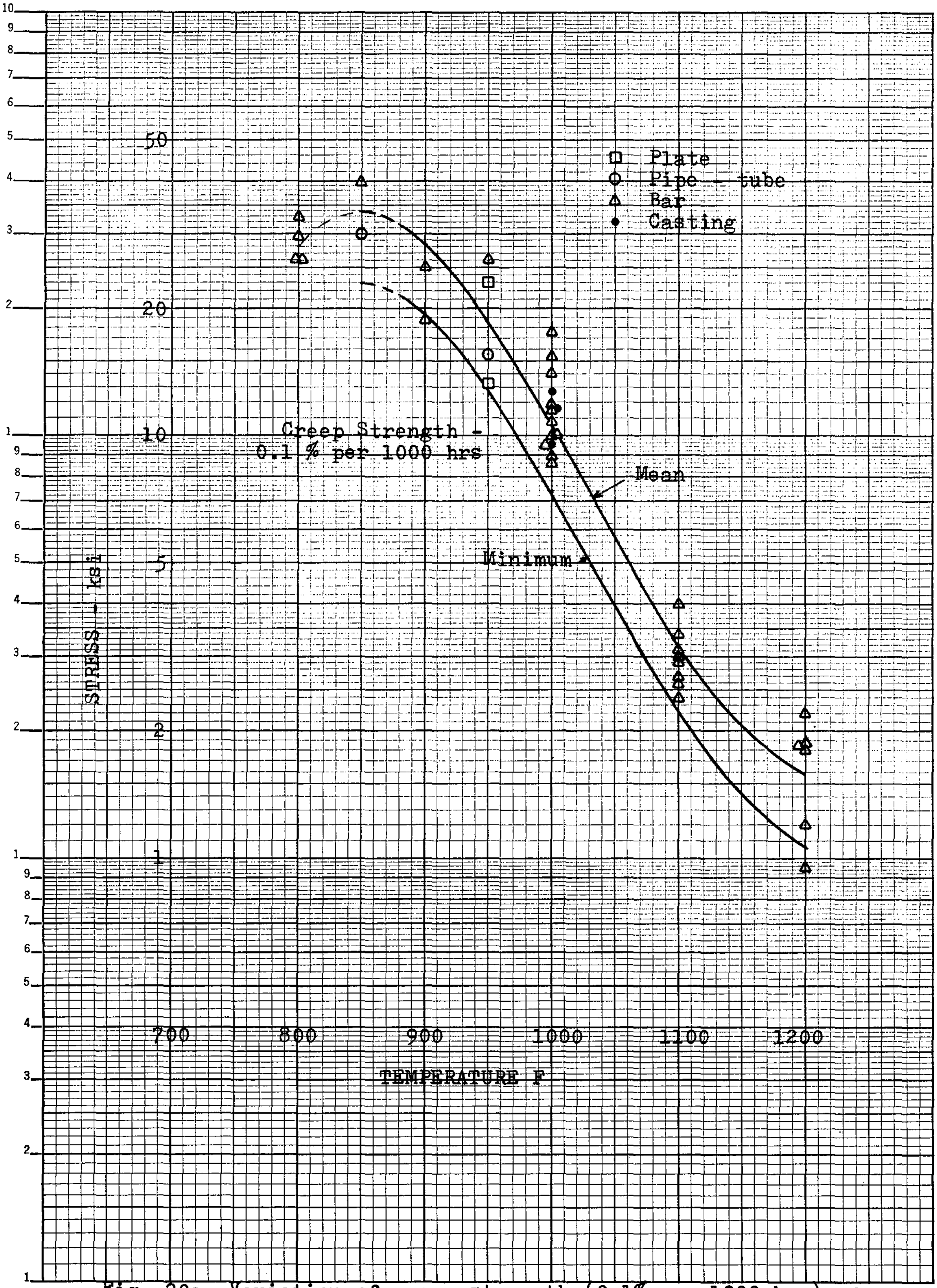

Fig. 20a Variation of creep strength (0.1% per 1000 hrs) of C-Mo steel with temperature.

