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Thank you so much for your time, and I am very much looking forward to your response.

Sincerely,

John Greenewald, Jr.

[redacted]

Sincerely,

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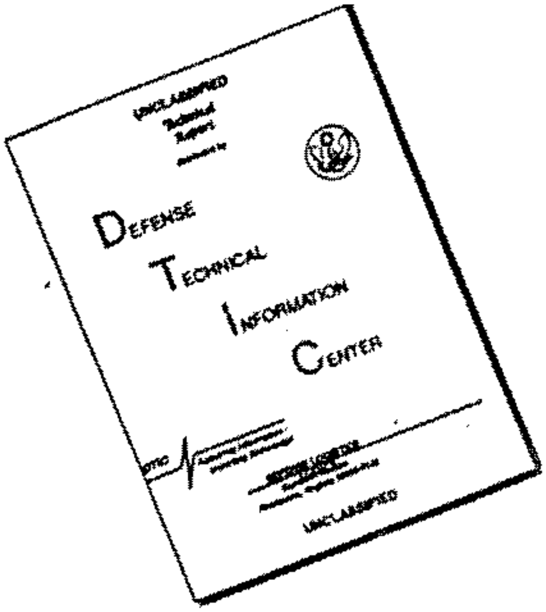

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VOLUME VI

(UNCLASSIFIED TITLE)
NUCLEAR RAMJET PROPULSION SYSTEM APPLIED RESEARCH AND ADVANCED TECHNOLOGY (PROJECT PLUTO)

VOLUME VI

STRUCTURAL MATERIALS INVESTIGATIONS

TECHNICAL DOCUMENTARY REPORT ASD-TDR-63-277, VOLUME VI

15 February 1963

Directorate of Aeromechanics
Propulsion Laboratory
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No. 655A, Tasks Nos. 1 and 5

(Prepared under Contract AF 33(657)-8123
by The Marquardt Corporation, Van Nuys, California
Author: R. D. Grossman)

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FOREWORD

This report was prepared by The Marquardt Corporation, Van Nuys, California, on Air Force Contract AF 33(657)-8123, under Tasks Nos. 1 and 5 of Project No. 655A, "Nuclear Ramjet Propulsion Systems Research and Technology." The work was administered under the direction of the Propulsion Laboratory (Directorate of Aeromechanics), Aeronautical Systems Division. R. F. Latham was Project Engineer for the Laboratory.

The studies presented here were performed during the contract period 1 January to 31 December 1962. The Marquardt Corporation activities were under the direction of A. O. Mooneyham, Senior Project Engineer. Chief contributors were J. G. Bendot, Aerothermodynamics; R. D. Grossman, Design and Development, and R. K. Nuno, Controls.

This report is the final technical summary report and concludes the work on Contract AF 33(657)-8123. The contractor's report number is Marquardt Report 6003. The volumes of this report are as follows:

Volume I: Summary

Volume II: Propulsion System Performance and Aerothermodynamics

Volume III: Propulsion System Controls

Volume IV: Propulsion System Design and Structural Analysis

Volume V: Propulsion System Test Planning and Ground Test Facility Studies

Volume VI: Structural Materials Investigations

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ABSTRACT

This volume presents the results of the materials investigations in support of the Pluto propulsion system effort conducted during calendar year 1962. The nickel base alloys Hastelloy C, X, and R-235; Rene' 41; and Inco 713C were investigated to obtain preliminary design data not available in the literature. The effects of welding and heat treatments on some of these alloys were studied.

This technical documentary report has been reviewed and is approved.

CONTENTS

MAC A473

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

MAC A472

ILLUSTRATIONS (Continued)

TABLES

MAC A 873

TABLES (Continued)

TABLES (Continued)

MAC A673

TABLES (Continued)

1.0 INTRODUCTION

The investigations reported herein were conducted under Air Force Contract AF 33(657)-8123 and are concerned with evaluation of materials potentially considered for propulsion system application at service temperatures ranging from approximately 950° to 1600°F and for periods of approximately 10 hours.

For temperatures below 1200°F, many alloys are available. However, for temperatures above 1200°F, the number of alloys potentially suitable for propulsion system application is quite limited. Of the alloys available for high temperature applications, some are of the solid solution strengthened type requiring simple heat treatments and are relatively easy to weld while others, because of their complicated strengthening mechanisms, require more complicated heat treatments and welding procedures. Hastelloy C and Hastelloy X alloys are of the first class and, in addition, are strongly resistant to oxidation. Hastelloy R-235, Rene' 41, and Inco 713C alloys are of the second class.

Literature surveys revealed, for the materials of interest, that creep-rupture data were not available for periods of less than 10 hours. Therefore, a program was initiated to obtain this design information, and, to set stress values for creep-rupture tests, short time tensile data were obtained. Since portions of the hardware will be fabricated by welding, data for welded material were obtained for design purposes and to determine welding methods and parameters. Since the design values of alloys can be made to vary widely by different heat treatments, by cyclic stresses encountered in testing and in service, and by notches introduced during fabrication, these effects were studied to establish preliminary design data.

Fabrication of intended hardware will require use of materials in the form of sheet, plate, forgings, and possibly castings. Hastelloy C, Hastelloy X, Hastelloy R-235, and Rene' 41 alloys are primarily available for hardware usage in the form of sheet, plate, forgings, and they may be obtained in cast forms if required. Inco 713C is only obtainable in cast forms. Since mechanical design values for each alloy vary significantly with form and fabrication history, material properties were investigated in forms considered potentially useful to establish preliminary design data. Only sheet and/or plate of the first four alloys listed above were investigated, since special requirements for castings of these materials are not currently envisioned due to the availability of Inco 713C.

Many of the short time tensile and creep-rupture data reported were obtained in 1961 but they are again reported here for completeness, since additional work was performed in 1962 to define some of the creep and rupture bands more clearly. Excessive scatter was encountered in earlier testing of welded samples. The investigations of Hastelloy C and Hastelloy X and the notch stress investigations of Hastelloy R-235 and Rene' 41 were performed in 1962. Cyclic materials investigations of Rene' 41 performed during 1962 are presented in Volume IV.

Manuscript released by The Marquardt Corporation on 15 February 1963 for publication as an ASD Technical Documentary Report.

2.0 SUMMARY

The nickel base alloys Hastelloy C, Hastelloy X, and Hastelloy R-235, Rene' 41, and Inco 713C were investigated to establish preliminary design data not available in the literature. Creep-rupture and short time tensile strengths of these alloys were obtained over the temperature range from 1200° to 1800°F for sheet and plate of R-235 and Rene' 41, plate of Hastelloy C, and cast specimens of Inco 713C. Creep-rupture data were obtained for short periods of time ranging from approximately 0.1 to 10 hours.

Investigations were conducted to determine the effects of welding on the creep-rupture and tensile properties of Hastelloy C, Hastelloy R-235, and Rene' 41. In addition, the effects of heat treatments and cyclic temperature under constant stress on Hastelloy C were studied. Tables and graphs are presented to illustrate the data obtained in these studies.

MAC A473

3.0 DISCUSSION

3.1 Mechanical Property Studies

3.1.1 Hastelloy C Alloy

Hastelloy C is a corrosion and oxidation resistant nickel base alloy. It contains chromium, iron, tungsten, and molybdenum as alloying elements. Due to its corrosion resistance, this alloy has found frequent use in the chemical industry. Its elevated temperature strength is obtained through solid solution mechanisms and, hence, it does not require elaborate strengthening heat treatments, which greatly facilitates and reduces the cost of fabricating large items of hardware. However, to put Hastelloy C in its optimum service condition, it is recommended by the alloy manufacturers that the alloy be given a solution anneal at 2225° to 2250°F followed by a rapid cooling. Unfortunately, few large commercial furnaces are available which will reach 2200°F. In addition, although the material had received wide acceptance for several years, it was, surprisingly, found that insufficient technology existed on the welding, forming, and heat treating of this alloy to produce high quality, reliable hardware items designed to meet stringent service requirements up to about 1500°F. It is also known that Hastelloy C is relatively difficult to weld properly, and that sometimes considerable porosity is encountered within welds due to the presence of impurities. These difficulties, it was believed, could be minimized or eliminated by using vacuum melted alloy and by employing proper welding techniques.

Due to the elevated temperature properties of Hastelloy C and its metallurgical stability, it was decided to undertake a study of this alloy to determine its potential as a candidate material for hardware fabrication.

3.1.1.1 Vacuum and Air Melted Alloys

The alloy was obtained as air melted and vacuum melted plate and forgings. The plate, both vacuum and air melted, was 0.25-inch thick; the air melted forging was a 3-inch diameter bar; and the vacuum melted forgings were 0.35-inch diameter bars machined from a forged ring. The vendor's certified chemical composition and room temperature tensile properties of air melted plate are given in Table I. The vendor's certified chemical analysis for vacuum melted plate, weld wire, plus room temperature tensile properties for vacuum melted plate are given in Table II. Comparison of Tables I and II shows that:

1. The relative chemical compositions do not indicate that there is an advantage in vacuum melting, since normally one would expect silicon (Si), phosphorous (P), and Sulphur (S) to be lower in the vacuum melted alloy. Actually, chromium (Cr), tungsten (W), carbon (C), molybdenum (Mo), (Si), (P), and (S) were slightly higher or within the margin of analysis in relation to the air melted material.

MAC A473

2. The mechanical properties of the vacuum melted alloy are comparable to those of the air melted material within the scatter usually found between different heats of the same alloy. The greatest advantage of vacuum melting was found during welding in that there was almost no porosity and very few detectable weld defects (See paragraph 3.1.1.4).

3.1.1.2 Short Time Tensile Studies

The short time tensile properties of air melted Hastelloy C plate tested at room temperature, 1000°, 1200°, 1400°, and 1600°F and of vacuum melted plate at room temperature and 1400°F are presented in Table III. The stress-strain curves for the air melted material are shown in Figure 1. These results indicate that Hastelloy C retains useful engineering strengths up to 1600°F. Comparison of the tensile data in Table III shows that the mechanical properties of the vacuum melted plate at room temperature and 1400°F are equal to those of the air melted material within the range of variation normally encountered.

3.1.1.3 Creep-Rupture Studies

The creep-rupture properties of air melted Hastelloy C at 1200°, 1400°, and 1600°F are given in Table IV and Figures 2 to 7. The creep-rupture properties of the vacuum melted alloy at 1400°F are shown in Table V. These properties fall within the bands of the air melted material plotted in Figure 4. These creep-rupture studies show that Hastelloy C has useful engineering strength levels for times less than 10 hours up to 1600°F. However, at 1600°F the stress levels must be maintained at about 10 ksi or less to prevent total deformations greater than 1% or rupture in 10 hours.

3.1.1.4 Welding Studies

An automatic MIG welding schedule was developed for vacuum melted Hastelloy C as shown in Table VI. A definite advantage was found in welding the vacuum melted stock in that porosity was reduced significantly and there was a marked reduction in inclusions as compared to those in air melted material. The developed schedule was used in welding various groups of test samples which were, in turn, utilized in a fairly comprehensive study to evaluate the effects of variables which might be introduced during hardware fabrication. Tensile properties of base and welded vacuum melted plate at room temperature and 1400°F are given in Tables VII and VIII. For the tests reported in Table VII, all ruptures occurred well outside of the weld zone and the values are, therefore, those of the base material. For the data reported in Table VIII, only one specimen ruptured in the weld and, except for this specimen, all values are essentially those of base material. Table IX and Figure 8 present the results of creep-rupture tests of welded plate. Figure 8 indicates that these results are within the scatter values for vacuum and air melted base plate material.

3.1.1.5 Heat Treatment Studies

The effect of solution annealing at 2050°F, instead of the recommended 2225°F, on the tensile properties of Hastelloy C at room temperature and 1400°F is shown in Table X. Only slight increases in ultimate strength with similar decreases in yield strength, and a definite reduction in elongation were noted. The proportional limit and Young's modulus remained essentially unchanged. This behavior can be ascribed to a slight age hardening effect produced by incomplete solid solubility as a result of annealing at a lower temperature as might be expected. These changes are considered to be within satisfactory limits and they indicate that hardware fabricated from Hastelloy C alloy could be solution annealed at 2050°F instead of 2225°F. This lower temperature would make available for fabrication usage a large number of heat treating furnaces which cannot operate above 2100°F.

Selected welded test specimens were subjected to a final heat treating cycle of 2215°F with 30-minute air cooling and they were subjected to bend tests of 180° at r = 2t (a 180° bend over a radius equal to two times the thickness of the material or a 0.5-inch radius for the specimens tested), and short time tensile tests at 1400°F. The results of these tests are shown in Table XI. The bend tests did not produce cracking and the observed tensile properties at 1400°F are considered comparable to non-heat treated alloy values within a usual scatter range.

The effects of heat treating and cooling cycles on forged cross sections were studied to determine the properties which may be expected in fabricated hardware. The tensile properties which result in a forging as a consequence of various typical manufacturing heat treating cycles are presented in Table XII. None of the cycles produced a significant change in the tensile properties at 1400°F. Only the proportional limit was lowered by about 5000 psi as a result of 2 cycles at 2225°F for 20 minutes, water quenched. The tensile properties for a forging at 1200° and 1400°F, resulting from various water and air cooling cycles, are presented in Table XIII. The data in Table XIII do not indicate any significant change in material properties due to heat treatment.

3.1.1.6 Cyclic Tests

Base metal and welded plate specimens were also subjected to cyclic temperature testing at constant stress. The test consisted of 35 cycles of 5 minutes each at 1400°F under a constant stress of 25.5 Kpsi as schematically illustrated in Figure 9. The heating portion of the cycle from 150° to 1400°F was accomplished in 3 minutes and cooling was accomplished in 5 minutes. The amount of creep deformation of the specimens was measured at 17, 25, and 35 cycles. Tensile properties after cyclic testing were obtained at 1400°F. These results are given in Table XIV.

Creep properties were not changed by cycling when compared to the uncycled alloy. Among the tensile properties, only the proportional limit and the Young's modulus were increased slightly by cycling. The results of cyclic tests performed on the vacuum melted Hastelloy C alloy are summarized in Figure 10. Based on these data, it appears that Hastelloy C, due perhaps to the fact that it is a solid solution strengthening alloy, is insensitive to variations in temperature such as may be encountered during repetitive ground testing of a propulsion system.

3.1.2 Hastelloy X Alloy

Hastelloy X is another member of the Hastelloy family of corrosion and oxidation resistant nickel base alloys. In comparison with Hastelloy C, Hastelloy X is more resistant to oxidation, somewhat weaker in mechanical properties, and it is considered easier to weld and fabricate. Hastelloy X also contains chromium, molybdenum, iron, and tungsten as alloying elements. However, the tungsten and molybdenum content are lower. Hastelloy X, like Hastelloy C, obtains its high temperature strength through solid solution mechanisms. The range of chemical compositions of Hastelloy X is presented in Table XV. Its recommended solid solution temperature is 2150°F. Hastelloy X is generally preferred to Hastelloy C (or Hastelloy B), because of its higher oxidation resistance, easier welding, machining, forming, and lower solution annealing temperature. The principal advantage of Hastelloy C over Hastelloy X is the former's higher mechanical properties. Since this difference becomes less at higher temperatures, the short time tensile and creep-rupture properties of 0.25 inch Hastelloy X plate were evaluated at 1400°F for comparative purposes.

3.1.2.1 Short Time Tensile Properties

The results of tensile tests performed for Hastelloy X are presented in Table XVI. Comparison of Table XVI with Table III for Hastelloy C shows that the proportional limit and 0.2% yield strength are approximately 9 and 5 Kpsi lower, respectively, and the ultimate strength is 7 to 8 Kpsi lower for Hastelloy X at 1400°F.

3.1.2.2 Creep-Rupture Properties

Creep-rupture properties for Hastelloy X are presented in Table XVII and Figure 11. Comparison with Table IV and Figures 4 and 5 for Hastelloy C indicates that Hastelloy X is weaker by about 2 to 3 Kpsi in 10-hour creep for deformations higher than 0.5%, and by approximately 10 Kpsi in 10-hour rupture. At deformations lower than 0.5%, within the range studied, creep values are approximately equivalent. Although more complete studies would be necessary, the above data indicate that Hastelloy X might be used with economic advantage instead of Hastelloy C if sufficient allowances can be made for lower mechanical properties.

3.1.3 Hastelloy R-235 Alloy

Hastelloy R-235 is a nickel base alloy containing chromium, iron, molybdenum, aluminum, and titanium. It has useful engineering strength up to 1800°F and it derives its high temperature strength from solid solution and precipitation mechanisms. The studies conducted during 1962 have provided additional creep-rupture values for welded stock which more clearly define the creep-rupture bands established in 1961 and provide tensile data not previously obtained. All of the work performed in 1961 and 1962 is presented here to make available a complete set of data. The alloy was obtained in the form of 0.072 and 0.063-inch sheet and 0.25-inch plate. Short time tensile, creep-rupture, and notch tensile studies were conducted with base and welded sheet and with plate. Welding schedules were established and welding was performed with and without Hastelloy R-235 alloy filler wire on sheet and with filler wire on plate.

3.1.3.1 Sheet and Plate Material

The vendor's certified chemical analysis and room temperature tensile properties are reported in Tables XVIII and XIX for sheet and plate material, respectively. These property data are comparable within the range of scatter.

3.1.3.2 Short Time Tensile Studies

The short time tensile properties of the alloy were studied at room temperature, 1200°, 1400°, 1600°, and 1800°F. The results are presented in Table XX and Figure 12 for sheet, and Table XXI and Figure 13 for plate. They show that the short time tensile properties of sheet, except for equal Young's Modulus, are higher at all temperatures, and that both forms of the alloy retain useful short time tensile properties up to 1800°F.

3.1.3.3 Creep-Rupture Studies

The creep and rupture properties of sheet and plate materials were studied at 1200°, 1400°, 1600°, and 1800°F. The creep-rupture properties of the sheet are presented in Tables XXII to XXV and Figures 14 to 17, and those of the plate in Tables XXVI to XXIX and Figures 18 to 21. At 1200° and 1400°F, no creep deformations were definable, i.e., the specimens either did not deform in creep or they ruptured, depending on the stress imposed. At 1600° and 1800°F, creep deformation was defined and measurable from 0.1% to 2.0% and rupture bands were established at all temperatures. The creep-rupture strengths for sheet and plate are considered comparable at all stress and temperature levels. The data indicate that the stress levels at 1800°F should be kept below 8 ksi to prevent creep deformations larger than 1% or rupture in 10 hours.

3.1.3.4 Welding Studies

Welding with the use of filler wire as opposed to fusion welding without filler has been used as standard practice in the manufacture of sheet hardware. Filler welding to date is believed to impart better mechanical properties to the fabricated assembly. However, non-filler welding is more desirable from the standpoint of ease of fabrication and lower tendency to induce impurities in the weld. Consequently, a comparative study of these two methods was performed.