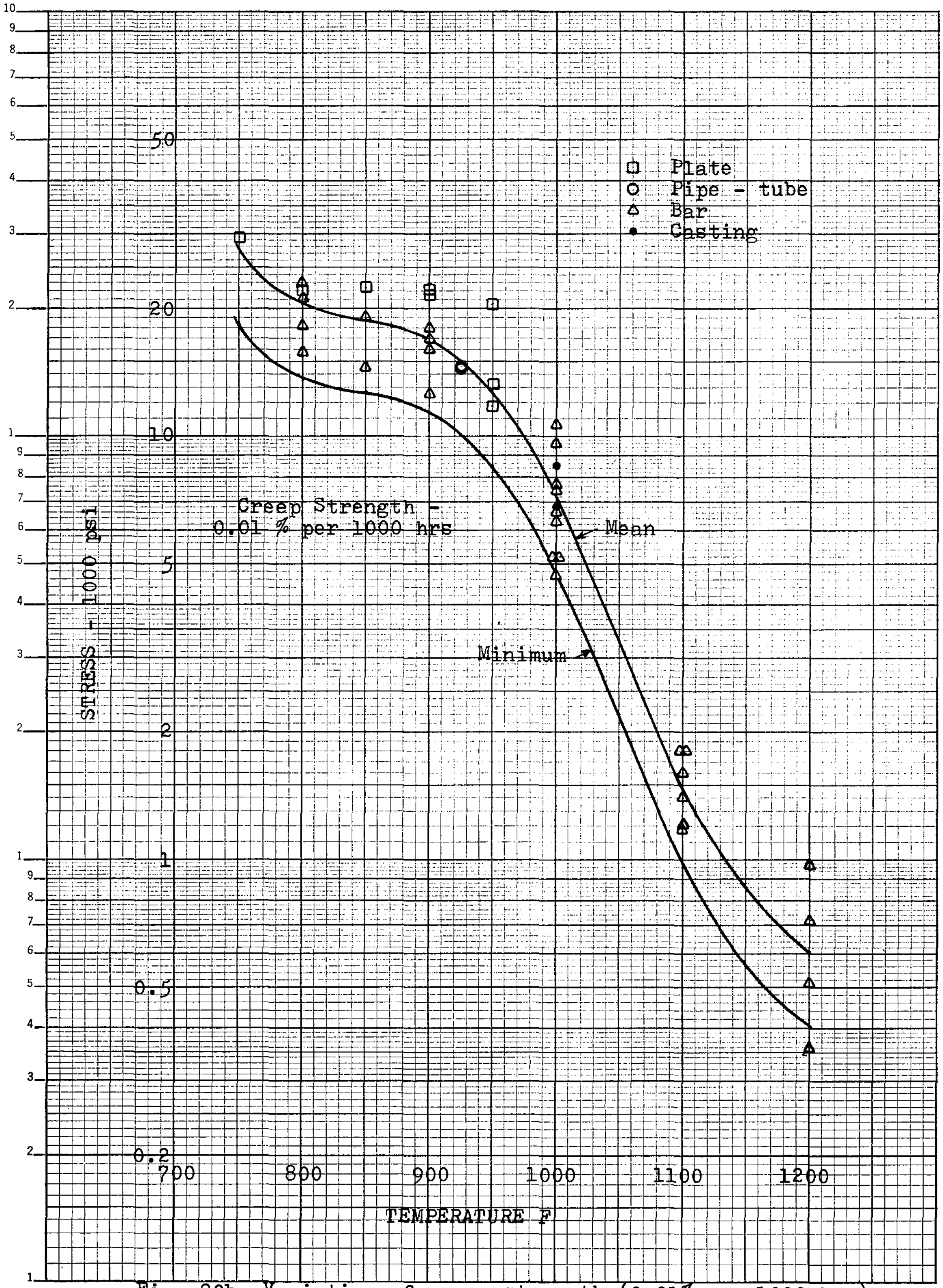

Fig. 20b Variation of creep strength (0.01% per 1000 hrs) of C-Mo steel with temperature.