The weld schedules developed for automatic TIG welding of sheet without and with filler wire, and of plate with filler wire, are presented in Tables XXX and XXXI, respectively. A tensile evaluation of welded sheet and plate was performed. No significant difference was found between non-filler and filler welds in sheet tested at room temperature, 1200°, 1400°, 1600°, and 1800°F. The tensile properties of welded plate were comparable to those of welded sheet (See Tables XXXII to XXXIV).

Creep-rupture properties at 1200°, 1400°, 1600°, and 1800°F of sheet welded without filler wire are presented in Table XXXV and Figures 22 to 25, and with filler wire in Table XXXVI and Figures 26 to 29. Certain portions of these data were obtained during 1961 but they are included here for completeness. The tests conducted during 1962 were performed to better define creep-rupture bands in times up to 10 hours and to establish preliminary design minimums by choosing lower stress levels at all temperatures. A summary of results for 0.1% creep of filler and non-filler welds and for base material is presented in Figure 30. Review of the data of Figure 30 indicates, within the limits of scatter, that there is no significant advantage of one method of welding over the other with respect to creep properties for sheet. Moreover, the creep strength of the welds appears to be equivalent to that of the base material.

The results of creep tests performed on welded plate at 1200°, 1400°, 1600°, and 1800°F are presented in Table XXXVII and Figures 31 to 34. A summary of results for 0.1% creep of welds and of base material is presented in Figure 35. The creep properties of the welded plate show a tendency to be somewhat lower than those of the base material at 1400°F and 1600°F.

3.1.3.5 Notch Effect Studies

A short series of tests was performed during 1962 on the effects of notches on the short time and 10-hour tensile properties of Hastelloy R-235 sheet. A notch with a stress concentration factor (K_t) of 2.5 was used for short time tensile properties at room temperature, 1200°, and 1600°F and for stress-rupture tests at 1400°F. The results of the short time tensile tests are presented in Table XXXVIII, and those of the stress rupture tests are presented in Table XXXIX. The tests showed an ultimate strength for the notched samples of 0.9 that of unnotched samples and about a 10 Kpsi reduction in 10-hour stress rupture life for the stress concentration factor used.

3.1.4 Rene' 41 Alloy

Rene' 41 is a nickel base alloy with additions of chromium, iron, cobalt, molybdenum, titanium, and aluminum for use at high temperatures. It retains higher strength levels than Hastelloy R-235 up to 1800°F, but it is more difficult to weld and requires a more complicated and lengthy heat treatment. It derives its high temperature strength from solid solution, precipitation, and dispersion mechanisms. The studies performed this year consisted of comparing the data previously obtained with published vendor data and of investigating the effects of cyclic stresses and of notch stress concentration on material properties. The data obtained in 1961 are presented for completeness.

3.1.4.1 Sheet and Plate Material

The vendor's certified chemical analysis of the sheet and plate, together with room temperature tensile properties are presented in Table XL. Their chemical analyses are comparable within a narrow range of variation.

3.1.4.2 Short Time Tensile Studies

The short time tensile properties of Rene' 41 sheet and plate were obtained at room temperature, 1200°, 1400°, 1600°, and 1800°F for 0.064-inch sheet and 5/16-inch plate. The properties are presented in Table XLI and Figure 36 for the sheet and Table XLII and Figure 37 for the plate. The short time tensile properties are considered equivalent at all temperatures.

3.1.4.3 Creep-Rupture Studies

The creep-rupture properties of the sheet and plate material were investigated at 1200°, 1400°, 1600° and 1800°F for periods up to 10 hours. The results of studies with sheet material are presented in Tables XLIII to XLVI and Figures 38 to 41. A summary of these results and comparison with alloy vendor data are presented in Figure 42. Results of studies on plate material are presented in Tables XLVII to L and Figures 44 to 46. The data for both sheet and plate indicate that at 1200°F stresses above the 0.2% yield stress will likely produce rupture in 10 hours, although the creep deformation is slight. Alternatively, stresses below the 0.2% yield value did not produce measurable creep or rupture in 10 hours. At 1400°, 1600°, and 1800°F, creep becomes distinctly measurable. At 1800°F, stress levels above 5 Kpsi will produce creep deformations of 0.5% or more in 10 hours. The creep properties for plate decrease faster than those of sheet up to 1800°F, but both retain useful strength levels at 1800°F for 10-hour applications.

A comparison of stress-rupture data with that of the vendor for 0.063 inch sheet between 1200 and 1800°F is presented in Figures 42 and 43. This comparison shows that the vendor's data are slightly lower at 1200° and 1400°F and slightly higher at 1600° and 1800°F than the values obtained in these studies. The heat treatment used by the vendor is considered significantly different from that used in these studies and may account for the differences which were obtained. Until more extensive heat treatment and creep-rupture studies can be performed, it is recommended that the data reported here be used for short time creep-rupture properties up to 10 hours.

3.1.4.4 Welding Studies

Automatic TIG weld schedules were determined for Rene' 41 sheet with and without filler wire and for plate with filler wire. The schedules developed for sheet and plate are presented in Tables LI and LII, respectively. The results of tensile tests performed at room temperature, 1200°, 1400°, 1600° and 1800°F on sheet welded without filler wire, with filler wire, and on plate are presented in Tables LIII, LIV, and LV, respectively. Fusion welding of sheet (without filler wire) consistently produced better results at all temperatures when compared to those obtained with filler welding.

The short time tensile properties of the welded plate were somewhat higher than those of the base material when Tables LV and XLII are compared. This difference can be attributed to normal material property scatter and is not considered significant. The ductility of the welded plate was not as high as that of the base material. However, welded plate can be used up to 1800°F under short time stresses.

The creep-rupture properties of Rene' 41 sheet welded without filler wire are presented in Table LVI and Figures 47 to 50. Figure 51 presents a comparison of 0.1% creep at 1200°, 1400°, 1600° and 1800°F for sheet parent metal versus fusion welded sheet without use of filler wire. The creep-rupture properties of welded Rene' 41 plate are presented in Table LVII and Figures 52 to 55 for tests conducted at 1200°, 1400°, 1600°, and 1800°F. The 0.1% creep values for welded plate tend to be lower than those of the base material as shown in Figure 55. Adjustments in design values for welded plate structures will have to be made accordingly.

Since fusion welding without introduction of a filler is a more satisfactory production method, it appears from these data that filler wire need not be used in the fabrication of Rene' 41 sheet.

3.1.4.5 Notch Effect Studies

For purposes of providing empirical design data, tensile and creep-rupture tests were performed on notched Rene' 41 sheet. A stress concentration factor (K_t) of 2.5 was used. The results of tensile tests are presented in Table LVIII for room temperature, 1400°, 1600°, and 1800°F. These data indicate that the effect of the imposed stress concentration at room temperature and 1400°F is to decrease the ultimate tensile properties by a factor of 0.1 whereas no decreases in tensile properties were indicated at 1600° and 1800°F. The results of creep-rupture tests at 1400° and 1600°F are presented in Table LIX. These data indicate that the stress rupture characteristics of the material at 1400°F are comparable to those of the base material, whereas the stress-rupture value at 1600°F drops to that value required to produce 0.1% creep in the base material.

3.1.5 Inco 713C Alloy

Inco 713C is a high temperature alloy particularly suitable for employment in cast form. Inco 713C is a nickel base alloy with additions of chromium, molybdenum, iron, titanium, and aluminum. Its high temperature properties are obtained from precipitation of the Ni-Ti-Al phase, carbide formation, and solid solution mechanism, and it has material properties similar to those of Hastelloy R-235 and Rene' 41.

Materials investigations were not performed with this alloy during 1962. However, data previously obtained are presented here for completeness. This alloy was tested in the form of cast test specimens. The vendor's certified chemical analysis and room temperature tensile properties for Inco 713C are presented in Table LX.

3.1.5.1 Short Time Tensile Studies

The results of tensile tests conducted at room temperature, 1200°, 1400°, 1600°, and 1800°F are presented in Table LXI and in Figure 56. The 0.2% yield to ultimate strength margin is less for Inco 713C than for Rene' 41. The ultimate strength for Inco 713C is lower than for Rene' 41 up to 1400°F but higher at 1600° and 1800°F. The elongation of Inco 713C is higher at all temperatures than for Rene' 41. Inco 713C retains useful strength levels up to 1800°F, which is better than any of the other alloys reported herein.

3.1.5.2 Creep-Rupture Studies

The creep and stress rupture values for this alloy were determined at 1200°, 1400°, 1600°, and 1800°F for periods up to 10 hours. The results of these tests are presented in Tables LXII, LXIII, LXIV, and LXV and Figures 57 to 60. The scatter in creep values was large at 1200°F (as shown in Table XLII) but creep times were discernible from times to produce rupture. Because of the scatter, only a rupture band was plotted. The scatter at 1400°, 1600°, and 1800°F was less, and creep and rupture bands were plotted for these temperatures.

When the results for Inco 713C are compared with data for Rene' 41 plate, it is seen that the rupture values for Inco 713C are slightly higher, but that the creep values are equal or slightly lower at all temperatures. These data indicate that Inco 713C retains sufficient strength for use up to 1800°F but that operating stress levels will have to be maintained below 15 Kpsi at 1800°F for a 0.5% creep deformation or less.

The results to date for Inco 713C have shown considerable scatter in the creep and rupture properties indicating that a much larger number of samples than those tested here would be required to establish final design data.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Hastelloy C is an alloy which retains useful engineering strengths up to 1600°F. Where extremely high quality welds are desired, vacuum melted stock should be used. However, no particular advantage is obtained with respect to the short time tensile or creep-rupture strengths by vacuum re-melting.

From the limited data reported herein for Hastelloy X and from the available literature, it appears that Hastelloy X can be used in lieu of Hastelloy C whenever lower design stress values can be accepted. Hastelloy X has an advantage in that it is easier to fabricate and weld than Hastelloy C. Both alloys (Hastelloy C and Hastelloy X) however, are easier to weld and fabricate then Rene' 41 and R-235.

Hastelloy R-235, Rene' 41, and Inco 713C retain useful engineering strengths up to 1800°F and they can be used up to that temperature provided that care is exercised in choosing creep-rupture and short time tensile design values.

Some differences in stress values for R-235 and Rene' 41 were encountered when comparing sheet with plate forms of the same sheet alloy showing generally higher values. Welding of the sheet and plate did not produce significant decreases in strength levels from those of the base material. However, a 90% efficiency number for welded structures is recommended based on some lowering of creep values. Fusion welding of R-235 and Rene' 41 sheet can be used successfully for hardware manufacture.

Hastelloy C proved rather insensitive to a variety of heat treatments and to limited cyclic tests, which is an asset in manufacture and hardware reliability.

TABLE I

CERTIFIED VENDOR REPORT FOR AIR MELTED HASTELLOY C 0.250-INCH PLATE

(Heat No. CI-3571)

CHEMICAL COMPOSITION

Cr	W	Fe	C	Si	Co	Mn	V	Mo	P	S	Ni
15.20	3.22	5.94	0.05	0.54	1.60	0.50	0.22	16.12	0.004	0.006	Bal.

ROOM TEMPERATURE TENSILE PROPERTIES
(As Received)

Ultimate Tensile Strength (psi)	0.2% Yield Strength (psi)	Elongation in 2 in. (%)
119,500	56,900	54.0

MAC A673

TABLE II

CERTIFIED VENDOR CHEMICAL ANALYSIS OF VACUUM MELTED HASTELLOY C

Chemical Composition	Cr	W	Fe	C	Si	Co	Ni	Mn	V	Mo	P	S	Cu
Welding Wire													
C1-3101 E	15.10	3.15	6.30	0.07	0.34	1.37	Bal.	0.40	0.19	16.20	0.007	0.006	0.05
C1-3102 E	14.84	3.99	6.25	0.05	0.45	1.45	Bal.	0.49	0.31	15.82	0.007	0.006	0.02
1/4-inch Plate													
C1-3103 E	15.59	4.00	5.50	0.06	0.59	1.24	Bal.	0.40	0.22	16.82	0.009	0.008	--
Forging													
C1-3106 E	15.09	3.86	6.04	0.05	0.45	1.47	Bal.	0.39	0.22	15.68	0.008	0.007	--

CERTIFIED ROOM TEMPERATURE TENSILE PROPERTIES FOR VACUUM MELTED 1/4-INCH PLATE (As Received)

Ultimate Tensile Strength (psi)	0.2% Yield Strength (psi)	Elongation in 2 in. (%)
121,900	58,000	50.0

TABLE III

SHORT TIME TENSILE PROPERTIES OF AIR MELTED HASTELLOY C PLATE

Material - 0.250 in. thick plate
Heat number - CI-3571
Heat treatment - As received
Heating method - Resistance
Test atmosphere - Air
Strain rate - 0.001 in./in./sec to yield
- 0.01 in./in./sec to rupture
Hold time - 15 min

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% YS (Kpsi)	UTS (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)
59F	RT	30.0	57.5	115.6	58	28.6
60F	1000	27.5	37.3	92.3	53	25.0
61F	1200	26.8	37.0	85.2	53	28.2
62F	1400	27.0	33.3	67.9	44	21.6
63F	1600	28.0	32.2	55.3	43	22.0

(Based on one sample at each temperature)

SHORT TIME TENSILE PROPERTIES OF VACUUM MELTED HASTELLOY C PLATE

Test machine - Marquardt TM-1
Heating - Resistance
Hold time - 15 min
Strain rates - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Atmosphere - Air
Gage length - 2 ins.
Heat treatment - 3 cycles, 2225°F, 20 minutes, AC

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% YS (Kpsi)	UTS (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)
887F	RT	27.5	50.3	116.0	41	28.9
888F	RT	28.1	51.3	117.0	45	28.1
889F	1400	22.5	31.0	75.0	48	20.8
890F	1400	21.5	30.0	74.9	48	20.1

(Based on one sample at each temperature)

TABLE IV

CREEP-RUPTURE PROPERTIES OF AIR MELTED HASTELLOY C PLATE

Material - 0.250 in. thick plate
Heating - Resistance
Gage length - 1.5 ins.
Heat number - CX-5571
Heat treatment - As received

Specimen Number	Test Temp. (°F)	Creep Stress (Kpsi)	Loading Strain* (%)	Time to Produce Indicated Creep (hours)								Time to Rupture (hours)	Elongation (%)
				0.05%	0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	10%		
948E	1200	50	6.7	0.07	0.85	1.42	3.30	6.92	13.3	22.8	--	27.8	25
949E	1200	65	9.0	--	--	--	--	0.01	--	--	--	--	--
950E	1200	45	5.8	0.17	0.57	1.47	3.57	8.82	16.5	30.0	--	--	--
951E	1200	40	1.6	5.00	9.00	13.9	39.2	46.9	78.0	132.0	--	--	--
952E	1400	45	2.8	--	0.01	0.02	0.07	0.12	0.22	0.45	--	--	--
953E	1400	40	2.8	--	0.01	0.02	0.12	0.28	0.50	0.43	2.12	3.9	33
954E	1400	35	0.5	0.03	0.07	0.15	0.35	0.60	0.97	1.67	3.63	--	--
955E	1400	30	0.13	0.02	0.13	0.57	1.17	1.82	2.92	5.10	10.7	--	--
54F	1400	30	0.12	0.15	0.23	0.58	1.08	1.53	2.39	3.67	6.20	--	--
55F	1400	25	0.08	0.18	0.33	0.77	1.76	2.96	5.51	11.1	30.6	--	--
56F	1400	25	0.05	0.37	0.62	1.02	1.75	2.90	4.81	8.9	19.8	46.6	49
57F	1400	20	0.01	1.57	2.53	5.09	4.75	--	--	--	--	--	--
58F	1400	20	--	0.33	0.97	1.91	3.96	7.8	13.8	26.9	--	--	--
956E	1600	25	0.6	--	0.01	0.02	0.03	0.05	0.09	0.18	0.40	0.75	35
957E	1600	20	0.14	0.01	0.02	0.05	0.10	0.17	0.30	0.53	1.10	2.20	37
958E	1600	15	0.05	0.03	0.08	0.13	0.35	0.57	1.07	2.00	4.72	--	--
959E	1600	10	0.01	0.93	2.47	0.85	1.83	4.00	8.6	25.0	--	--	--
50F	1600	20	0.20	0.02	0.03	0.07	0.10	0.17	0.39	0.53	1.10	--	--
51F	1600	12.5	0.05	0.02	0.12	0.23	0.55	1.02	1.83	3.35	7.3	9.1	25
52F	1600	6	0.01	0.23	0.58	1.62	3.75	7.8	20.6	--	--	--	--
53F	1600	6	0.02	1.15	2.38	5.75	11.2	--	--	--	--	--	--

* Strain resulting after applying load to heated specimen stabilized at test temperature.