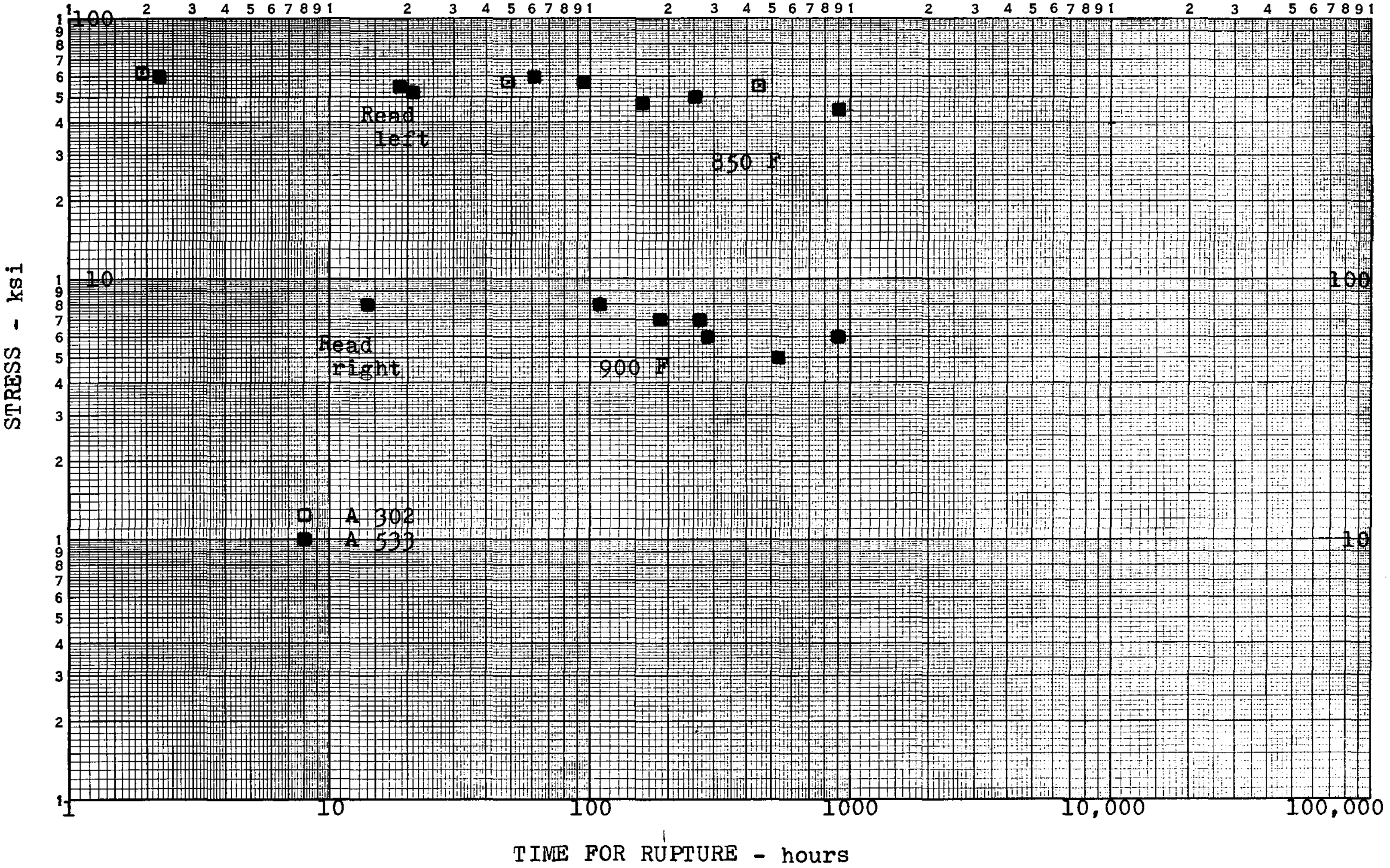

Fig. 21a Stress vs time for rupture of Mn-Mo steels.

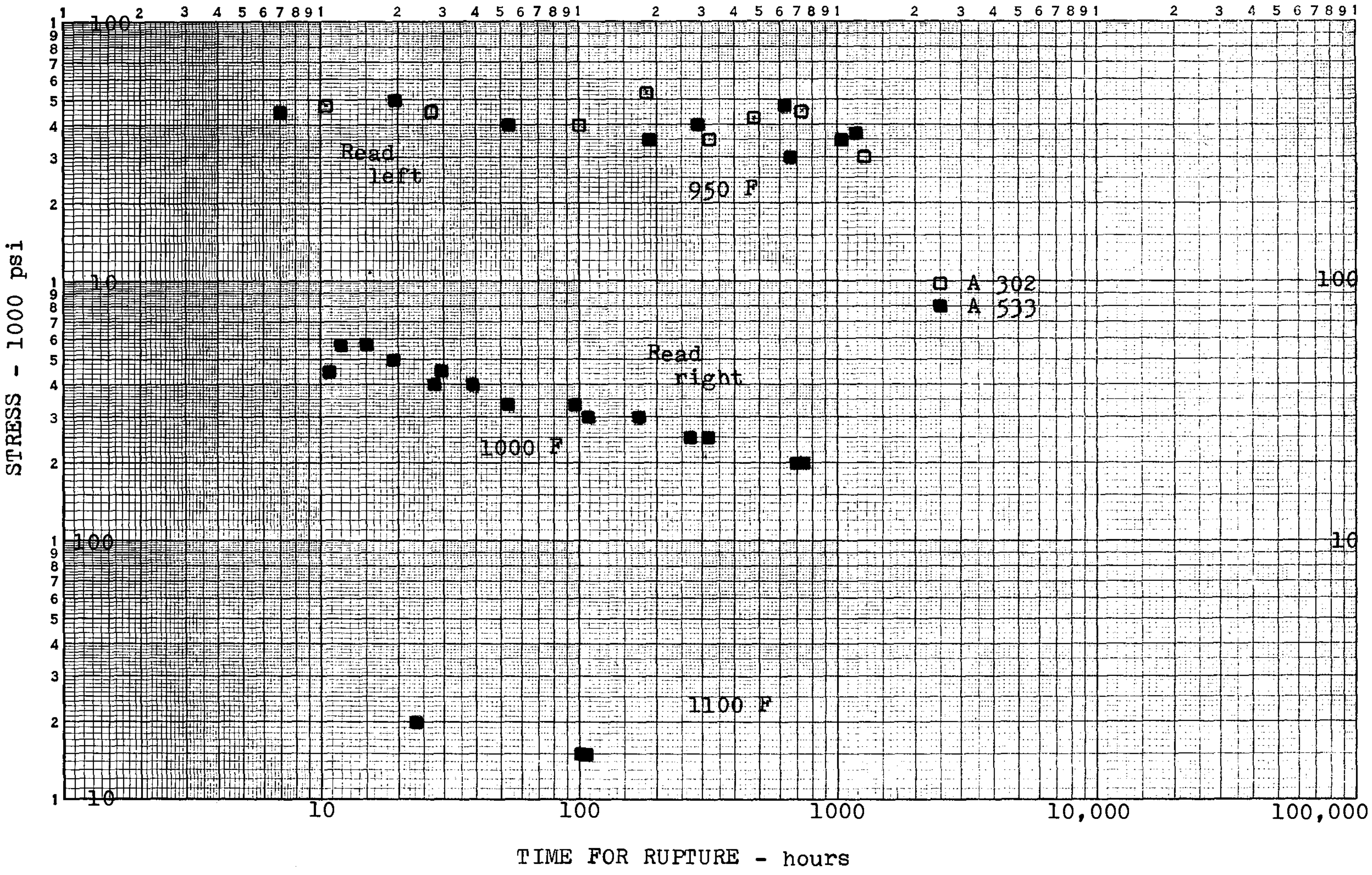

Fig. 21b Stress vs time for rupture of Mn-Mo steels.

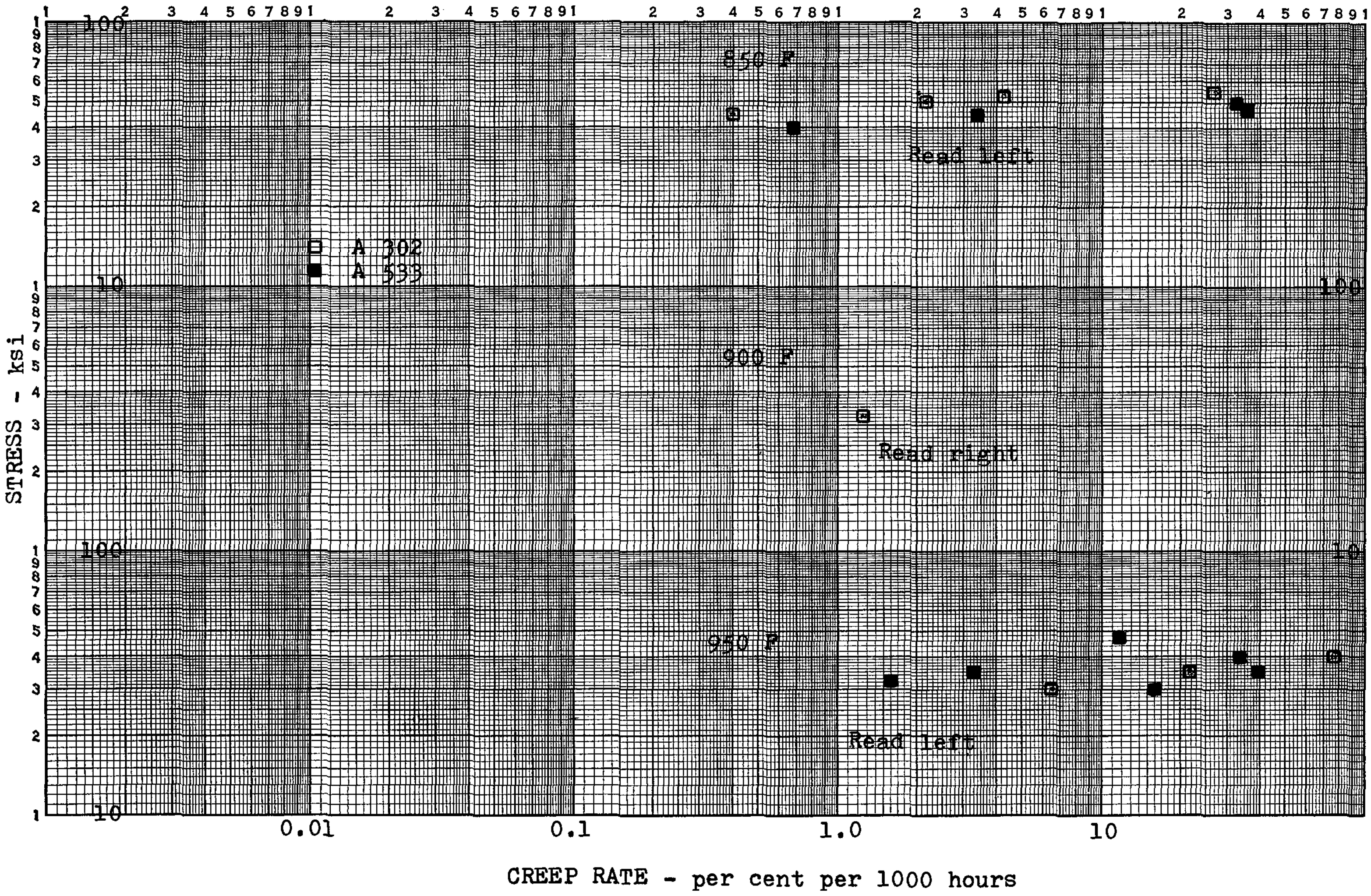

Fig. 22 Stress vs secondary creep rate of Mn-Mo steels.