TABLE V

CREEP-RUPTURE PROPERTIES OF VACUUM MELTED HASTELLOY C PLATE AT 1400°F

Test machine - Resistance heated, arc weld, creep
Gage length - 1.5 ins.
Atmosphere - Air
Heat treatment - 3 cycles, 2225°F, 20 minutes, AC
Material - Vacuum melt, 0.250 in. plate

Specimen Number	Test Temperature (°F)	Creep Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Creep (hours)								Time to Rupture (hours)	Elongation in 1.5 in. (%)
				0.05%	0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	5.0%		
884F	1400	25.5	0.05	0.35	0.75	1.2	2.3	2.9	4.6	7.7	9.2	30.1	37
885F	1400	25.5	0.10	1.2	1.5	2.0	2.8	3.9	5.8	9.2	10.9	150.7	52
886F	1400	25.5	0.15	0.65	1.5	2.4	3.7	5.1	7.6	12.3	15.2	67.6	40

TABLE VI

MIG WELDING SCHEDULE FOR HASTELLOY C

Material - Vacuum melted, 0.250-in. Hastelloy C Plate

Vaccum melted, 1/32-in. diameter Hastelloy C Weld Wire

Type of Groove	Passes	Amps	Travel in./min	Wire Feed in./min	Voltage	Shield Gas		
						Torch	Trailing	Back Up
V (60° included angle)						He	A	A
	1st	230	30	800	36	50 CFH	25 CFH	20 CFH
	2nd	230	30	800	40	50 CFH	25 CFH	20 CFH

TABLE VII

TENSILE PROPERTIES OF TRANSVERSE WELDED VACUUM MELTED HASTELLOY C PLATE

Test machine - Marquardt TM-1
Heating - Resistance
Hold time - 15 min
Atmosphere - Air

Strain rates - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Gage length - 2 ins.
Heat treatment - 3 cycles, 2225°F, 20 minutes, AC

Specimen Number	Test Temp. (°F)	Prop. Limit (Kpsi)	Yield Strength (Kpsi)	Ultimate Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)	Fracture Location
825F	RT	35.0	52.7	122.5	49	29.4	0.5 in. from center of weld, Parent Metal
826F	RT	30.0	54.0	121.0	47	31.5	0.5 in. from center of weld, Parent Metal
827F	RT	36.0	52.3	116.0	48	30.0	0.5 in. from center of weld, Parent Metal
828F	1400	23.0	29.6	75.5	43	23.7	0.5 in. from center of weld, Parent Metal
829F	1400	19.0	28.4	77.0	47	21.5	0.4 in. from center of weld, Parent Metal
830F	1400	19.0	29.0	75.0	45	22.0	0.5 in. from center of weld, Parent Metal

PARENT METAL VACUUM MELTED HASTELLOY C PLATE

Specimen Number	Test Temp. (°F)	Prop. Limit (Kpsi)	Yield Strength (Kpsi)	Ultimate Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)	Fracture Location
887F	RT	27.5	50.3	116.0	41	28.9	--
888F	RT	28.1	51.5	117.0	48	28.1	--
889F	1400	22.5	31.0	75.0	48	20.8	--
890F	1400	21.5	30.0	74.9	48	20.1	--

TABLE VIII

TENSILE PROPERTIES OF VACUUM MELTED HASTELLOY C PLATE AND TRANSVERSE WELDS

Heat treatment - 2225°F, 20 min, AC
3 cycles
Aged - 1400°F, 3 hrs, AC
Heating - Resistance
Material - Vacuum melted 0.250 in. plate
Hold time - 15 min
Gage length - 2 ins.
Atmosphere - Air
Strain rate - 0.001 in./in./sec to yield
0.05 in./in./sec to rupture
Test machine - TM-1

Specimen Number	Specimen Type	Test Temp. (°F)	Prop. Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)	Fracture Location
855AP	Weld	RT	26.0	53.9	115.0	40	27.2	0.6 in. from center of weld
(Average of 3 welds*)		RT	33.6	55.0	119.8	48	30.3	0.6 in. from center of weld
891F	Parent	RT	28.0	56.0	113.0	45	27.5	--
(Average of 2 parent*)		RT	27.8	50.8	116.5	45	28.5	--
855P	Weld	1400	18.5	29.0	74.1	36	20.4	In weld
(Average of 3 welds*)		1400	20.3	29.0	75.8	45	22.6	0.5 in. from center of weld
829P	Parent	1400	19.4	32.0	89.5	53	22.2	--
(Average of 2 parent*)		1400	22.0	30.5	75.0	48	20.4	--

* No 1400°F aging

TABLE IX

CREEP-RUPTURE PROPERTIES OF TRANSVERSE WELDED HASTELLOY C PLATE

Material - Vacuum melt, 0.250-in. plate
Test machine - Resistance heated, arc weld, creep frame
Gage length - 1.5 in.
Atmosphere - Air
Heat treatment - 3 cycles, 2225°F, 20 minutes AC

Specimen Number	Test Temp. (°F)	Creep Stress (Ksi)	Thermal Expansion (%)	Loading Strain* (%)	Time to Produce Indicated Creep (hours)					Time to Rupture (hours)	Elongation (%)
					0.1%	0.2%	0.5%	1.0%	2.0%		
831F	1425	25.5	0.98	0.27	0.37	0.6	1.05	1.62	2.58	15.3	27
832F	1425	25.5	0.93	0.15	0.33	0.6	1.02	1.55	2.4	12.4	24
833FA	1400	25.5	1.1	0.10	0.70	1.15	1.8	2.85	4.62	24.4	25
835F	1400	25.5	1.07	0.10	0.58	0.98	1.8	2.5	4.7	36	60
831FA	1400	25.5	1.05	0.15	1.2	2.55	4.1	6.0	9.4	69	37

* Strain resulting after applying load to heated specimen stabilized at test temperature.

TABLE X

TENSILE PROPERTIES OF AIR MELTED 0.250-INCH HASTELLOY C PLATE

Heating - Resistance
Hold time - 15 min
Strain rate - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Gage length - 2 ins.
Atmosphere - Air

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)	Heat Treatment
[illegible]	RT	22.4	56.1	116.4	60	27.0	As received
[illegible]	RT	24.8	55.2	125.5	39	29.3	2050°F, 2 hrs, AC
219P	RT	25.3	55.0	124.3	34	28.0	2050°F, 2 hrs, AC
217P	1400	26.0	38.0	82.1	58	23.0	As received
220P	1400	25.2	34.9	90.0	39	20.9	2050°F, 2 hrs, AC
221P	1400	26.1	36.0	90.1	40	21.8	2050°F, 2 hrs, AC

TABLE XI

TENSILE AND BEND TEST CONTROLS FOR
FINAL HEAT TREATMENT OF WELDED 0.250-INCH HASTELLOY C PLATE ASSEMBLY

Specimens - Vacuum melted, 0.250 in. thick plate from same plate nozzle was manufactured from
Heat treatment - 2215°F, 30 min, AC

BEND TESTS

Specimen Number	Test Temperature	Bend Radius	Bend Angle	Remarks
93G	RT	2 x Thickness (0.500 in.)	180°	No cracking
94G	RT	2 x Thickness (0.500 in.)	180°	No cracking
95G	RT	2 x Thickness (0.500 in.)	180°	No cracking
96G	RT	2 x Thickness (0.500 in.)	180°	No cracking

Atmosphere - Air
Heating - Resistance
Gage length - 2 ins.
Strain rate - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Hold time - 15 min

TENSILE TESTS

Specimen Number	Type	Test Temp. (°F)	Prop. Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)
97G	Weld	1400	25.0	35.0	80.9	31	23.0
98G	Weld	1400	--	34.3	78.0	40	20.2
99G	Parent	1400	21.0	31.0	79.4	50	22.5
100G	Parent	1400	22.6	33.2	84.2	48	22.3

MAC A457

TABLE XII

HEAT TREAT TENSILE PROPERTIES OF VACUUM MELTED HASTELLOY C BAR FROM RING FORGING

Specimen - Round bar, 0.357-in. reduced section diameter
Atmosphere - Air
Heating - Resistance
Hold time - 5 min
Strain rate - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Gage length - 1.5 in.

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 1.5 in. (%)	Young's Modulus (10^6 psi)
103G	1400	21.8	29.0	70.2	49	19.9
104G	1400	19.1	28.5	73.5	53	21.0
	Heat treatment: 2 cycles, 2225°F, 20 minutes, AC					
105G	1400	16.0	28.1	75.1	48	19.0
106G	1400	15.0	27.3	--	--	20.4
	Heat treatment: 2 cycles, 2225°F, 20 min, AC + 1 cycle, 2225°F, 20 min, WQ					
107G	1400	21.7	28.9	73.3	51	19.1
108G	1400	20.0	29.0	74.8	52	20.1
	Heat treatment: 2 cycles, 2225°F, 20 min, AC + 1 cycle, 1500°F 1 hr, AC					
109G	1400	22.0	30.0	75.1	50	19.3
	Heat treatment: 2 cycles, 2225°F, 20 min, AC + 1 cycle, 2225°F, 20 min, WQ + 1 cycle, 1500°F, 1 hr, AC					

TABLE XIII

EFFECT OF QUENCHING RATES ON THE TENSILE PROPERTIES OF VACUUM MELTED HASTELLOY C ROUND BARS FROM RING FORGING

Specimen - Round bar, 0.350-in. reduced section diameter
Atmosphere - Air
Heating - Resistance
Hold time - 5 min
Strain rate - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture

Specimen Number	Heat Treat Temperature (°F)	Cooling Rate	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 1 in. (%)	Young's Modulus (10^6 psi)
35G	2225	Flange WQ	1200	19.0	28.5	--	--	24.6
39G	2225	Flange WQ	1200	---	25.0	--	--	24.0
38G	2225	Flange WQ	1200	20.4	27.3	80.5	69	23.4
41G	2225	Flange WQ	1200	21.6	27.1	79.3	67	24.1
37G	2225	Flange AC	1200	17.5	28.0	80.0	59	22.0
40G	2225	Flange AC	1200	19.9	28.8	79.0	59	21.0
44G	2225	Direct WQ	1200	15.2	30.3	83.6	60	22.0
78G	2100	Flange WQ	1200	18.2	28.0	82.9	65	23.1
79G	2100	Flange AC	1200	19.0	28.9	80.0	53	20.3
42G	2225	Flange WQ	1400	17.5	28.1	74.5	68	22.5
45G	2225	Flange WQ	1400	20.0	30.0	75.9	52	22.1
43G	2225	Flange AC	1400	18.0	28.0	74.0	60	21.5
46G	2225	Flange AC	1400	16.0	27.2	72.0	62	23.0
44AG	2225	Direct WQ	1400	17.0	29.0	73.1	60	21.9
80G	2100	Flange WQ	1400	20.0	29.0	75.9	58	21.7
81G	2100	Flange AC	1400	19.8	29.0	74.5	58	21.5

TABLE XIV

CYCLIC TESTS FOR VACUUM MELTED HASTELLOY C PLATE

Test conditions - 35 cycles - 150°F to 1400°F in 3 min,
Hold at 1400°F ±50°F for 5 min,
Cool to 150°F in 5 min

Stress - 25.5 Kpsi maintained on specimen throughout entire 35 cycles

Material - Vacuum melted Hastelloy C 0.250 in. plate

Gage length - 2 ins.

Atmosphere - Air

Heat treatment - 3 cycles, 2225°F, 20 min, AC

Specimen Number	Type	Creep Deformation		
		17 cycles (85 min) (1.42 hr)	25 cycles (125 min) (2.08 hr)	35 cycles (175 min) (2.92 hr)
851F	Welded	0.23%	0.29%	0.3%
852F	Welded	0.21	0.36	0.64
893F	Parent	0.17	0.22	0.3
894F	Parent	0.18	0.20	--

TENSILE PROPERTIES AFTER CYCLIC EXPOSURE

Hold time - 5 min
Strain rate - 0.001 in./in./min to yield
0.01 in./in./min to rupture

Specimen Number	Type	Test Temp. (°F)	Prop. Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)	Fracture Location
851F	Welded	1400	23.1	31.5	69.7	42	20.4	Parent Metal-0.34 in. from center weld
852F	Welded	1400	25.0	34.5	73.2	43	20.0	Parent Metal-0.5 in. from center weld
893F	Parent	1400	26.3	32.9	75.6	50	24.9	--

TABLE XV

RANGE OF CHEMICAL COMPOSITION OF HASTELLOY X

Ni	Co	Cr	Mo	W	Fe	C	Si	Mn
Balance	0.5-2.5	20.5-23.0	8.0-10.0	0.2-1.0	17.0-20.0	0.05-0.15	1.0 Max.	1.0 Max.

MAC 4673

TABLE XVI

SHORT TIME TENSILE STRENGTH OF HASTELLOY X PLATE

Material - Hastelloy X, 0.250 in. plate
Condition - As received
Heating method - Resistance
Atmosphere - Air
Gage length - 2.0 ins.
Strain rate - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Hold time - 15 min
Test sample - Per Dwg. X14281

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation at UTS (%)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)
973F	1400	18.0	28.9	59.0	19	41	19.9
974F	1400	17.5	28.2	61.1	24.9	42	19.6
975F	1400	19.0	28.1	62.0	27.9	42	19.5
	Average at 1400°	18.1	28.4	60.7	23.9	41.6	19.7

TABLE XVII

CREEP-RUPTURE PROPERTIES OF HASTELLOY X PLATE

Material - 0.250 in. plate, as received
Heating - Resistance
Gage length - 1.5 ins.
Atmosphere - Air

Specimen Number	Test Temp. (°F)	Creep Stress (Kpsi)	Time to Produce Indicated Creep (hours)								Time to Rupture (hrs)	Elongation in 1.5 in. (%)
			0.05%	0.1%	0.2%	0.5%	1.0%	2.0%	3.0%	5.0%		
446F	1400	21	0.75	1.0	1.5	2.9	5.1	10.4	--	--	64.0	10*
447F	1400	21	0.7	1.1	1.7	3.7	13.0	--	--	--	70.0	11*
451F	1400	21	0.2	0.45	0.95	2.2	4.6	11.8	20.6	33.3	69.2	26*
--	1400	21	0.4	0.7	1.2	2.6	5.2	12.8	20.5	33.2	69.1	25*
448F	1400	27.5	0.25	0.35	0.6	0.9	1.5	--	--	--	12.7	13*
449F	1400	27.5	0.15	0.25	0.45	0.8	1.3	--	--	--	9.1	11*
978F	1400	14	0.55	1.1	2.1	6.4	23.7	76.8	--	--	--	--
977F	1400	14	0.55	1.4	3.2	10.1	40.3	--	--	--	--	--

* Specimen broke outside gage marks.

TABLE XVIII

CERTIFIED VENDOR CHEMICAL COMPOSITION AND ROOM TEMPERATURE TENSILE PROPERTIES OF R-235 ALLOY SHEET

CHEMICAL COMPOSITION
OF R-235 ALLOY SHEET
(HEAT RV-7304)

Cr	Fe	Mo	Al	Ti	Co	Si	Mn	P	S	B	C	Ni
14.94	9.65	5.41	1.90	2.52	0.14	0.10	0.02	0.001	0.011	0.005	0.13	Balance

ROOM TEMPERATURE TENSILE PROPERTIES
OF R-235 ALLOY SHEET
(HEAT RV-7304)

Sheet Thickness (in.)	Ultimate Tensile Strength (psi)	0.2% Yield Strength (psi)	Elongation in 2.0 in. (%)
0.072	139,500	82,300	32

TABLE XIX

CERTIFIED VENDOR CHEMICAL COMPOSITION AND ROOM TEMPERATURE TENSILE PROPERTIES OF R-235 ALLOY PLATE

(Heat No. RV 7498)

CHEMICAL COMPOSITION

Cr	Fe	Mo	Al	Ti	Co	C	S	Mn	Si + P	B	Ni
15.63%	10.06	5.39	1.96	2.58	0.70	0.15	0.010	0.03	0.25	0.04	Balance

ROOM TEMPERATURE TENSILE PROPERTIES

Plate Thickness (in.)	Ultimate Tensile Strength (psi)	0.2% Yield Strength (psi)	Elongation in 2.0 in. (%)
0.25	143,800	79,500	39

MAC A673

TABLE XX

SHORT TIME TENSILE STRENGTH OF R-235 ALLOY SHEET

Material - Heat No. RV 7304
Condition - Aged at 1600°F for 30 min
Thickness - 0.072 in.
Heating method - Resistance
Test atmosphere - Air
Gage length - 2.0 in.
Strain rate - 0.001 in./in./sec to yield
- 0.01 in./in./sec to rupture
Hold time - 15 min

Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)
RT	89.0	103.0	167.0	27.5	31.0
1200	88.0	97.0	140.0	30.0	25.0
1400	94.0	107.0	133.0	7.5	24.0
1600	63.0	88.0	98.0	2.5	20.0
1800	26.0	30.0	40.7	15.0	15.6

MAC A473

TABLE XXI

SHORT TIME TENSILE STRENGTH OF R-235 ALLOY SHEET

Material	- Heat No. 7498
Condition	- 2200°F for 15 min, WQ
	- 2050°F for 30 min, AC
Thickness	- 0.250 in.
Heating method	- Resistance
Test atmosphere	- Air
Gage length	- 2.0 in.
Strain rate	- 0.001 in./in./sec to yield
	0.01 in./in./sec to rupture
Hold time	- 15 min

Test Temperature (°F)	Proporitonal Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)
RT	70	94.2	156.3	33	31.5
1200	60	84.3	106.0	24.5	26.0
1400	62	82.0	104.7	10	24.0
1600	54	72.9	83.0	9.5	21.0
1800	14	14.8	25.1	34.5	13.5

MAC 4673

TABLE XXII

1200°F CREEP TEST RESULTS FOR R-235 ALLOY SHEET

Material - Heat No. RU 7304
Condition - Aged at 1600°F for 30 min
Thickness - 0.072 in.
Heating method - Resistance
Gage length - 1.5 in.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1%	2%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation After Rupture (%)
30	0.10	--	--	--	--	--	949	None	--	--
40	0.12	--	--	--	--	--	1208	None	--	--
50	0.23	--	--	--	--	--	1282	None	--	--
60	0.28	--	--	--	--	--	750	None	--	--
70	0.30	--	--	--	--	--	--	--	2194	2
70	0.28	--	--	--	--	--	1322	None	--	--
80	0.35	--	--	--	--	--	1258	None	--	--
80	0.31	--	--	--	--	--	1035	None	--	--
90	0.33	--	--	--	--	--	1358	None	--	--
90	0.38	--	--	--	--	--	--	--	1130	2
100	1.50	--	--	--	--	--	--	--	422	2
100	1.50	--	--	--	--	--	--	--	387	--
100	1.50	402	--	--	--	--	--	--	423	--
110	2.75	0.5	2	--	--	--	--	--	80	3.5
110	2.77	0.5	6	--	--	--	--	--	69	5.0
110	2.78	0.5	1.5	44	--	--	--	--	48	4.0

TABLE XXIII

1400°F CREEP TEST RESULTS FOR R-235 ALLOY SHEET

Material - Heat No. HV 7304
Condition - Aged at 1600°F for 30 min
Thickness - 0.072 in.
Heating method - Resistance
Gage length - 1.5 ins.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (Min) 0.1%	0.2%	0.5%	1%	2%	Test Discontinued Time (min)	Test Discontinued Elongation in 1.5 in. (%)	Specimen Failed Time (min)	Specimen Failed Specimen Elongation after Rupture (%)
40	0.19	378	--	--	--	--	1189	0.17	--	--
40	0.13	181	1020	--	--	--	1317	0.22	--	--
40	0.19	420	--	--	--	--	891	0.17	--	--
45	0.23	617	--	--	--	--	--	--	1161	2
50	0.19	740	--	--	--	--	--	--	1072	1.8
50	0.21	1575	--	--	--	--	1680	0.11	--	--
50	0.24	1106	--	--	--	--	--	--	1106	--
55	0.25	100	--	--	--	--	--	--	141	2.5
60	0.26	--	--	--	--	--	--	--	51	2

TABLE XXIV

1600°F CREEP TEST RESULTS FOR R-235 ALLOY SHEET

Material - Heat No. RV 7304
Condition - Aged at 1600°F for 30 min
Thickness - 0.072 in.
Heating method - Resistance
Gage length - 1.5 ins.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1%	2%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
10	0.07	485	--	--	--	--	495	0.10	--	--
20	0.14	17	180	2194	4575	--	5378	1.4	--	--
20	0.13	34	304	--	--	--	562	0.23	--	--
20	0.12	40	298	--	--	--	1238	0.33	--	--
20	0.10	35	171	1280	--	--	1281	0.5	--	--
25	0.15	16	214	622	950	1205	--	--	1228	3
25	0.16	15	228	--	--	--	680	0.47	--	--
25	0.16	9	204	701	--	--	702	0.50	--	--
30	0.17	10	38	179	318	428	--	--	439	4
30	0.19	8	45	181	373	--	--	--	451	3
30	--	--	--	--	--	--	--	--	630	4
37	0.21	5	15	62	110	--	--	--	124	1.4
40	0.24	9	19	39	61	--	--	--	91	1.7
42.8	0.26	4	8	19	31	--	--	--	32	1.2

TABLE XXV

1800°F CREEP TEST RESULTS FOR R-235 ALLOY SHEET

Material - Heat RV 7304
Condition - Aged at 1600°F for 30 min
Thickness - 0.072 in.
Heating method - Resistance
Gage length - 1.5 ins.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1%	2%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
5	0.03	190	1290	--	--	--	1297	0.20	--	--
5	0.02	220	--	--	--	--	910	0.13	--	--
5	0.02	697	4100	--	--	--	5683	0.35	--	--
10	0.06	4	37	161	234	304	425	12	--	--
10	0.06	40	90	168	217	256	290	10	--	--
10	0.04	7	50	356	651	740	1170	7	--	--
20	0.10	0.2	0.2	1.5	3	5.5	--	--	9	8
20	0.13	0.1	0.5	1.5	4	8	--	--	17	10
20	0.16	1	2	4.5	8	12	--	--	23	10

TABLE XXVI

1200°F CREEP TEST RESULTS FOR R-235 ALLOY PLATE

Material - Heat No. RV 7498
Condition - 2200°F for 15 min, WQ
2050°F for 30 min, AC
Thickness - 0.250 in.
Heating method - Resistance
Gage length - 1.5 ins.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min) 0.1%	0.2%	0.5%	1%	2%	Test Discontinued: Time (min)	Test Discontinued: Elongation in 1.5 in. (%)	Specimen Failed: Time (min)	Specimen Failed: Specimen Elongation after Rupture (%)
70	0.27	--	--	--	--	--	1259	None	--	--
70	0.26	--	--	--	--	--	1364	None	--	--
75	0.33	1137	1144	--	--	--	--	--	1149	1
75	0.27	--	--	--	--	--	1146	None	--	--
80	0.8	1238	1242	--	--	--	--	--	1242	3
80	0.5	946	952	--	--	--	--	--	952	3
85	1.9	428	430	--	--	--	--	--	432	5
90	**	158	160	--	--	--	--	--	162	6
90	**	435	436	--	--	--	--	--	437	7
100	*	--	--	--	--	--	--	--	0.5	7

* Not measurable because of rapid failure.

** Not measured; too large to measure on chart (4%).

TABLE XXVII

1400°F CREEP TEST RESULTS FOR R-235 ALLOY PLATE

Material - Heat No. RV 7498
Condition - 2200°F for 15 min, WQ
2050°F for 30 min, AC
Thickness - 0.250 in.
Heating method - Resistance
Gage Length - 1.5 ins.
Atmosphere - Air

Stress (Ksi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1%	2%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
35	0.12	--	--	--	--	--	4000	0.03	--	--
40	0.14	--	--	--	--	--	1104	0.08	--	--
40	0.15	--	--	--	--	--	1459	0.04	--	--
40	0.16	--	--	--	--	--	1272	0.02	--	--
50	0.20	1220	--	--	--	--	1351	0.18	--	--
50	0.22	3010	--	--	--	--	1542	0.13	--	--
55	0.22	--	--	--	--	--	--	--	418	*
55	0.24	900	1110	--	--	--	--	--	1187	3
60	0.25	271	278	--	--	--	--	--	288	3
60	0.30	--	--	--	--	--	--	--	108	*

TABLE XXVIII

1600°F CREEP TEST RESULTS FOR R-235 ALLOY PLATE

Material - Heat No. RV 7498
Condition - 2200°F for 15 min, WQ
2050°F for 30 min, AC
Thickness - 0.250 in.
Heating method - Resistance
Gage length - 1.5 inch
Test atmosphere - Air

Stress (Ksi)	Loading Strain (%)	Time to Produce Indicated Amount of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.2%	0.3%	0.5%	1%	2%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
15	0.04	--	--	--	--	--	4228	None	--	--
20	0.07	3540	--	--	--	--	1449	0.18	--	--
20	0.06	610	1227	--	--	--	1467	0.24	--	--
20	0.05	1130	--	--	--	--	1260	0.15	--	--
30	0.14	75	152	345	530	735	--	--	861	8
30	0.14	40	105	260	416	581	--	--	720	8
30	0.16	72	139	214	328	460	--	--	550	9
40	0.21	5	11	25	41	63	--	--	88	9
40	0.19	12	21	37	56	76	--	--	83	5

TABLE XXIX

1800°F CREEP TEST RESULTS FOR R-235 ALLOY PLATE

Material - Heat No. RV 7498
Condition - 2200°F for 15 min, WQ
2050°F for 30 min, AC
Thickness - 0.250 in.
Heating method - Resistance
Gage length - 1.5 in.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1%	2%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
5	0.01	105	316	439	532	651	--	--	1008	22
5	0.04	165	360	565	760	1005	--	--	1866	20
5	0.02	424	623	962	--	--	1210	0.97	--	--
7.5	0.04	18	46	92	131	174	--	--	357	15*
7.5	0.05	64	143	258	320	395	--	--	627	24
7.5	0.07	34	60	93	122	155	--	--	316	18*
10	0.08	2	4	8.5	13	20	--	--	36	21
10	0.08	--	0.5	1.5	4	8	--	--	32	22
15	0.10	--	--	--	5.5	8.5	--	--	14	23
20	0.47	--	--	--	--	--	--	--	1	26

* Specimen not completely broken.

TABLE XXX

WELDING SCHEDULE FOR
0.064-INCH R-235 ALLOY SHEET

Material	Filler Wire	Speed (ipm)	Current (amperes)	Voltage	Wire Feed (ipm)	Electrode Diameter (in.)
R-235 Sheet	None	28	95	14	--	3/32
R-235 Sheet	0.040-in. dia R-235	26	180	13	16	3/32

All welding was performed on the Berkeley-Davis automatic machine using helium gas to protect the top of the welds and argon gas for back-up. A special trailing cup was used to give added gas protection, and a wet rag was applied behind the trailing cup during welding to serve as a quick quench. All panels were roll planished after welding and dye checked.

TABLE XXXI

TIG WELDING SCHEDULE FOR 0.250-INCH R-235 ALLOY PLATE

Material	Welding Pass	Filler Wire	Welding Speed (ipm)	Current (amperes)	Voltage	Electrode All Passes
R-235 Plate	1	None	15	175	11	3/32 in. diameter, 1% thoriated tungsten
	2	1/16 in. dia R-235	15	275	11.5	
	3	1/16 in. dia R-235	15	300	11.5	
	4	1/16 in. dia R-235	15	310	11.5	
	5	1/16 in. dia R-235	15	300	11.5	
	6	None	15	250	11	

NOTES:

1. Material cleaned in an alkaline solution followed by M.E.K. prior to welding.

2. Copper hold down and back-up bars were used.

3. All welding was performed on a Berkeley-Davis automatic welding machine (WL-777) using helium gas for torch side protection and argon gas for back-up protection.

TABLE XXXII

SHORT TIME TENSILE PROPERTIES
OF WELDED R-235 ALLOY SHEET

Material - 0.063 in. sheet, fusion welded without filler wire
Heat treatment - After welding, 1600°F 30 min
Heating method - Resistance
Test atmosphere - Air
Strain rate - 0.001 in./in./sec to yield
- 0.01 in./in./sec to rupture
Hold time - 15 min

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Location of Fracture
109F	RT	94.0	111.0	149.0	10	Weld
110F	RT	90.0	110.0	166.0	20	Weld
111F	1200	60.0	99.5	140.0	12	Parent metal
112F	1200	79.0	98.0	142.0	18	Parent metal
113F	1400	76.0	105.0	128.0	5	Edge of weld
114F	1400	78.0	104.0	127.5	4.5	Edge of weld
115F	1600	53.0	76.0	87.5	2	Edge of weld
116F	1600	50.0	*	75.5	2.5	Edge of weld
117F	1800	14.0	21.5	34.3	14	Parent metal
118F	1800	16.6	21.9	30.5	14	Parent metal

* Ultimate tensile strength reached before 0.2% offset.

TABLE XXXIII

SHORT TIME TENSILE PROPERTIES
OF WELDED R-235 ALLOY SHEET

Material	- 0.063 inch Sheet fusion welded with R-235 filler wire
Heat treatment	- After welding, 1600°F 30 min
Heating method	- Resistance
Test atmosphere	- Air
Strain rate	- 0.001 in./in./sec to yield 0.01 in./in./sec to rupture
Hold time	- 15 min

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)
150F	RT	88.0	117.5	171.0	22
151F	1200	74.0	100.0	135.0	16
152F	1400	80.0	100.0	[illegible]	[illegible]
153F	1600	68.0	78.0	90.0	1
154F	1800	16.0	22.0	32.2	13

MAC A473

TABLE XXXIV

TENSILE PROPERTIES OF WELDED R-235 ALLOY PLATE

Material - 0.250 in. R-235 welded (transverse) with R-235 filler wire
Heat treatment - After welding, 2200°F, 15 min, WQ; 2050°F, 30 min, AC
Heating - Resistance
Hold time - 15 min
Strain rate - 0.001 in./in./sec to yield; 0.01 in./in./sec to rupture
Atmosphere - Air

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)	Fracture Location
584F	1200	59.0	82.0	121.0	18	23.4	Parent metal
585F	1400	69.0	86.1	112.0	8	24.1	Parent metel
586F	1600	60.4	75.2	93.0	6	19.3	Parent metal
587F	1800	15.0	23.0	27.9	33	15.8	Parent metal

TABLE XXXV

CREEP-RUPTURE PROPERTIES OF R-235 ALLOY SHEET WELDED WITHOUT FILLER METAL

Material - 0.063 in. sheet, transverse welded without filler metal
Heating - Resistance

Gage length - 1.5 ins.
Heat treatment - After welding, 1600°F, 30 min, AC

Spec. No.	Test Temp. (°F)	Creep Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Creep (hours)							Time to Rupture (hours)	Elongation in 1.5 in. (%)
				0.05%	0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
120F	1200	70	--	12.2	--	--	--	--	--	--	12.2	1
125F	1200	80	--	--	--	--	--	--	--	--	4.97	1
129E	1200	86	0.28	4.63	--	--	--	--	--	--	4.63	1
130E	1200	95	0.37	0.53	--	--	--	--	--	--	1.23	1
131E	1200	105	0.71	0.03	1.13	1.73	--	--	--	--	1.73	2
121F	1400	30	--	2.4	4.15	111.0	--	--	--	--	--	--
126F	1400	35	--	0.58	1.98	19.6	--	--	--	--	--	--
127F	1400	40	--	0.15	0.93	8.1	--	--	--	--	90.5	1
128F	1400	44	--	0.27	4.72	--	--	--	--	--	10.4	1
132E	1400	45	0.26	0.83	1.03	2.26	--	--	--	--	2.3	1
133E	1400	50	0.30	0.75	1.20	--	--	--	--	--	1.2	2
134E	1400	55	0.21	0.06	0.33	0.63	--	--	--	--	0.63	1
149E	1400	60	0.37	0.05	0.16	0.23	--	--	--	--	0.23	1
143F	1600	11	--	0.20	1.1	27.0	--	--	--	--	--	--
144F	1600	16	--	0.18	0.48	25.0	156.8	--	--	--	--	--
139E	1600	20	0.17	0.03	0.25	1.98	14.7	27.1	33.2	36.1	36.1	5
138E	1600	25	0.24	0.03	0.06	0.45	2.83	5.3	6.86	--	7.03	3
137E	1600	30	0.20	0.02	0.05	0.25	1.27	2.63	--	--	2.93	1
136E	1600	35	0.36	--	0.02	0.08	0.32	--	--	--	0.47	2
Spare	1800	5	--	0.53	2.5	11.1	--	--	--	--	--	--
145F	1800	6	--	0.30	2.8	10.5	24.7	31.7	37.6	41.9	44.1	14
142E	1800	7	0.03	0.08	0.57	1.75	6.4	10.8	14.5	--	19.7	6
141E	1800	9	--	0.32	1.25	2.33	4.16	5.8	7.6	9.1	9.9	15
147F	1800	9	--	0.02	0.45	2.5	4.5	6.8	9.9	14.5	15.7	11
148F	1800	11	--	0.02	0.15	0.35	0.7	0.97	1.3	1.5	1.6	16
140E	1800	12	0.03	0.02	0.03	0.13	0.30	0.42	0.55	0.63	0.67	17

TABLE XXXVI

CREEP-RUPTURE PROPERTIES OF R-235 ALLOY SHEET WELDED WITH R-235 FILLER METAL

Material - 0.063 in. R-235 transverse welded with R-235 filler metal
Heating - Resistance

Gage length - 1.5 ins.
Heat treatment - After welding, 1600°F, 30 min, AC

Spec. No.	Test Temp. (°F)	Creep Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Creep (hours) 0.05%	0.1%	0.2%	0.5%	1.0%	2.0%	4.0%	Time to Rupture (hours)	Elongation in 1.5 in. (%)
166F	1200	80	0.33	5.25	5.27	--	--	--	--	--	5.3	2
165F	1200	86	0.40	3.7	--	--	--	--	--	--	3.7	2
164F	1200	95	0.61	1.93	2.7	--	--	--	--	--	2.7	2
155F	1400	30	0.13	2.1	25.4	--	--	--	--	--	--	--
156F	1400	35	0.20	1.57	11.1	32.6	--	--	--	--	--	--
169F	1400	40	0.26	0.25	1.31	--	--	--	--	--	1.35	1
168F	1400	45	0.20	0.25	1.22	--	--	--	--	--	1.22	2
167F	1400	50	0.22	--	0.27	--	--	--	--	--	0.27	2
157F	1600	9	0.01	2.4	5.65	--	--	--	--	--	--	--
158F	1600	12	0.01	--	0.52	3.45	67.8	--	--	--	--	--
172F	1600	15	0.00	--	0.50	3.9	35.3	--	--	--	--	--
171F	1600	20	0.10	--	0.27	2.98	17.6	30.6	37.9	42.1	42.9	7
170F	1600	25	0.17	--	0.43	1.57	13.7	27.5	35.3	--	39.5	6
159F	1600	31	0.18	0.05	0.20	0.70	2.1	3.8	--	--	4.17	2
160F	1800	4	0.02	0.15	1.8	8.05	24.2	29.8	31.7	32.5	33.3	8
174F	1800	5	0.03	0.15	0.45	3.5	7.1	8.9	10.5	11.8	12.6	15
163F	1800	5	0.01	--	0.65	3.07	10.3	12.8	14.5	16.2	19.1	24
161F	1800	6	0.02	--	0.1	0.73	5.75	11.7	14.5	15.7	16.6	12
173F	1800	7	0.02	0.25	2.2	5.0	9.6	11.5	13.0	14.0	15.5	15
175F	1800	7	0.02	0.32	1.43	5.0	--	--	--	--	16.7	3
162F	1800	8	0.02	--	0.33	1.33	4.5	6.55	8.58	10.3	11.4	14

MAC A673

TABLE XXXVII

CREEP-RUPTURE PROPERTIES OF R-235 ALLOY PLATE WELDED WITH R-235 FILLER METAL

Material - 0.250 in. plate welded with R-235 filler metal
Heating - Resistance
Gage length - 1.5 ins.

Heat treatment - After welding: 2200°F, 15 min WQ; 2050°F, 30 min AC
Heat number - HV 7496

Spec. No.	Test Temp. (°F)	Creep Stress (Ksi)	Loading Strain (%)	Time to Produce Indicated Creep (hours)							Time to Rupture (hours)	Elongation in 1.5 in. (%)
				0.05%	0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
604F	1200	83	0.37	22.3	12.4	--	--	--	--	--	12.4	5
603F	1200	88	1.67	3.[illegible]	--	--	--	--	--	--	3.52	5
845F	1400	40	--	0.15	5.1	55	--	--	--	--	--	--
855F	1400	45	--	[illegible]	0.80	51	--	--	--	--	112.9	2
608F	1400	50	0.20	4.62	4.7	--	--	--	--	--	4.7	--
607F	1400	54	0.34	2.65	2.0	--	--	--	--	--	2.67	--
606F	1400	58	0.23	0.58	1.8	--	--	--	--	--	1.85	4
856F	1600	16	--	[illegible]	20.0	55	67	--	--	--	--	--
611F	1600	19	0.11	[illegible]	6.6	15.3	42.1	53.3	63.3	70.2	72.6	10
850F	1600	22	--	1.3	4.8	37	41	59	72.5	--	79.4	6
610F	1600	25	0.30	0.13	0.23	1.65	7.0	11.7	15.1	16.6	16.7	6
[illegible]	1600	30	0.27	0.17	0.33	0.8	2.15	3.33	4.52	--	5.07	6
859F	1800	2.0	--	--	--	--	--	--	--	--	--	--
862F-A	1800	2.0	--	37.1	--	--	--	--	--	--	--	--
615F	1800	2.0	0.00	0.77	7.27	22.8	42.8	44.6	--	--	44.6	2
859F	1800	3.5	--	25.0	91.6	151.0	--	--	--	--	--	--
861F-A	1800	3.5	--	13.8	25.1	70.9	--	--	--	--	--	--
614F	1800	3.5	0.27	[illegible]	0.7	3.0	7.8	11.8	15.8	20.6	23.0	15
860F	1800	5.0	--	8.9	14.6	31.5	63	92.5	--	--	--	--
613F	1800	5.5	[illegible]	0.35	1.6	6.0	20.7	16.2	27.4	24.6	31.9	23
863F	1800	6.5	--	1.25	2.1	3.7	15.5	23.0	29.8	37	41.2	16
605F	1800	6.5	[illegible]	[illegible]	0.05	0.15	0.35	0.58	1.07	1.87	2.58	23

TABLE XXXVIII

COMPARISON OF TENSILE DATA FOR NOTCHED AND UNNOTCHED R-235 ALLOY SHEET

Specimen Number	Type	Specimen	Test Temperature (°F)	Elongation in 2 in. (%)	Ultimate Tensile Strength (Kpsi)	Notched Tensile Ratio (1)
--	R-235 sheet	Unnotched	RT	27.5	167.0	0.9
51G	R-235 sheet	K_t = 2.5	RT	--	147.3	
--	R-235 sheet	Unnotched	1200	30.0	140.0	0.9
52G	R-235 sheet	K_t = 2.5	1200	--	120.4	
--	R-235 sheet	Unnotched	1600	2.5	98.0	0.9
53G	R-235 sheet	K_t = 2.5	1600	--	90.7	
Heat Treatment: 1600°F, 30 min						