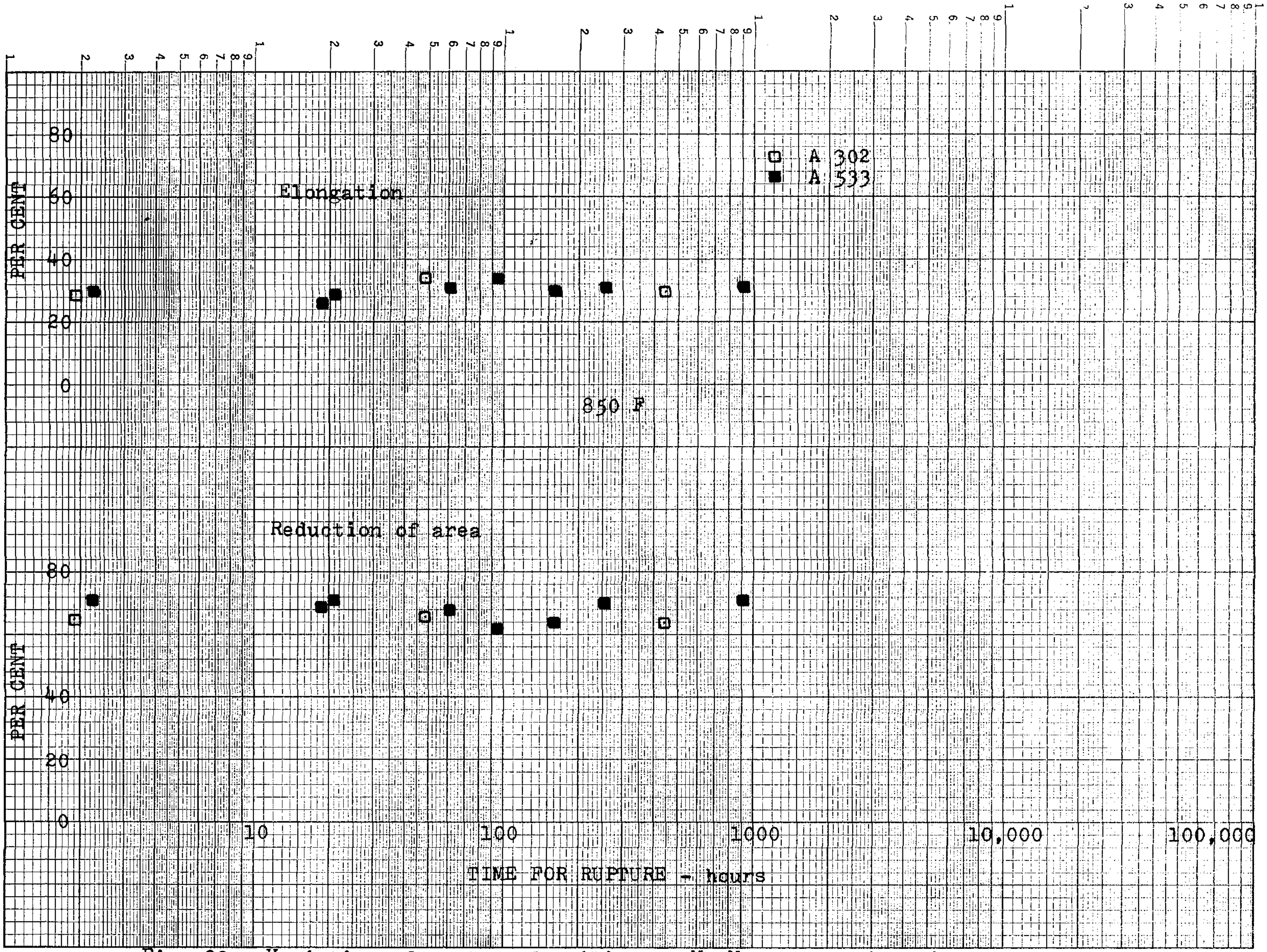

Fig. 23a Variation of rupture ductility of Mn-Mo steels with time for rupture.

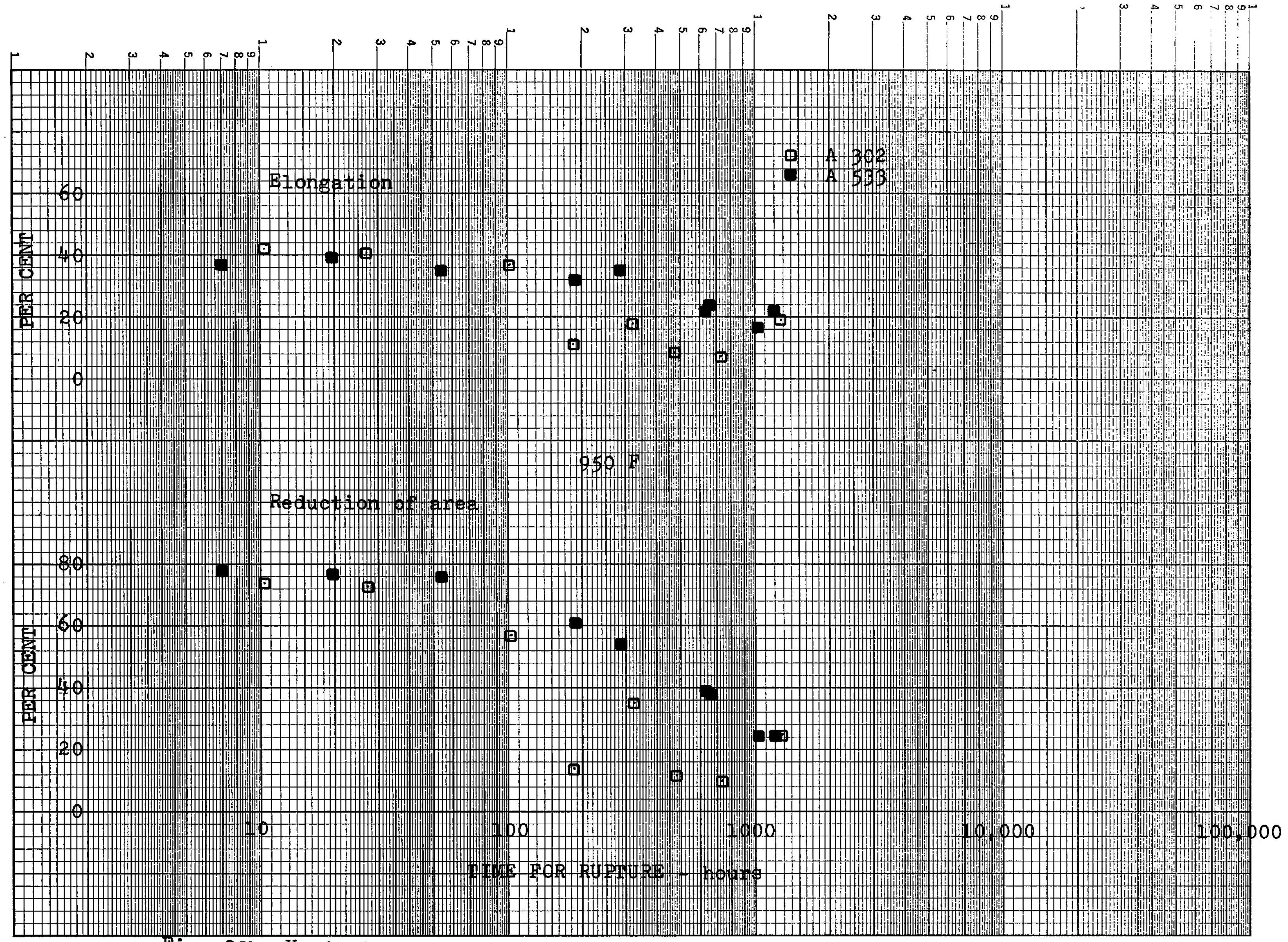

Fig. 23b Variation of rupture ductility of Mn-Mo steels with time for rupture.