(1) $\frac{\text{Notched Tensile Strength}}{\text{Unnotched Tensile Strength}}$

MAC A673

TABLE XXXIX

RUPTURE DATA FOR NOTCHED R-235 ALLOY SHEET

Specimen Number	Type	Specimen	Test Temperature (°F)	Load (Kpsi)	Rupture Time (hours)
49G	R-235	$K_t = 2.5$	1400	38	9.7
50G	R-235	$K_t = 2.5$	1400	42	7.7
48G	R-235	$K_t = 2.5$	1400	46	0.9

TABLE XL

CERTIFIED VENDOR REPORT FOR RENE' 41 0.064 INCH ALLOY SHEET

Heat No. TV 272

CHEMICAL COMPOSITION

Cr	Co	Mo	Al	Ti	Fe	C	Si	S	Mn	B	Ni
18.86	10.98	9.84	1.48	3.11	0.57	0.10	0.11	0.005	0.01	0.005	Balance

CERTIFIED VENDOR
CHEMICAL COMPOSITION FOR
RENE' 41 ALLOY PLATE

(Heat No. TV 598)

Cr	Fe	C	Si	Co	Mn	Mo	P	S	Al	Ti	B	Ni
18.74	0.88	0.09	0.24	11.07	0.01	10.04	0.001	0.009	1.48	3.13	0.007	Balance

CERTIFIED VENDOR ROOM TEMPERATURE TENSILE PROPERTIES
FOR RENE' 41 ALLOY PLATE

(Heat No. TV 598)

Thickness (in.)	Ultimate Tensile Strength (psi)	0.2% Yield Strength (psi)	Elongation in 2 in. (%)
0.3125	153,000	93,500	40

MAC A473

TABLE XLI

SHORT TIME TENSILE PROPERTIES OF RENE' 41 ALLOY SHEET

Heat number - TV 272
Condition - 2150°F, 2 hrs, AC
1650°F, 2 hrs, AC
Heating method - Resistance
Test atmosphere - Air
Thickness - 0.064 in.
Gage length - 2 in.
Strain rate - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Hold time - 15 min

Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)
RT	75	102.2	148.4	13	30.5
1200	58.4	89.8	134.2	23	22
1400	56.4	90.9	139.6	17	20
1600	52.8	81.9	97.2	9.5	19
1800	30.7	38.6	44.8	15	12

MAC A673

TABLE XLII

SHORT TIME TENSILE STRENGTH OF RENE' 41 ALLOY PLATE

Heat number - TV 598
Condition - 2150°F, 2 hrs, AC
1650°F, 4 hrs, AC
Thickness - 5/16 in.
Heating method - Resistance
Test atmosphere - Air
Gage length - 2 ins.
Strain rate - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Hold time - 15 min

Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)
RT	94	110	138	4.5	30
1200	73	96	--*	--*	24
1400	76	102	151	10.5	21
1600	65	88	100	4.5	19
1800	27	29	39	22	17.5

* Grips failed and ultimate was not obtained.

MAC A673

TABLE XLIII

CREEP-RUPTURE PROPERTIES OF RENE' 41 ALLOY SHEET AT 1200°F

Machine - Arc weld
Heating - Resistance
Gage length - 1.5 in.
Sheet thickness - 0.064 in.
Heat number - TV 272 (Haynes)
Heat treatment - Sol. H.T. 2150°F, 2 hrs, AC
Aged at 1650°F, 4 hrs, AC

Specimen Number	Creep Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Creep (min)							Time for Indicated Max. Creep		Time to Rupture (min)	Elongation in 1.5 in. (%)
			0.05%	0.1%	0.2%	0.4%	0.6%	0.8%	1.0%	(%)	(min)		
426D	125	11.1	--	--	--	0.1	0.5	1.5	4	--	--	54	12
424D	120	9.3	--	--	--	0.3	1	4	10	--	--	108	10
425D	120	8.9	--	--	--	1	4	10	19	--	--	143	10
422D	110	4.1	1	5	29	833	--	--	--	--	--	1194	6
423D	110	5.0	1	5	28	631	--	--	--	--	--	717	6
433D	105	4.1	3	517	--	--	--	--	--	0.15	1712	--	4.1
420D	100	1.7	18	1233	--	--	--	--	--	0.17	2448	--	1
421D	100	2.0	6	16	2404	--	--	--	--	0.22	2589	--	2
432D	100	1.4	1112	--	--	--	--	--	--	0.08	2805	--	1
431D	95	0.68	189	--	--	--	--	--	--	0.05	1348	--	--
418D	90	0.57	15	--	--	--	--	--	--	0.07	1442	--	--
430D	90	0.63	--	--	--	--	--	--	--	0.01	5410	--	--

TABLE XLIV

CREEP-RUPTURE PROPERTIES FOR RENE' 41 ALLOY SHEET AT 1400°F

Machine - Arc weld
Heating - Resistance
Gage length - 1.5 in.
Sheet thickness - 0.064 in.
Heat number - TV 272 (Haynes)
Heat treatment - Sol. H.T. 2150°F, 2 hrs, AC
Aged at 1650°F, 4 hrs, AC

Specimen Number	Creep Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Creep (min)							Time for Indicated Max. Creep		Time to Rupture (min)	Elongation in 1.5 in. (%)
			0.05%	0.1%	0.2%	0.4%	0.6%	0.8%	1.0%	(%)	(min)		
417D	85	0.24	9	30	95	164	204	--	--	--	--	210	2.5
427D	85	0.57	40	84	137	195	232	253	--	--	--	254	2
410D	80	0.37	22	50	99	165	200	--	--	--	--	203	2
411D	80	0.21	30	90	155	229	278	--	--	--	--	283	2
412D	70	0.39	40	85	180	500	670	900	987	--	--	987	2
413D	70	0.27	240	495	815	--	--	--	--	--	--	822	1.5
414D	70	0.40	135	465	780	1007	--	--	--	--	--	1008	2
428D	70	0.38	180	246	330	430	480	--	--	--	--	498	2
419D	60	0.25	890	1220	1715	2590	2935	3360	3600	--	--	3900	3
415D	60	0.27	171	426	1310	2250	2850	3180	3280	--	--	3280	2
429D	55	0.53	2020	2305	4074	--	--	--	--	0.2	4074	--	--
416D	50	0.47	651	3000	--	--	--	--	--	0.16	5400	--	--

TABLE XLV

1600°F CREEP TEST RESULTS
FOR RENE' 41 ALLOY SHEET

Material - Heat No. TV 272
Condition - 2150°F, 2 hrs, AC
1650°F, 2 hrs, AC
Thickness - 0.064 in.
Heating method - Resistance
Gage length - 1.5 in.
Test atmosphere - Air

Stress (Kpsi)	Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed		
		0.1%	0.2%	0.5%	1.0%	2.0%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Chart Elongation (%)	Specimen Elongation after Rupture (%)
25	0.09	1022	1800	3065	3900	4690	--	--	5704	5	7
30	0.17	523	640	945	1140	1377	--	--	1527	4.6	5
30	0.15	558	930	1215	1388	1545	1545	2	--	--	--
35	0.17	172	345	488	590	689	--	--	758	3.8	5
35	0.18	145	237	366	434	502	--	--	585	4.6	7
40	0.24	72	130	208	260	310	--	--	361	4.5	6
40	0.27	133	187	248	300	354	--	--	399	3.9	5
45	0.32	20	58	109	139	167	--	--	190	4.1	6
51.5	0.41	15	27	45	58	71	--	--	77	3	4

TABLE XLVI

1800°F CREEP TEST RESULTS FOR RENE' 41 ALLOY SHEET

Material - Heat No. TV 272
Condition - 2150°F, 2 hrs, AC
1650°F, 4 hrs, AC
Thickness - 0.064 in.
Heating method - Resistance
Gage length - 1.5 in.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1.0%	2.0%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
5	0.02	2300	--	--	--	--	5552	0.11	--	--
10	0.04	134	680	1020	--	--	1832	0.93	--	--
10	0.07	245	480	760	1100	1402	--	--	1718	6
12.5	0.07	145	200	310	507	522	--	--	629	8
15	0.12	105	155	228	289	362	--	--	483	9
15	0.13	120	170	237	296	372	--	--	507	9
20	0.16	10	14	20	27	37	--	--	55	11
20	0.18	4	10	17	24	29	--	--	39	11
30	0.28	--	--	--	1	2	--	--	5	11

TABLE XLVII

1200°F CREEP TEST RESULTS FOR RENE' 41 ALLOY PLATE

Material - Heat No. TV 598
Condition - 2150°F, 2 hrs, AC
1650°F, 2 hrs, AC
Plate thickness - 0.3125 in.
Heating method - Resistance
Gage length - 1.5 in.
Test atmosphere - Air

Specimen Thickness (in.)	Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
			0.1%	0.2%	0.5%	1.0%	2.0%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
0.3125	70	0.39	--	--	--	--	--	4118	0.03	--	--
0.3125	70	0.31	--	--	--	--	--	1221	0.01	--	--
0.3125	70	0.35	--	--	--	--	--	1050	0.01	--	--
0.250	100	0.80	--	--	--	--	--	1297	0.07	--	--
0.250	110	2.3	--	--	--	--	--	1046	0.07	--	--
0.200	115	2.9	244	835	2070	--	--	--	--	2371	6
0.200	120	5.2	1	3	195	765	1555	--	--	1788	8
0.200	122.5*	--	--	--	--	--	--	--	--	0	3
0.200	125*	--	--	--	--	--	--	--	--	0	3

* Specimens tested at 122.5 and 125 Kpsi failed on loading.

TABLE XLVIII

1400°F CREEP TEST RESULTS FOR RENE' 41 ALLOY PLATE

Material - Heat No. TV 598
Condition - 2150°F, 2 hrs, AC
1650°F, 2 hrs, AC
Plate thickness - 0.3125 in.
Heating method - Resistance
Gage length - 1.5 in.
Test Atmosphere - Air

Specimen Thickness (in.)	Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
			0.1%	0.2%	0.5%	1.0%	2.0%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
0.3125	50	0.08	--	--	--	--	--	1320	0.02	--	--
0.3125	50	0.12	--	--	--	--	--	3525	0.05	--	--
0.3125	60	0.27	--	--	--	--	--	1292	0.07	--	--
0.3125	60	0.17	2290	3740	--	--	--	4227	0.23	--	--
0.3125	70	0.28	575	970	1570	1950	--	--	--	2025	3
0.250	70	0.32	368	680	1300	1905	--	--	--	2003	2
0.250	70	0.33	371	625	990	--	--	1025	0.7	--	--
0.250	75	0.37	188	271	460	607	812	--	--	1004	5
0.250	75	0.37	185	290	532	735	917	--	--	1058	5
0.250	80	0.48	60	135	246	--	--	--	--	274	2
0.250	80	0.41	93	166	275	394	512	--	--	579	4

TABLE XLIX

1600°F CREEP TEST RESULTS FOR RENE' 41 ALLOY PLATE

Material - Heat No. TV 598
Condition - 2150°F, 2 hrs, AC
1650°F, 4 hrs, AC
Plate thickness - 0.3125 in.
Heating method - Resistance
Gage length - 1.5 in.
Test Atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1.0%	2.0%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
20	0.06	--	--	--	--	--	1602	0.07	--	--
25	0.09	--	--	--	--	--	1329	0.05	--	--
30	0.13	405	--	--	--	--	640	0.11	--	--
30	0.15	870	1235	1830	2113	2400	--	--	2715	9
30	0.13	665	1220	1900	2235	2540	2683	3.0	--	--
35	0.15	217	410	657	765	868	--	--	974	9
40	0.14	93	244	450	565	654	--	--	789	8
40	0.18	175	290	430	513	588	--	--	655	6
45	0.21	61	118	191	237	277	--	--	298	6

TABLE L

1800°F CREEP TEST RESULTS FOR RENE' 41 ALLOY PLATE

Material - Heat No. TV 598
Condition - 2150°F, 2 hrs, AC
1650°F, 4 hrs, AC
Plate thickness - 0.3125 in.
Heating method - Resistance
Gage length - 1.5 in.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1.0%	2.0%	Time (min)	Elongation in 1.5 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
5	0.03	365	2970	--	--	--	4016	0.23	--	--
5	0.03	--	--	--	--	--	341**	0.08	--	--
10	0.04	195	265	355	413	465	--	--	645	15
10	0.06	140	390*	--	--	--	--	--	--	--
10	0.04	175	240	312	357	404	--	--	478	18
15	0.08	98	140	190	228	268	--	--	338	14
20	0.10	9	16	31	43	56	--	--	73	12
20	0.11	12	24	44	56	68	--	--	113	18
20	0.12	13	23	31	40	46	--	--	54	12
30	0.15	--	1.5	2	3.5	5	--	--	8	11

* Temperature erratic, test discontinued, data point questionable.

** Test discontinued to repair machine, cables overheating.

TABLE LI

TIG WELDING SCHEDULE FOR 0.064-INCH RENE' 41 ALLOY SHEET

Material	Filler Wire	Speed (ipm)	Current (amperes)	Voltage	Wire Feed (ipm)	Electrode Diameter (in.)
Rene' 41 sheet	None	30	75	17.5	--	3/32
Rene' 41 sheet	0.040-in. dia Rene' 41	30	125	14	16	3/32

All welding was performed on the Berkeley-Davis automatic machine using helium gas to protect the top of the weld and argon gas for back up. A special trailing cup was used to give added gas protection, and a wet rag was applied behind the trailing cup during welding to serve as a quick quench. All panels were roll plenished after welding and dye checked.

TABLE LII

TIG WELDING SCHEDULE FOR 0.250-INCH RENE' 41 ALLOY PLATE

Material	Welding Pass	Filler Wire	Welding Speed (ipm)	Current (amps)	Voltage	Electrode all Passes
Rene' 41 plate	1	None	15	225	10.5	3/32 diameter, 1% thoriated tungsten
	2	1/16-in. dia Rene' 41	15	260	10.5	
	3	1/16-in. dia Rene' 41	15	300	11	
	4	1/16-in. dia Rene' 41	15	330	11	
	5	1/16-in. dia Rene' 41	15	335	11	
	6	1/16-in. dia Rene' 41	15	225	11	

NOTES:

1. Material cleaned in alkaline solution followed by M.E.K. prior to welding.
2. Copper hold down and back up bars were used.
3. All welding was performed on a Berkeley-Davis Automatic Welding Machine (WL-777) using helium gas for torch side protection and argon gas for backup protection.

TABLE LIII

SHORT TIME TENSILE PROPERTIES OF WELDED RENE' 41 ALLOY SHEET
WELDED WITHOUT FILLER WIRE

Material - 0.053-in. sheet transverse fusion welded without filler wire
Heat treatment - After welding, 2150°F, 2 hrs; 1650°F, 4 hrs
Hold time - 15 min
Heating method - Resistance
Test atmosphere - Air
Strain rate - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Heat number - TV 225

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Location of Fracture
176F	RT	64.6	93.6	148.0	27	Parent metal
177F	1200	44.0	80.0	119.5	27	Parent metal
178F	1400	70.0	88.0	109.0	8	Parent metal
179F	1600	51.0	78.0	97.2	7.5	Parent metal
180F	1800	26.0	32.8	43.9	16	Parent metal

Based on one specimen at each test temperature

TABLE LIV

SHORT TIME TENSILE PROPERTIES OF WELDED RENE' 41 ALLOY SHEEET
WELDED WITH RENE' 41 FILLER WIRE

Material	- 0.053-in. sheet transverse fusion welded with Rene' 41 filler wire
Heat treatment	- After welding, 2150°F, 2 hrs; 1650°F, 4 hrs
Heating method	- Resistance
Test atmosphere	- Air
Strain rate	- 0.001 in./in./sec to yield 0.01 in./in./sec to rupture
Hold time	- 15 min
Heat number	- TV 225

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Location of Fracture
181F	RT	86.0	103.5	122.5	5	Parent metal
222F	RT	81.0	104.0	136.0	6.5	Parent metal
223F	RT	81.0	104.0	119.5	2.5	Parent metal
182F	1200	70.0	88.5	122.0	29.0	Parent metal
183F	1400	74.5	93.0	114.0	4.0	Parent metal
184F	1600	67.5	80.0	93.0	3.0	Heat affected zone
185F	1800	24.5	36.0	43.4	12.0	Edge of weld

MAC A673

TABLE LV

TENSILE PROPERTIES OF WELDED RENE' 41 ALLOY PLATE

Material - 0.250 in. Rene' 41 plate, welded (transverse) with Rene' 41 filler wire
Heat treatment - After welding, 2150°F, 2 hrs, AC; 1650°F, 4 hrs, AC
Heating - Resistance
Hold time - 15 min
Strain rate - 0.001 in./in./sec to yield 0.01 in./in./sec to rupture
Test atmosphere - Air

Specimen Number	Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 2 in. (%)	Young's Modulus (10^6 psi)	Location of Fracture
381F	RT	84.9	113.0	168.0	13.5	28.9	Parent metal
382F	1200	72.0	97.5	138.0	8.0	24.2	Parent metal
383F	1400	68.0	87.9	142.0	8.0	21.9	Weld
384F	1600	75.0	94.2	108.0	8.5	20.7	Weld
385F	1800	29.5	38.7	47.9	5.0	16.9	Weld

TABLE LVI

CREEP-RUPTURE PROPERTIES OF FUSION WELDED RENE' 41 ALLOY SHEET

Machine - Arc weld
Heating - Resistance
Gage length - 1.5 in.
No filler wire added
Sheet thickness - 0.050 in.
Heat number - TV 225 (Haynes)
Heat treatment - Sol. H.T. 2150°F, 2 hr, AC
Aged at 1650°F, 4 hr, AC

Specimen Number	Test Temperature (°F)	Creep Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Creep (min)					Time for Indicated Max Creep		Time to Rupture (min)	Elongation in 1.5 in. (%)
				0.05%	0.2%	0.5%	1.0%	2.0%	(%)	(min)		
925E	1200	105	2.2	5	1320	--	--	--	0.26	1395	--	--
926E	1200	100	1.9	1260	--	--	--	--	--	--	5212	--
927E	1200	95	0.9	420	--	--	--	--	0.07	3901	--	--
928E	1400	70	0.30	15	120	245	--	--	--	--	330	--
929E	1400	65	0.38	90	527	872	1203	--	--	--	1332	2
930E	1400	60	0.17	420	--	--	--	--	0.17	1428	--	--
931E*	1600	32	0.17	210	707	1055	1320	1573	--	--	1582	4
932E	1600	29	0.20	18	265	735	--	--	0.50	820	--	--
933E	1600	24	0.15	100	--	--	--	--	--	--	2497	--
934E	1800	11	0.10	21	162	251	295	332	--	--	3041	7
936E	1800	7	0.10	330	450	310	--	--	0.93	1150	--	--

* Rupture occurred in the weld.

ASD-TDR-63-277, Vol. VI

TABLE LVII

CREEP-RUPTURE PROPERTIES OF WELDED RENE' 41 ALLOY PLATE

Material - 0.25 in. Rene' 41 plate, welded (transverse) with Rene' 41 filler metal
Heating - Resistance
Gage length - 1.5 in.
Heat treatment - After welding; 2150°F, AC; 1650°F, 4 hrs, AC

Specimen Number	Test Temperature (°F)	Creep Stress (Kpsi)	Loading Strain* (%)	Time to Produce Indicated Creep (hours)							Time to Rupture (hours)	Elongation in 1.5 in. (%)
				0.05%	0.1%	0.2%	0.5%	1.0%	2.0%	4.0%		
431F	1200	95	1.17	17.5	32.5	59.5	113.0	--	--	--	--	--
432F	1200	90	0.50	--	--	--	--	--	--	--	--	--
433F	1400	81	0.63	0.05	0.30	1.0	2.0	2.9	3.95	--	4.77	6
434F	1400	76	0.53	0.65	1.0	1.93	3.67	5.55	7.9	10.63	10.6	6
435F	1400	71	0.45	--	--	0.1	0.42	1.1	2.5	4.57	7.3	14
436F	1400	67	0.27	4.55	8.47	13.7	25.1	33.7	42.7	--	45.4	3
445F	1400	62	0.60	1.33	5.47	19.8	38.0	48.0	56.8	--	57.2	3
437F	1600	45	0.70	--	0.05	0.22	0.52	0.92	1.4	--	1.7	6
438F	1600	39	0.37	0.67	1.33	2.42	4.0	5.42	6.77	--	8.0	6
439F	1600	34	0.17	0.60	1.5	2.5	4.1	5.13	7.0	7.48	7.5	3
440F	1600	28	0.33	3.7	5.7	8.8	15.1	19.25	--	--	--	--
441F	1800	16	0.13	--	0.12	0.25	1.2	1.77	2.77	3.65	3.75	9
442F	1800	12	0.10	--	1.0	1.6	2.57	3.5	4.5	5.58	6.1	9
443F	1800	9	0.13	0.60	1.5	4.0	8.7	12.35	--	20.9	23.9	12
444F	1800	5	0.05	20.92	32.57	--	--	--	--	3	32.6	1

* Strain resulting after applying load to heated specimen stabilized at test temperature.

TABLE LVIII

COMPARISON OF TENSILE DATA FOR NOTCHED AND UNNOTCHED RENE' 41 ALLOY SHEET

Identification Number	Type	Specimen	Test Temperature (°F)	Elongation in 2 in. (%)	Ultimate Tensile Strength (Kpsi)	Notched Tensile Ratio (1)
--	Rene' 41	Unnotched (2)	RT	14	194.8	0.9
60G	Rene' 41	$K_t = 2.5$	RT	--	178.8	
--	Rene' 41	Unnotched	1400	6	151.1	0.9
61G	Rene' 41	$K_t = 2.5$	1400	--	138.3	
--	Rene' 41	Unnotched	1600	5	106.4	1.8
62G	Rene' 41	$K_t = 2.5$	1600	--	101.8	
--	Rene' 41	Unnotched	1800	15	41.5	1.0
63G	Rene' 41	$K_t = 2.5$	1800	--	42.0	
Heat Treatment: 1950°F Solution, 1400°F, 16 hr						

(1). $\frac{\text{Notched Tensile Strength}}{\text{Unnotched Tensile Strength}}$

(2). Data from Haynes-Stellite for all unnotched Rene' 41

TABLE LIX

RUPTURE DATA FOR NOTCHED RENE' 41 ALLOY

Identification Number	Type	Specimen	Test Temperature (°F)	Load (Kpsi)	Rupture Time (hr)
54G	Rene' 41	$K_t = 2.5$	1400	48	151.3
56G	Rene' 41	$K_t = 2.5$	1400	58	38.4
59G	Rene' 41	$K_t = 2.5$	1400	70	11.2
55G	Rene' 41	$K_t = 2.5$	1600	25	20.4
57G	Rene' 41	$K_t = 2.5$	1600	30	4.2
58G	Rene' 41	$K_t = 2.5$	1600	35	1.7

TABLE LX

CERTIFIED VENDOR REPORT ON INCO 713C ALLOY TEST BARS

(Heat No. 357)

CHEMICAL COMPOSITION

Cr	Mo	Fe	Co	Cu	Ti	Al	C	Si	Cb & Ta	Zr	B	Ni
12.56%	4.52	1.30	0.18	0.01	0.74	5.83	0.16	0.16	2.12	0.17	0.0008	Balance

ROOM TEMPERATURE TENSILE PROPERTIES

Ultimate Tensile Strength (psi)	0.2% Yield Strength (psi)	Elongation in 1.0 in. (%)	Reduction of Area (%)
130,300	119,400	6	13

TABLE LXI

SHORT TIME TENSILE STRENGTH OF CAST INCO 713C ALLOY

Material - Heat No. 357
Condition - As cast
Heating method - Resistance
Test atmosphere - Air
Gage diameter - 0.250 in.
Gage length - 1 in.
Strain rate - 0.001 in./in./sec to yield
0.01 in./in./sec to rupture
Hold time - 15 min

Test Temperature (°F)	Proportional Limit (Kpsi)	0.2% Yield Strength (Kpsi)	Ultimate Tensile Strength (Kpsi)	Elongation in 1 in. (%)	Young's Modulus (10^6 psi)
RT	95	116	124	3	28.0
RT	86	115	132	5.5	27.2
1200	80	104	128	4	26
1400	89	108	128	2	25
1600	84	110.5	119	3	18
1800	34	51	74	6.5	14

MAC A879

TABLE LXII

1200°F CREEP TEST RESULTS FOR CAST INCO 713C ALLOY

Material - Heat No. 357
Condition - As received
Gage diameter - 0.250 in.
Heating method - Resistance
Gage length - 1 in.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1.0%	2.0%	Time (min)	Elongation in 1 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
100	1	--	--	--	--	--	1368	0.05	--	--
105	1.15	125	195	603	2190	3792	--	--	3793	3
110	1.2	265	466	--	--	--	1395	0.45	--	--
110	1.3	255	453	837	--	--	1404	0.85	--	--
115	1.8	36	385	1218	--	--	1616	0.63	--	--
115	1.45	145	240	405	805	--	--	--	1514	3
120	1.9	35	120	--	--	--	--	--	202	2
120	2.6	1	10	--	--	--	--	--	209	4

TABLE LXIII

1400°F CREEP TEST RESULTS FOR CAST INCO 713C ALLOY

Material - Heat No. 357
Condition - As received
Gage diameter - 0.250 in.
Heating method - Resistance
Gage length - 1 in.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1.0%	2.0%	Time (min)	Elongation in 1 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
50	0.21	53	367	--	--	--	1756	0.3	--	--
50	0.20	--	--	--	--	--	1295	0.08	--	--
70	0.35	10	75	760	2825	--	5617	1.49	--	--
70	0.38	26	112	1040	--	--	1306	0.6	--	--
80	0.47	10	36	160	600	1510	--	--	1617	3
80	0.42	17	60	185	450	1000	--	--	1276	3
85	0.56	1	12	59	235	489	--	--	677	4
90	0.60	1	5	45	117	225	--	--	327	4.5
90	0.52	4	10	30	82	150	--	--	167	3

TABLE LXIV

1600°F CREEP TEST RESULTS FOR CAST INCO 713C ALLOY

Material - Heat No. 357
Condition - As cast
Gage diameter - 0.250 in.
Heating method - Resistance
Gage length - 1 in.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min)					Test Discontinued		Specimen Failed	
		0.1%	0.2%	0.5%	1.0%	2.0%	Time (min)	Elongation in 1 in. (%)	Time (min)	Specimen Elongation after Rupture (%)
30	0.21	135	528	--	--	--	2941	0.48	--	--
40	0.30	83	--	--	--	--	502*	--	--	--
40	0.30	57	165	688	--	--	1316	0.4	--	--
45	0.35	10	65	240	467	775	--	--	782	4
45	0.30	16	50	210	480	905	--	--	1043	5
50	0.37	8	37	77	212	431	--	--	695	5
50	0.35	2	12	106	390	709	--	--	942	5
60	1.0	1	3	21	57	126	--	--	127	3
60	0.65	1	2	11	29	65	--	--	67	5

* Extensometer fell off.

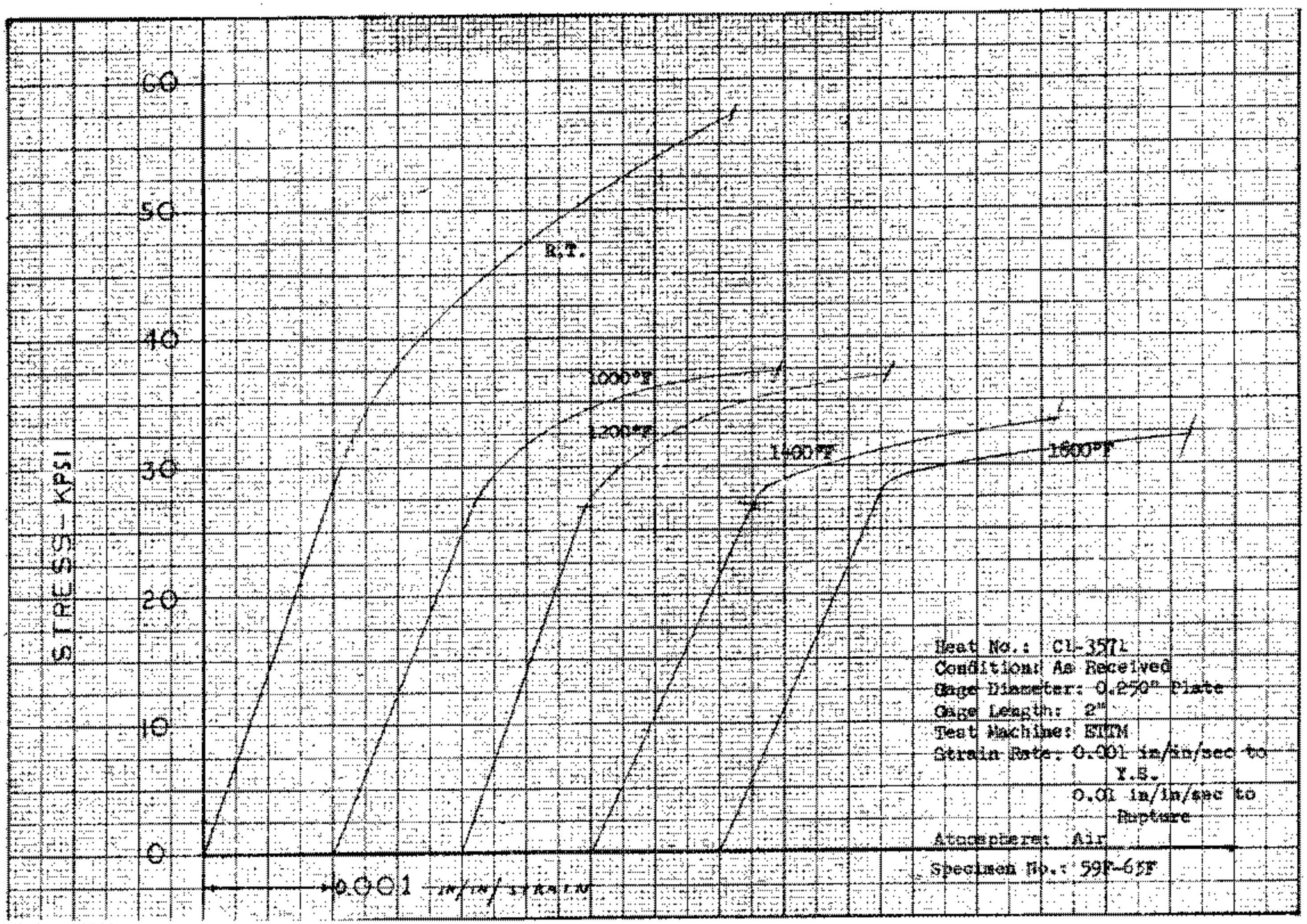
MAC A673

TABLE LXV

1800°F CREEP TEST RESULTS FOR CAST INCO 713C ALLOY

Material - Heat No. 357
Condition - As received
Thickness - 0.250 in.
Heating method - Resistance
Gage length - 1 in.
Test atmosphere - Air

Stress (Kpsi)	Loading Strain (%)	Time to Produce Indicated Amounts of Creep Strain (min) 0.1%	0.2%	0.5%	1.0%	2.0%	Test Discontinued Time (min)	Test Discontinued Elongation in 1 in. (%)	Specimen Failed Time (min)	Specimen Failed Specimen Elongation after Rupture (%)
10	0.05	23	295	--	--	--	4320	0.40	--	--
10	0.06	56	167	--	--	--	1390	0.38	--	--
10	0.09	72	746	--	--	--	750	0.20	--	--
15	0.11	2	8	206	--	--	1319	0.82	--	--
20	0.16	2	10	72	810	--	1495	1.55	--	--
20	0.17	2	4	67	596	--	1135	1.25	--	--
25	0.22	--	1.5	23	195	492	--	--	604	12
25	0.18	2	6	37	326	622	--	--	736	9
30	0.20	0.5	3	18	122	171	--	--	208	9
30	0.28	--	1	16	71	145	--	--	190	7



STRESS - KPSI
60
50
40
30
20
10
0
R.T.
1000°F
1200°F
1400°F
1600°F
0.001 IN/IN/ STRAIN
Heat No.: CL-3571
Condition: As Received
Gage Diameter: 0.250" Plate
Gage Length: 2"
Test Machine: ETTM
Strain Rate: 0.001 in/in/sec to Y.S.
0.01 in/in/sec to Rupture
Atmosphere: Air
Specimen No.: 59F-65F