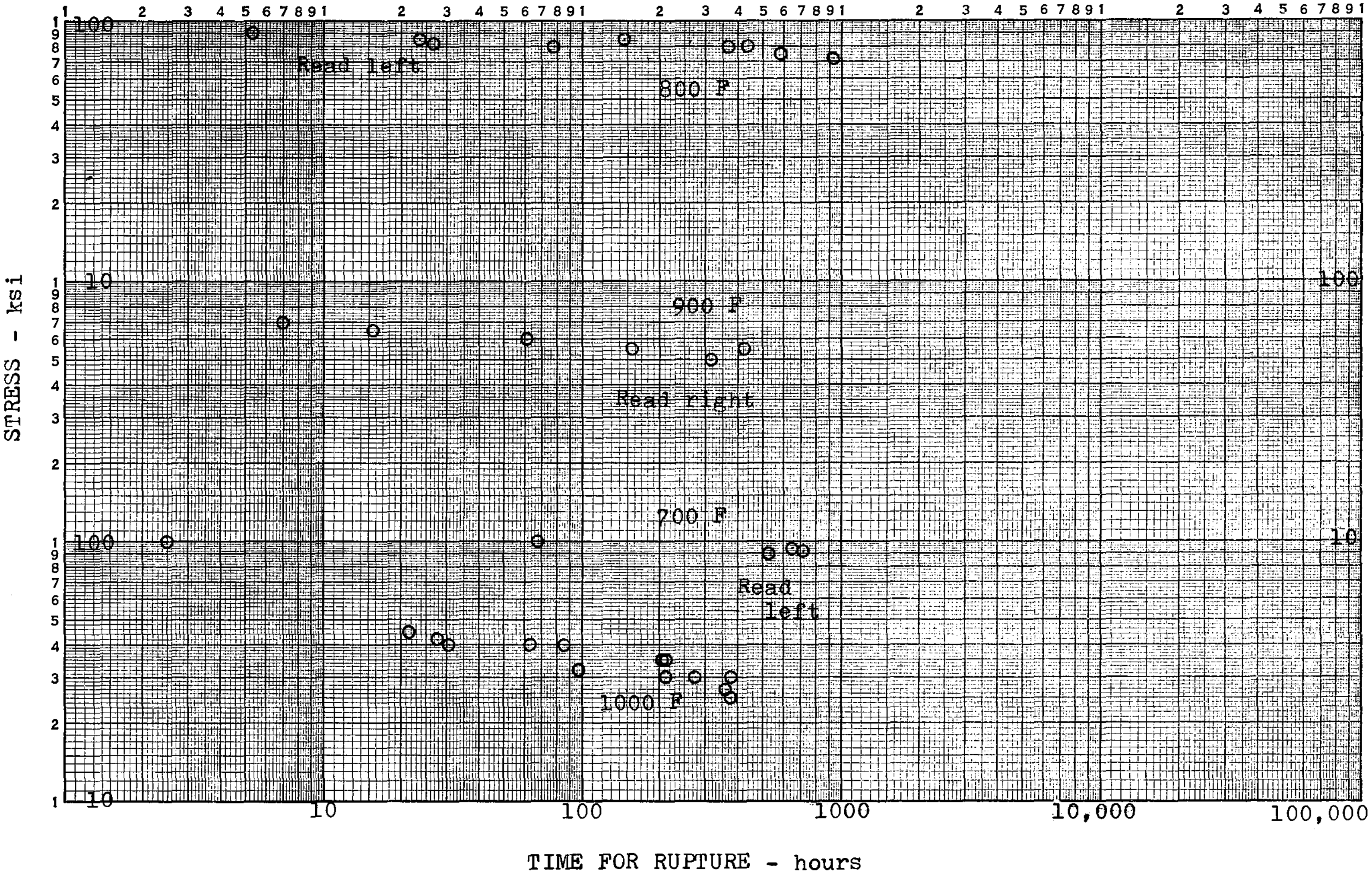

Fig. 24 Stress vs time for rupture of Mn-Mo steel, A 514C.