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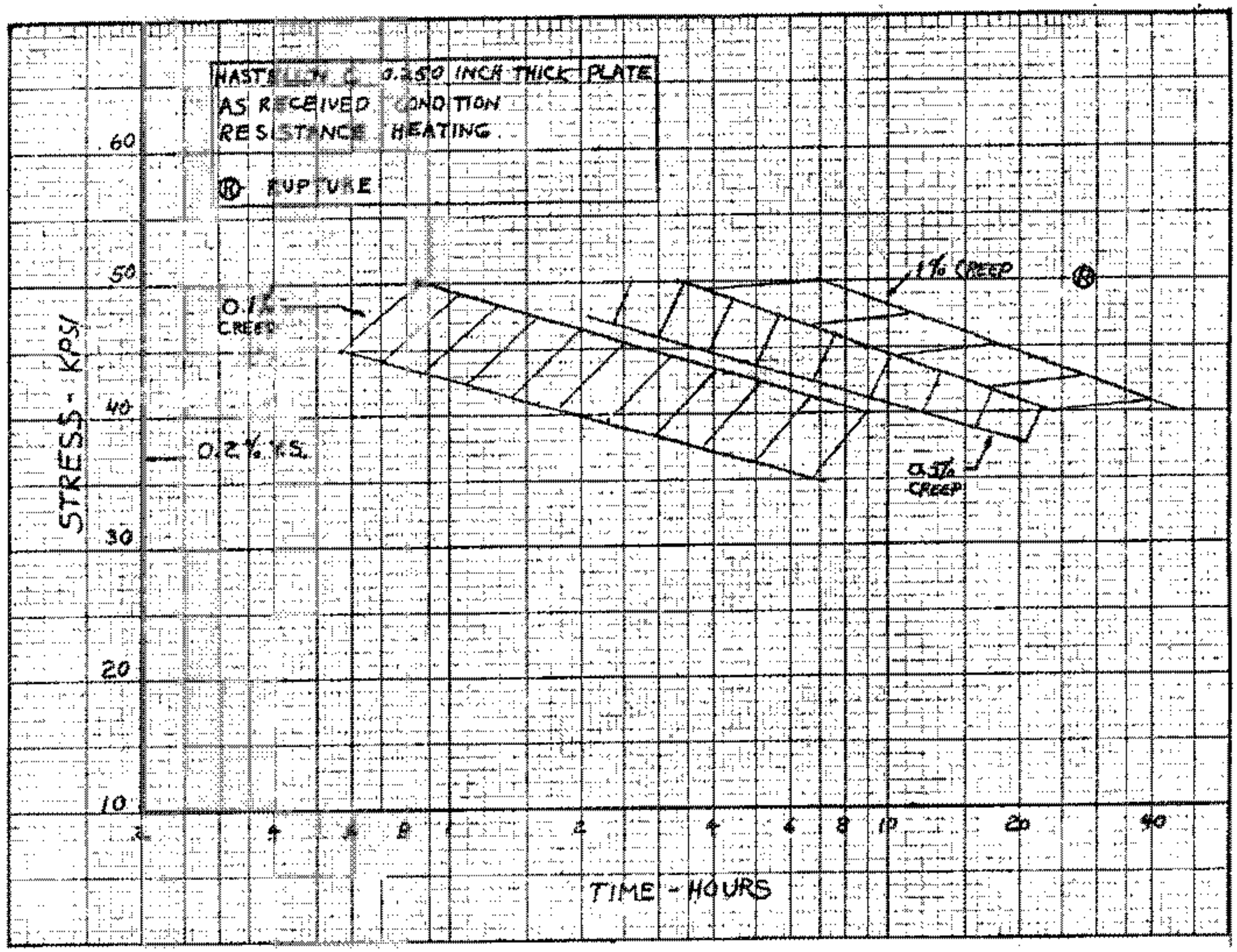
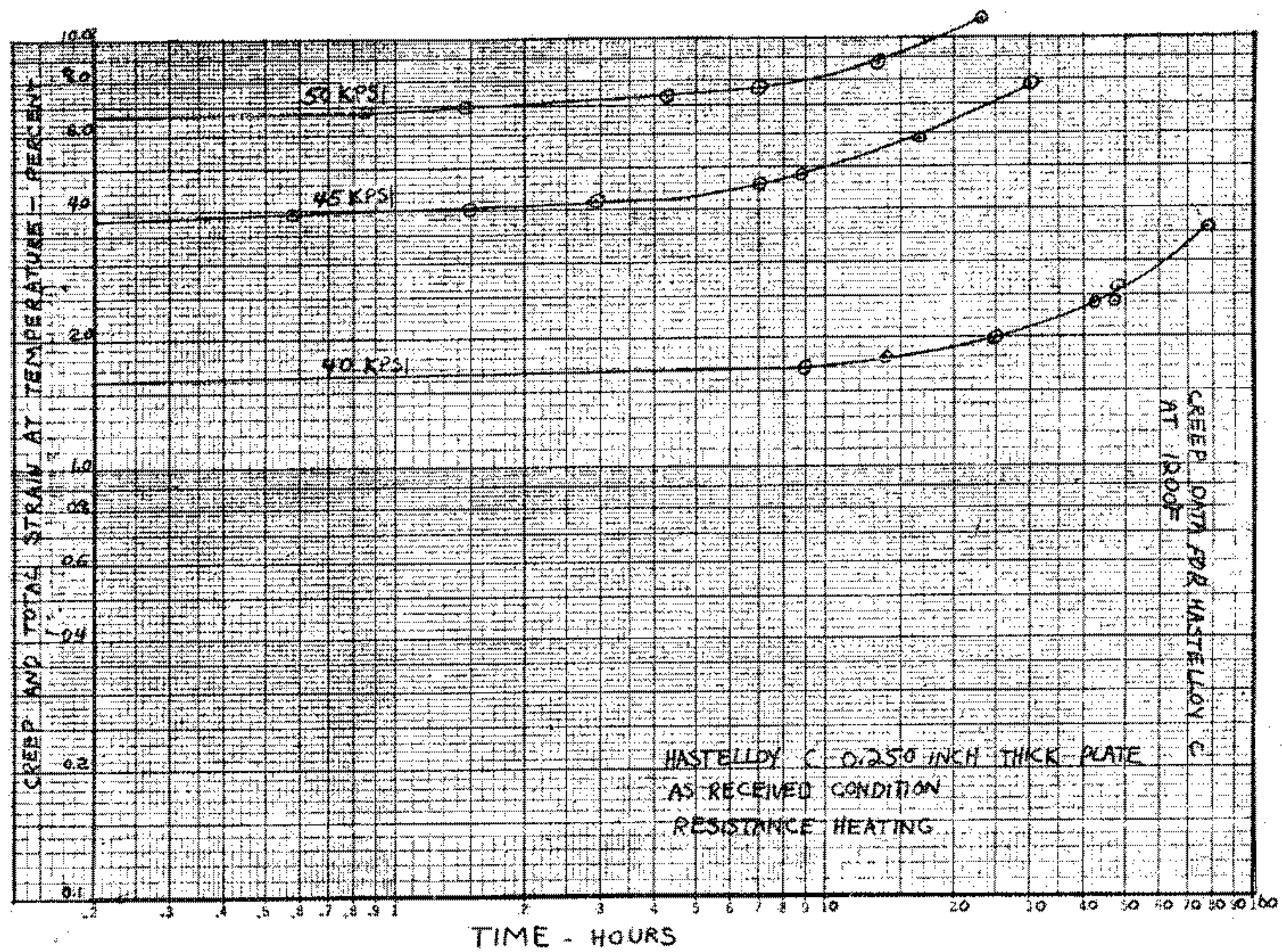
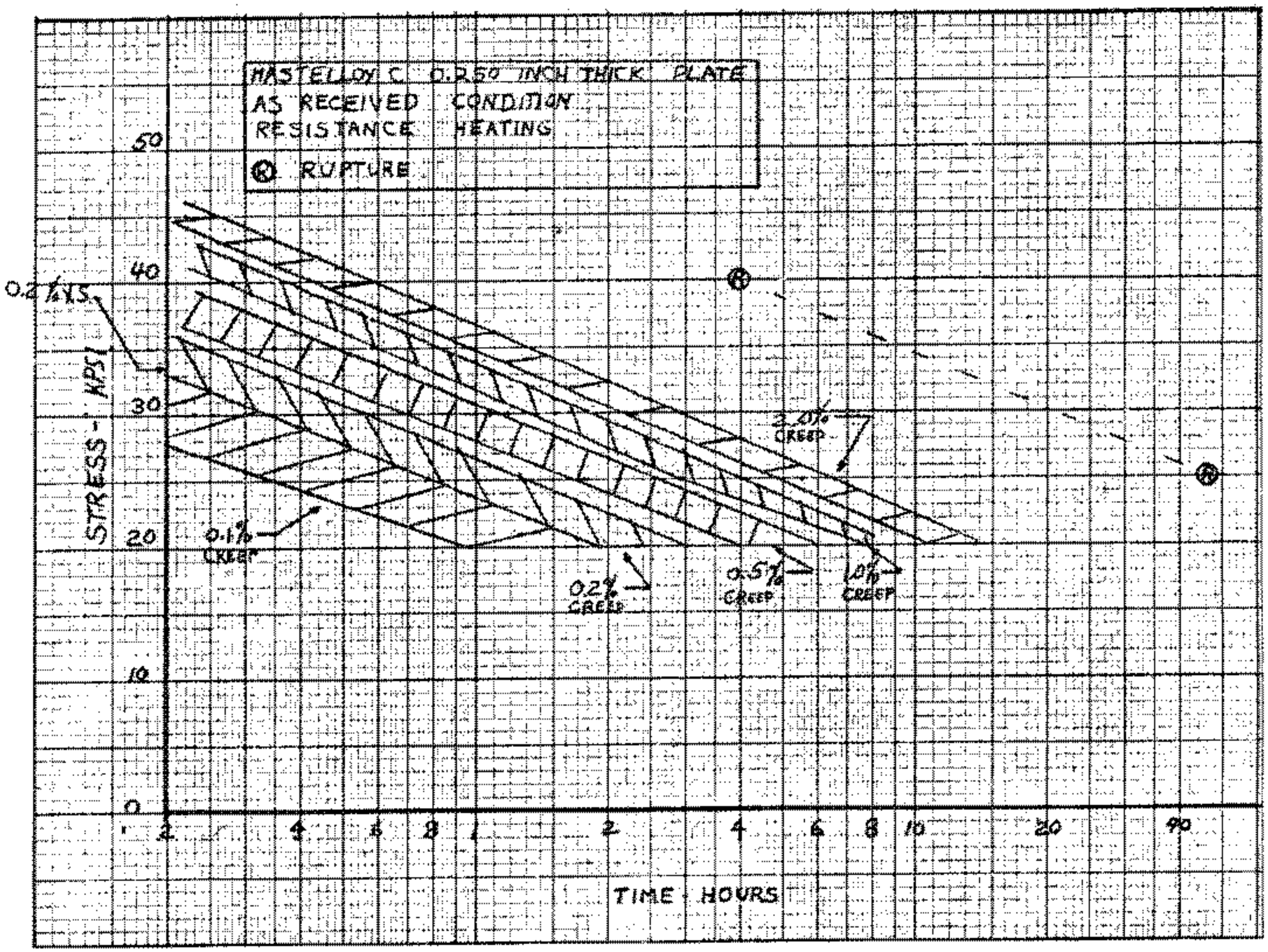
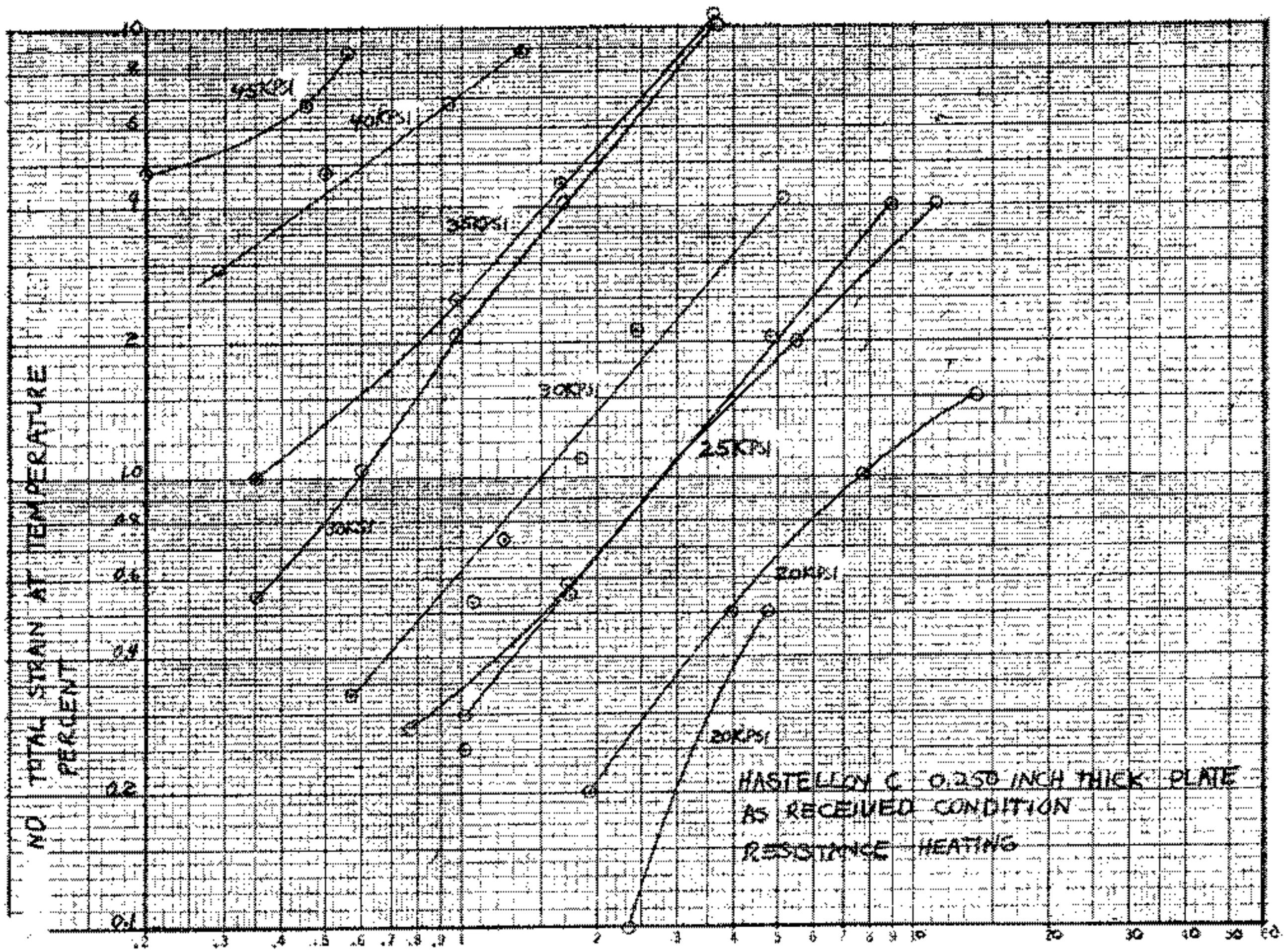


FIGURE 2 - 1200°F Creep and Stress-Rupture for Hastelloy C


CREEP DATA FOR HASTELLOY C
AT 1200F
HASTELLOY C 0.250 INCH THICK PLATE
AS RECEIVED CONDITION
RESISTANCE HEATING
50 KPSI
45 KPSI
40 KPSI
CREEP AND TOTAL STRAIN AT TEMPERATURE - PERCENT
TIME - HOURS



HASTELLOY C 0.250 INCH THICK PLATE
AS RECEIVED CONDITION
RESISTANCE HEATING
® RUPTURE
0.2% Y.S.
0.1% CREEP
0.2% CREEP
0.5% CREEP
1.0% CREEP
2.0% CREEP
STRESS - KPSI
TIME HOURS



NO TOTAL STRAIN AT TEMPERATURE PERCENT
45KPSI
40KPSI
35KPSI
30KPSI
30KPSI
25KPSI
20KPSI
20KPSI
HASTELLOY C 0.250 INCH THICK PLATE
AS RECEIVED CONDITION
RESISTANCE HEATING