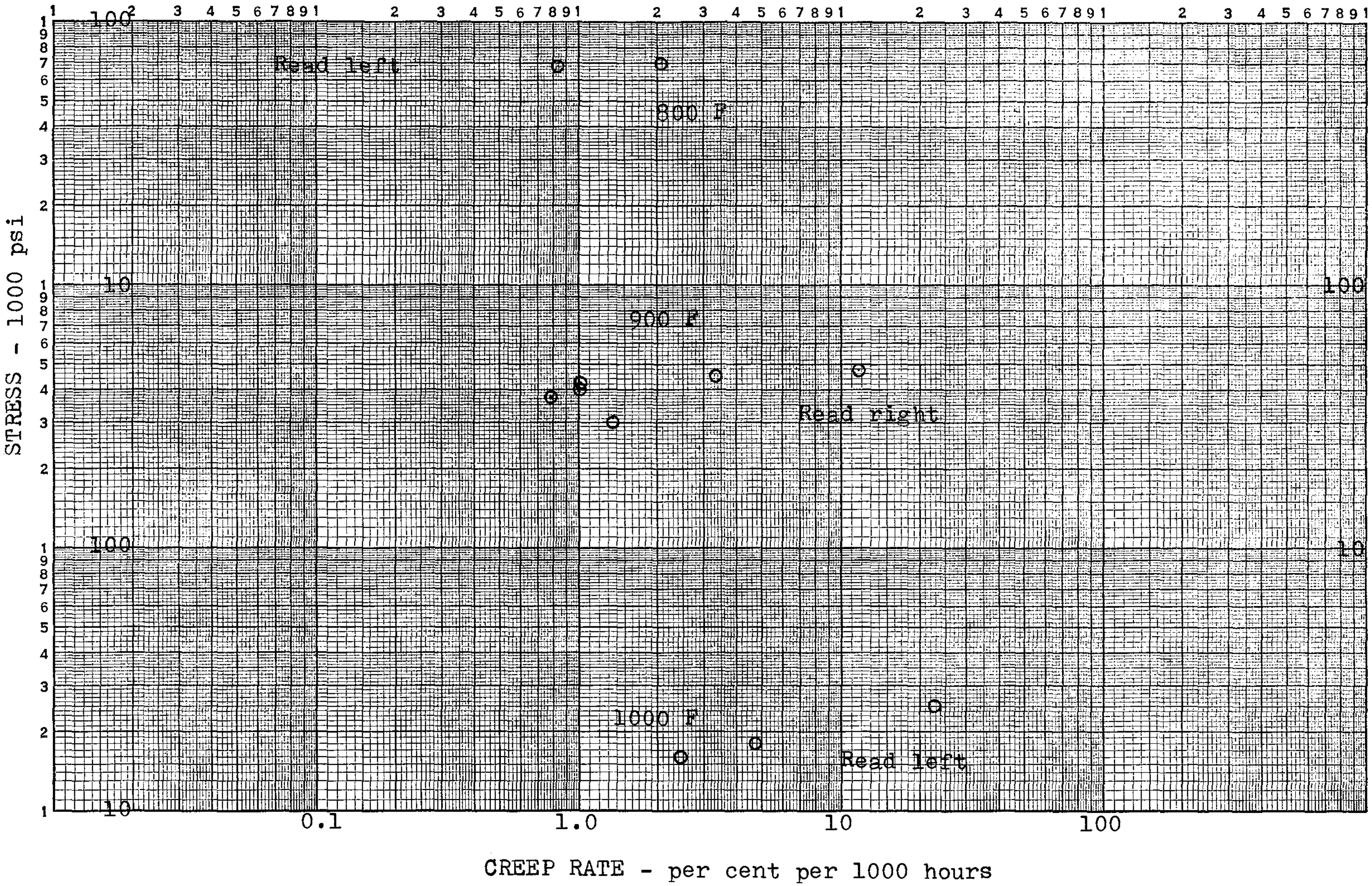

Fig. 25 Stress vs secondary creep rate of Mn-Mo steel, A 514C.

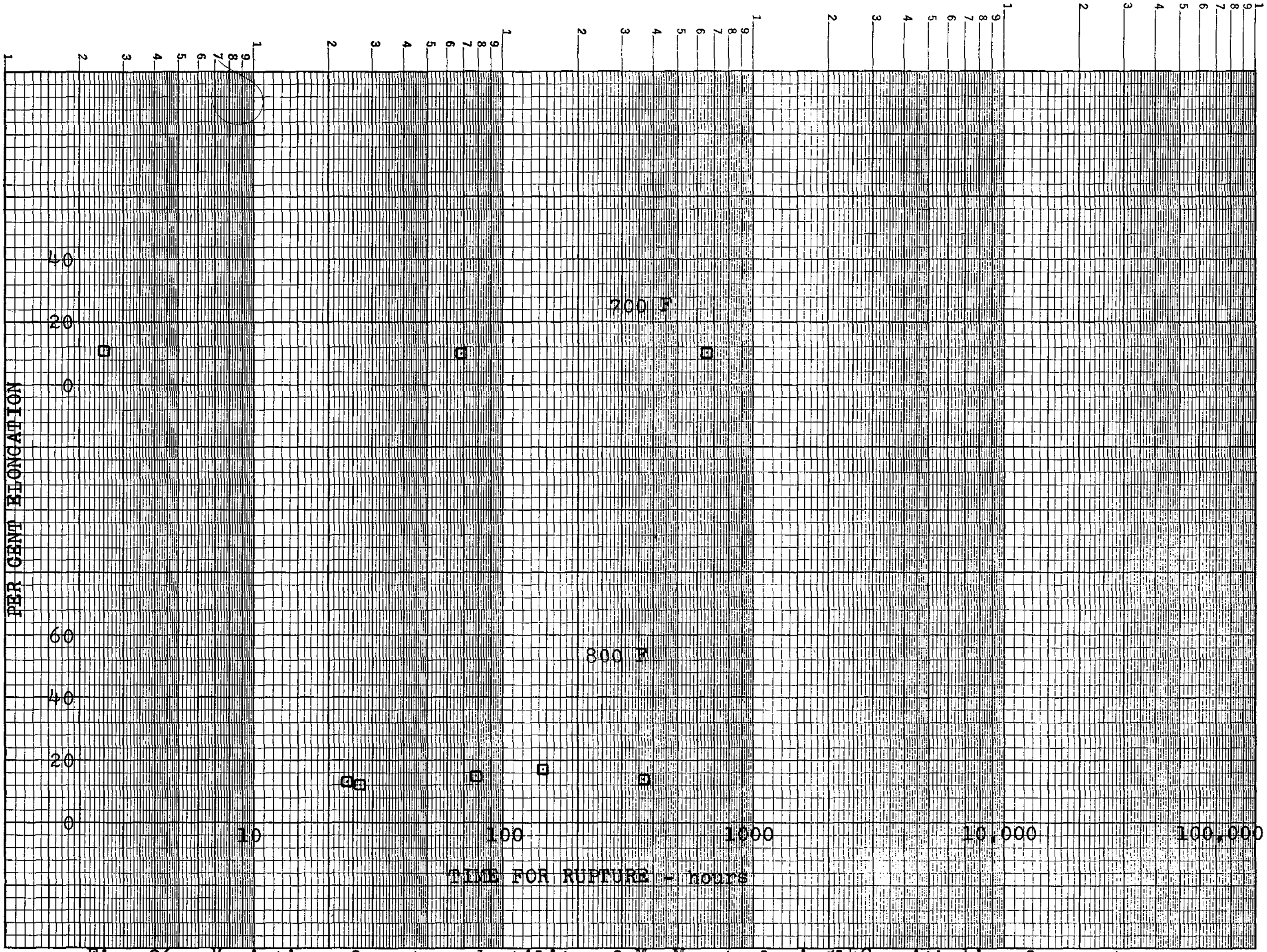

Fig. 26a Variation of rupture ductility of Mn-Mo steel, A 514C, with time for rupture.

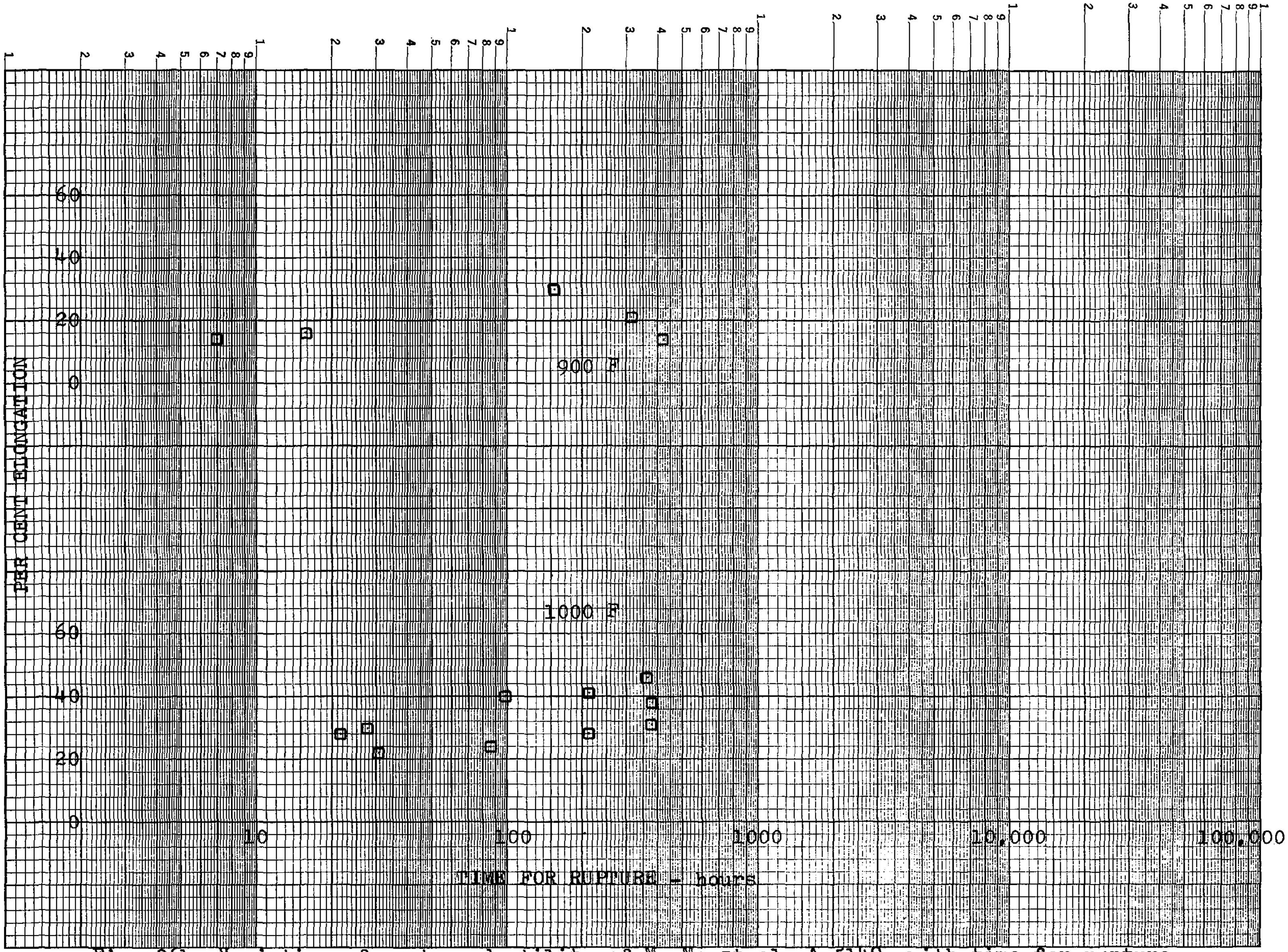

Fig. 26b Variation of rupture ductility of Mn-Mo steel, A 514C, with time for rupture.