MAC A673

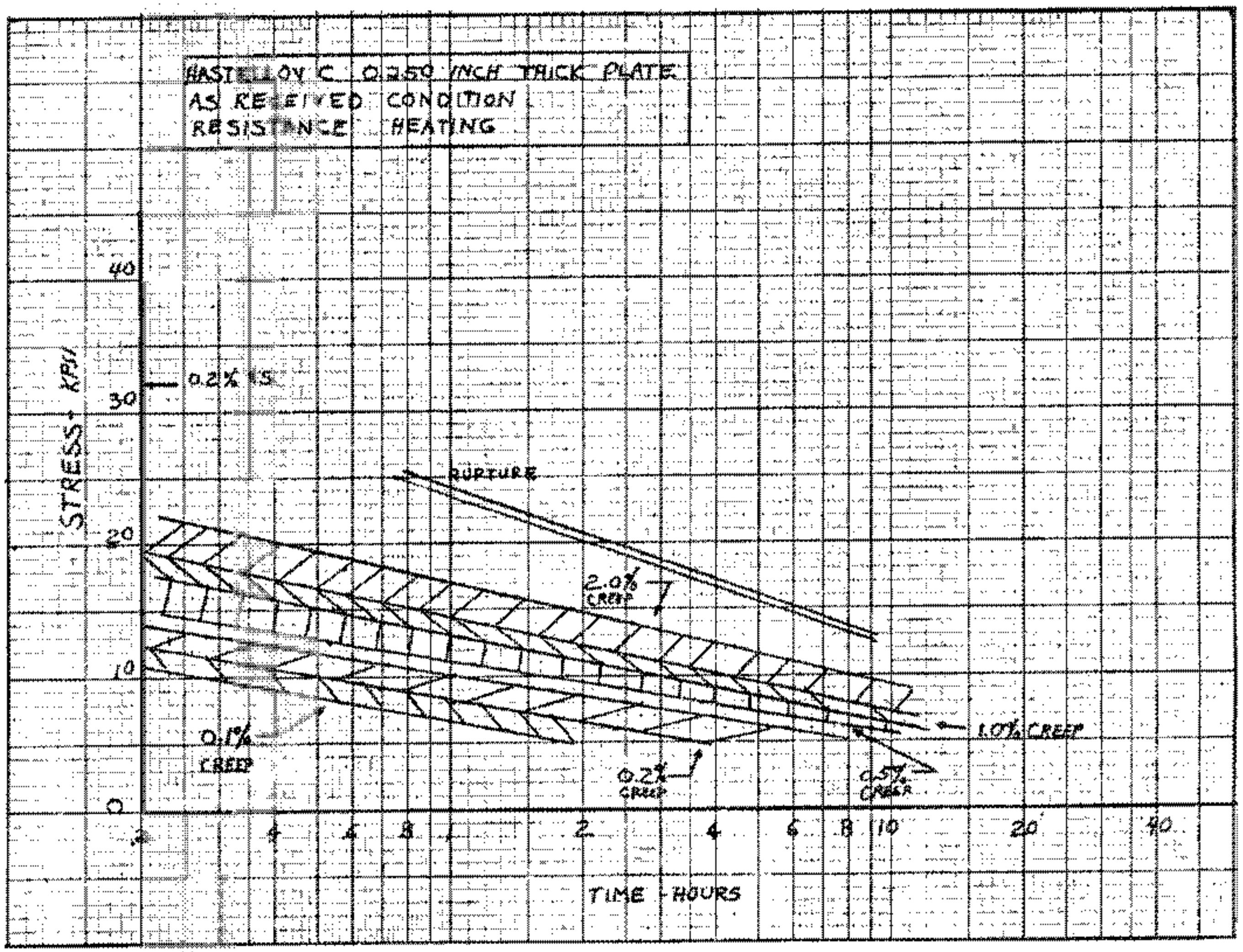


FIGURE 6 - 1600°F Creep and Stress-Rupture Data for Hastelloy C

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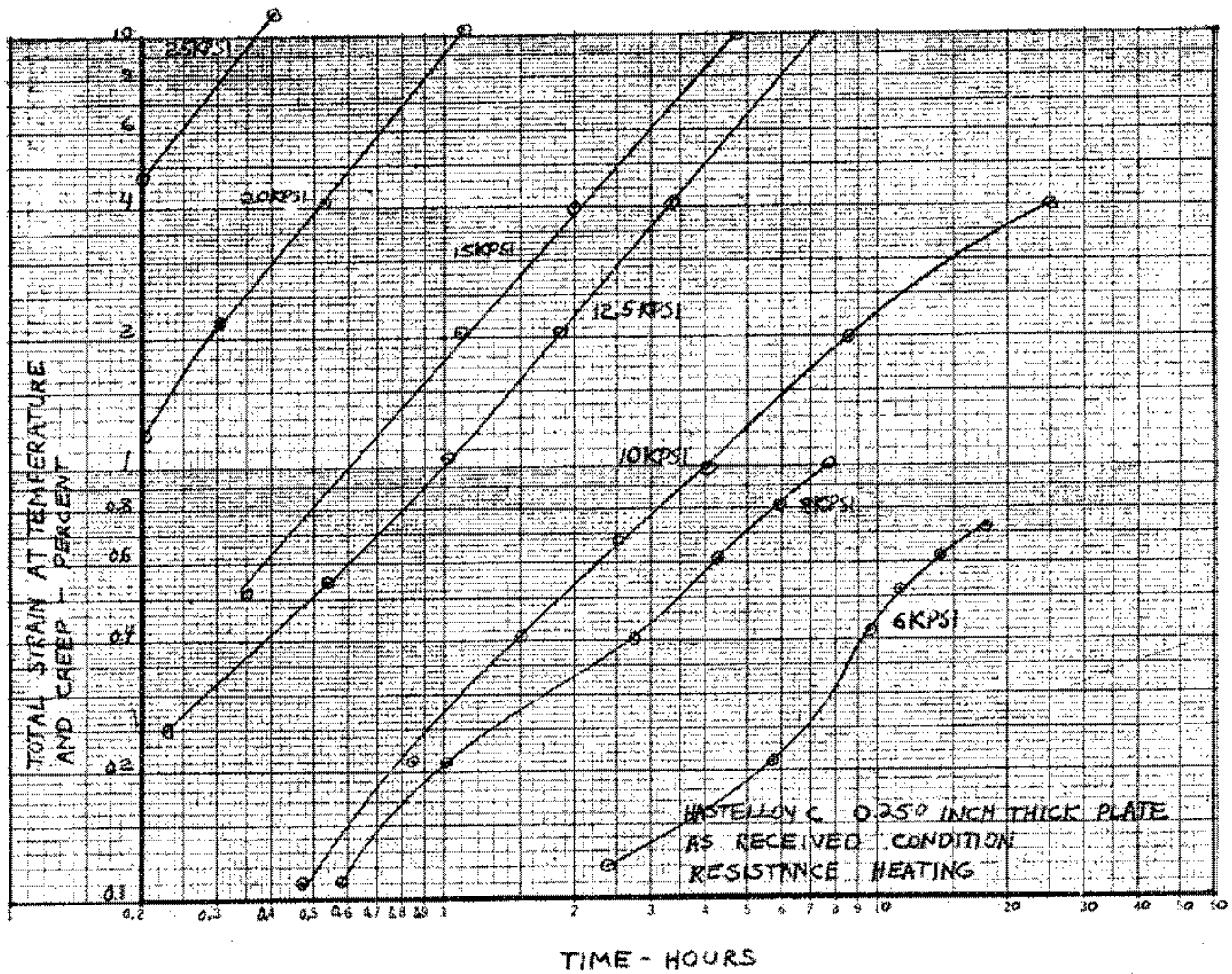
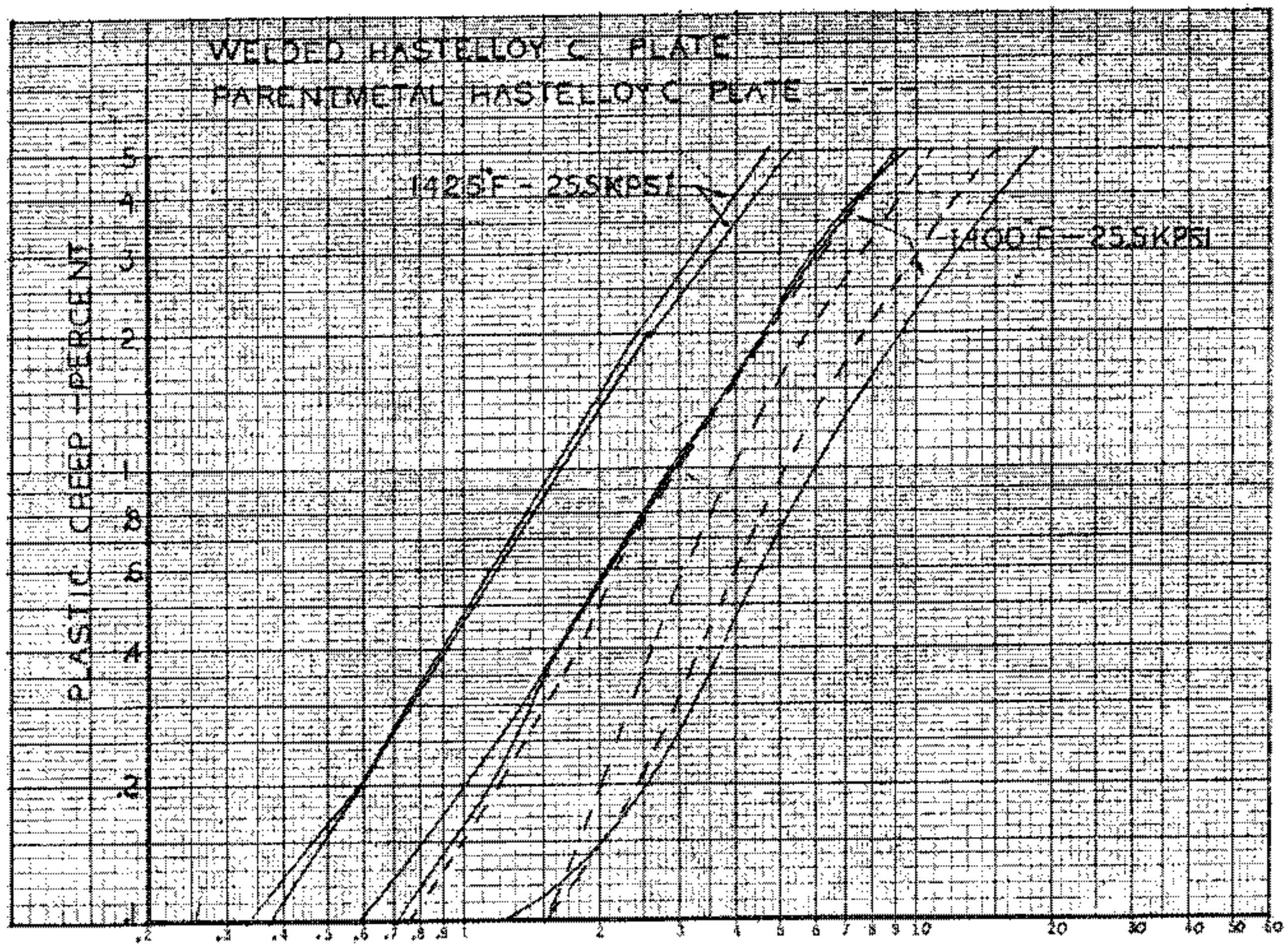


FIGURE 7 - Creep Data for Hastelloy C at 1600°F


WELDED HASTELLOY C PLATE
PARENTMETAL HASTELLOY C PLATE ----
1425 F - 25.5 KPSI
1400 F - 25.5 KPSI
PLASTIC CREEP - PERCENT
.1
.2
.4
.6
.8
1
2
3
4
5
.2
.3
.4
.5
.6
.7
.8
.9
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60

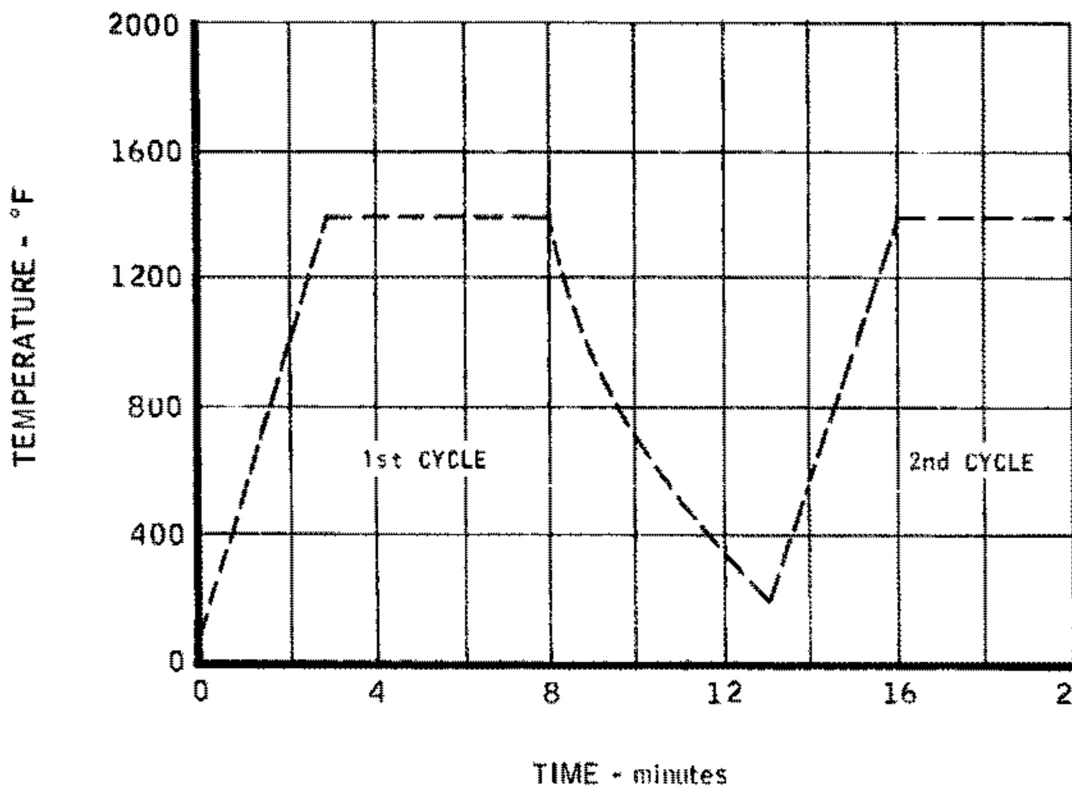
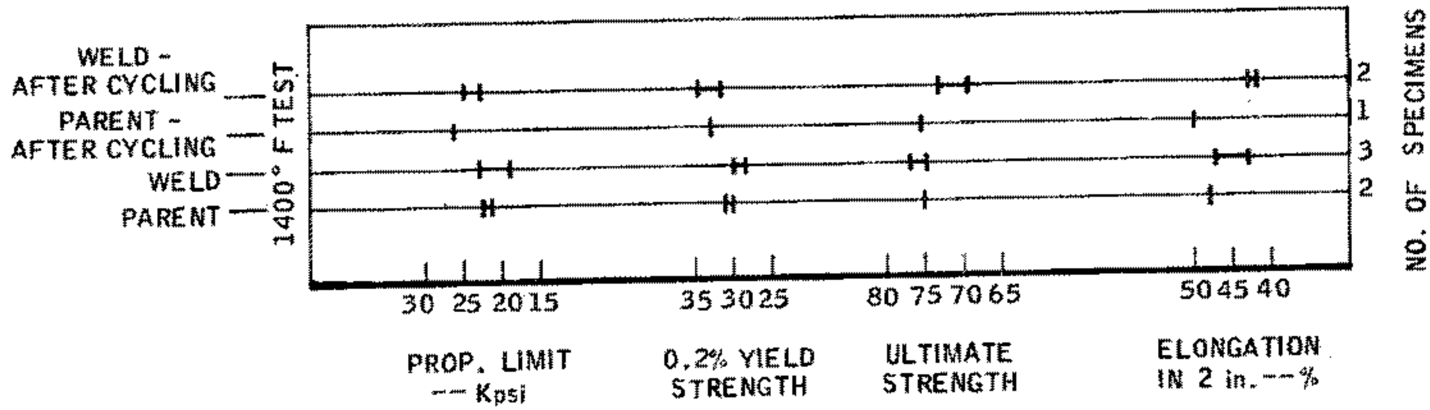


FIGURE 9 - Cyclic Test Schematic for Hastelloy C



NOTE: Cycling consisted of 35 cycles -- 150°F to 1400°F in 5 min., hold at 1400°F, 5 min., cool to 150°F in 5 min., 25.5 kpsi maintained on specimen throughout entire 35 cycles.

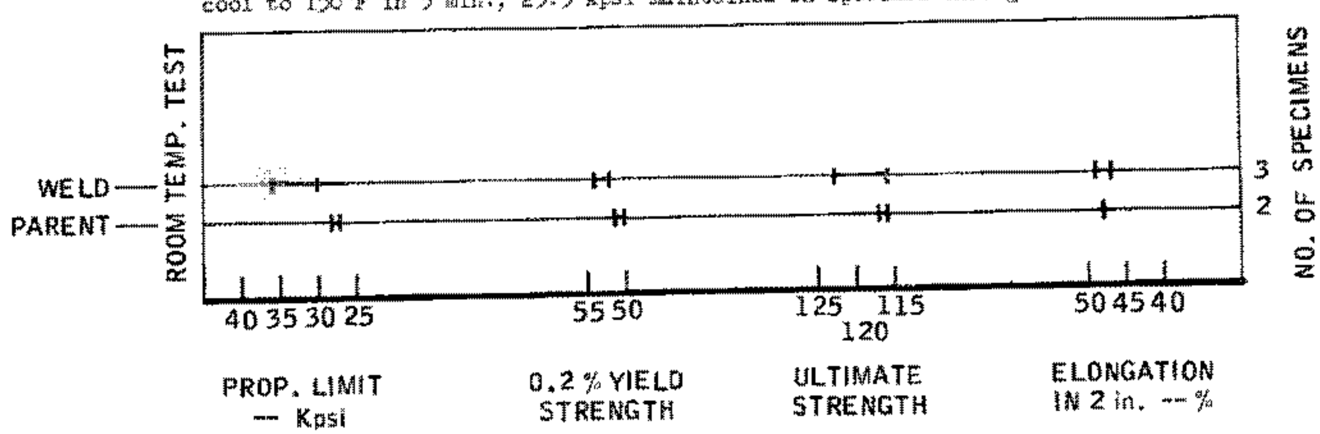
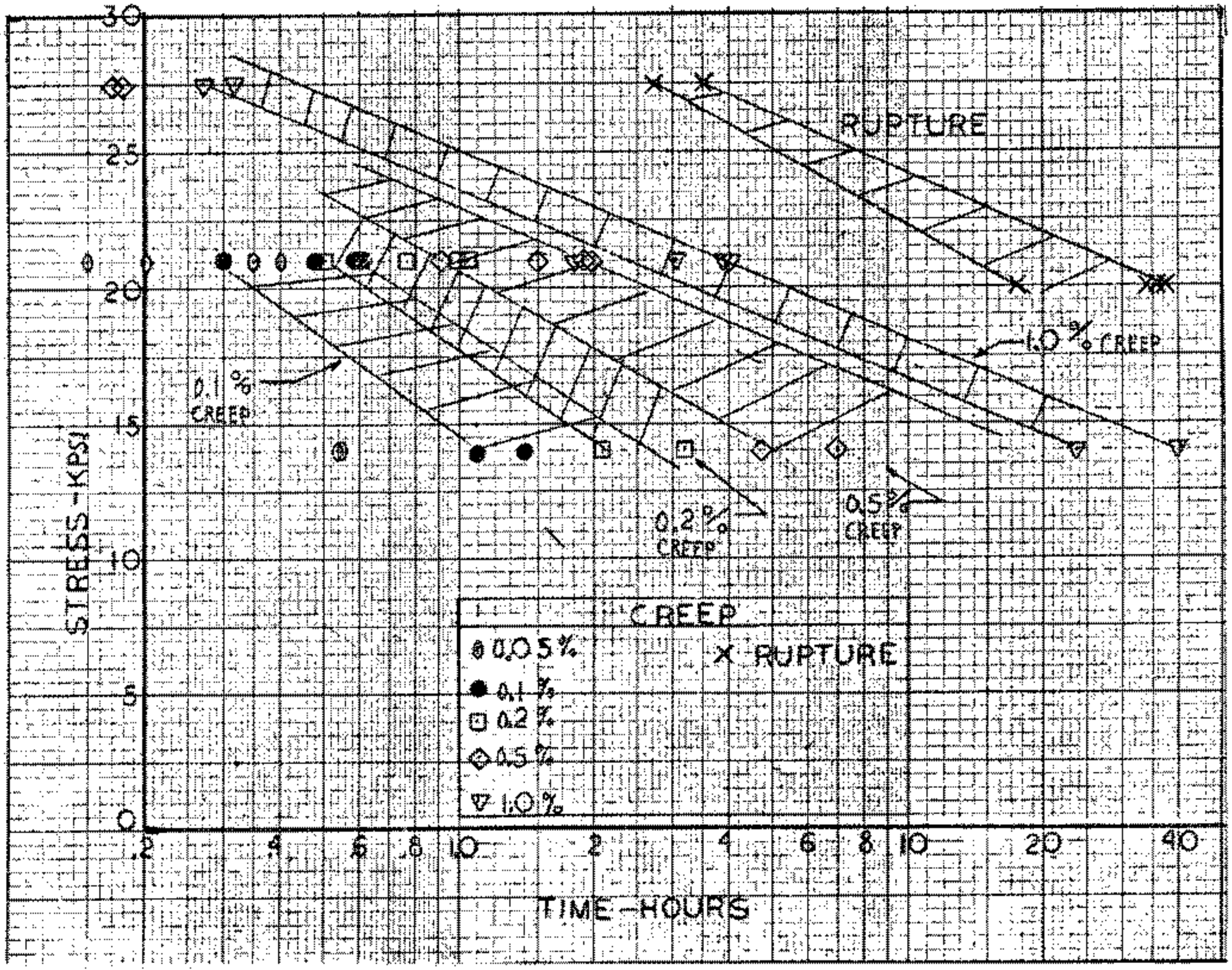
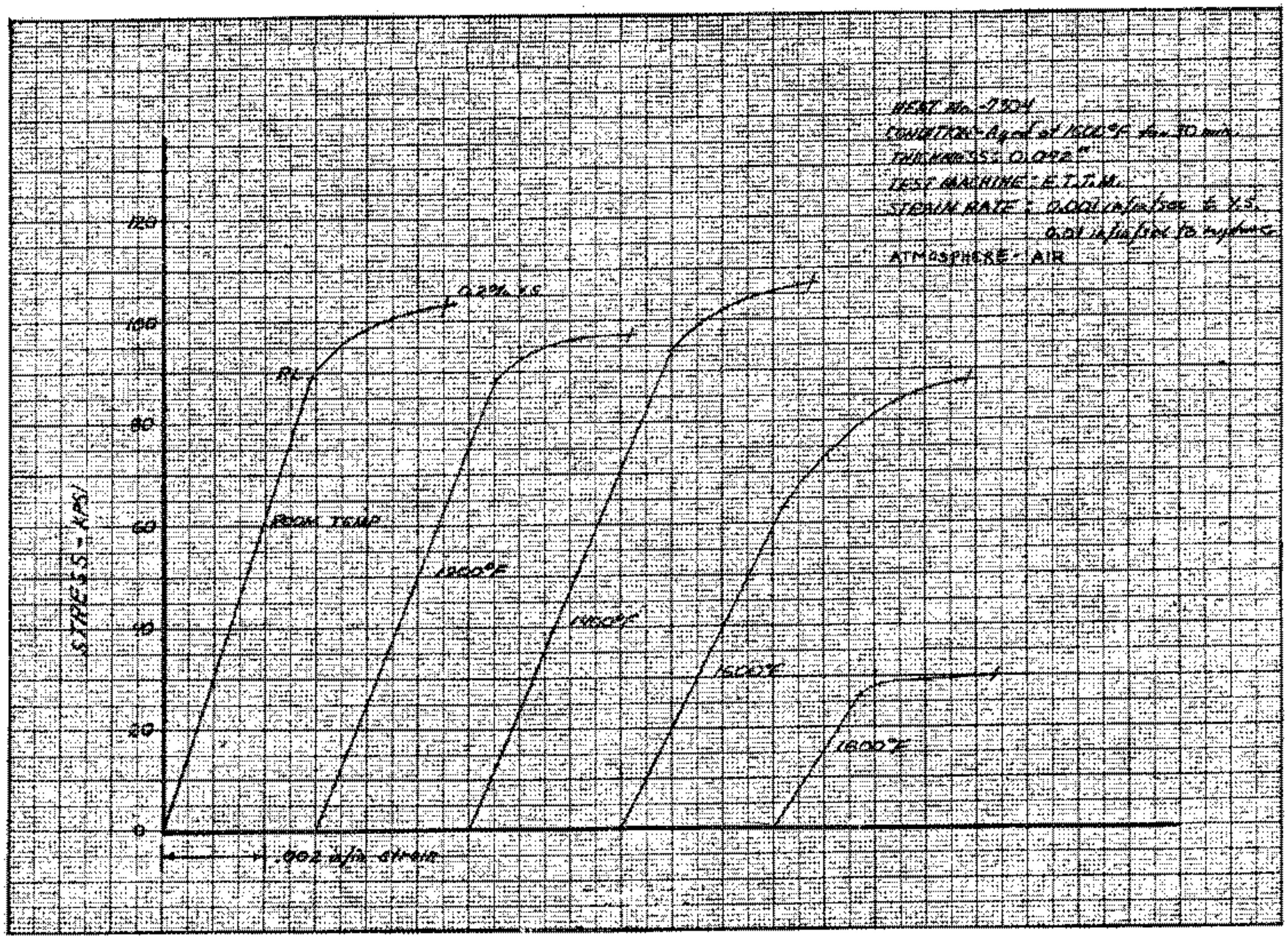


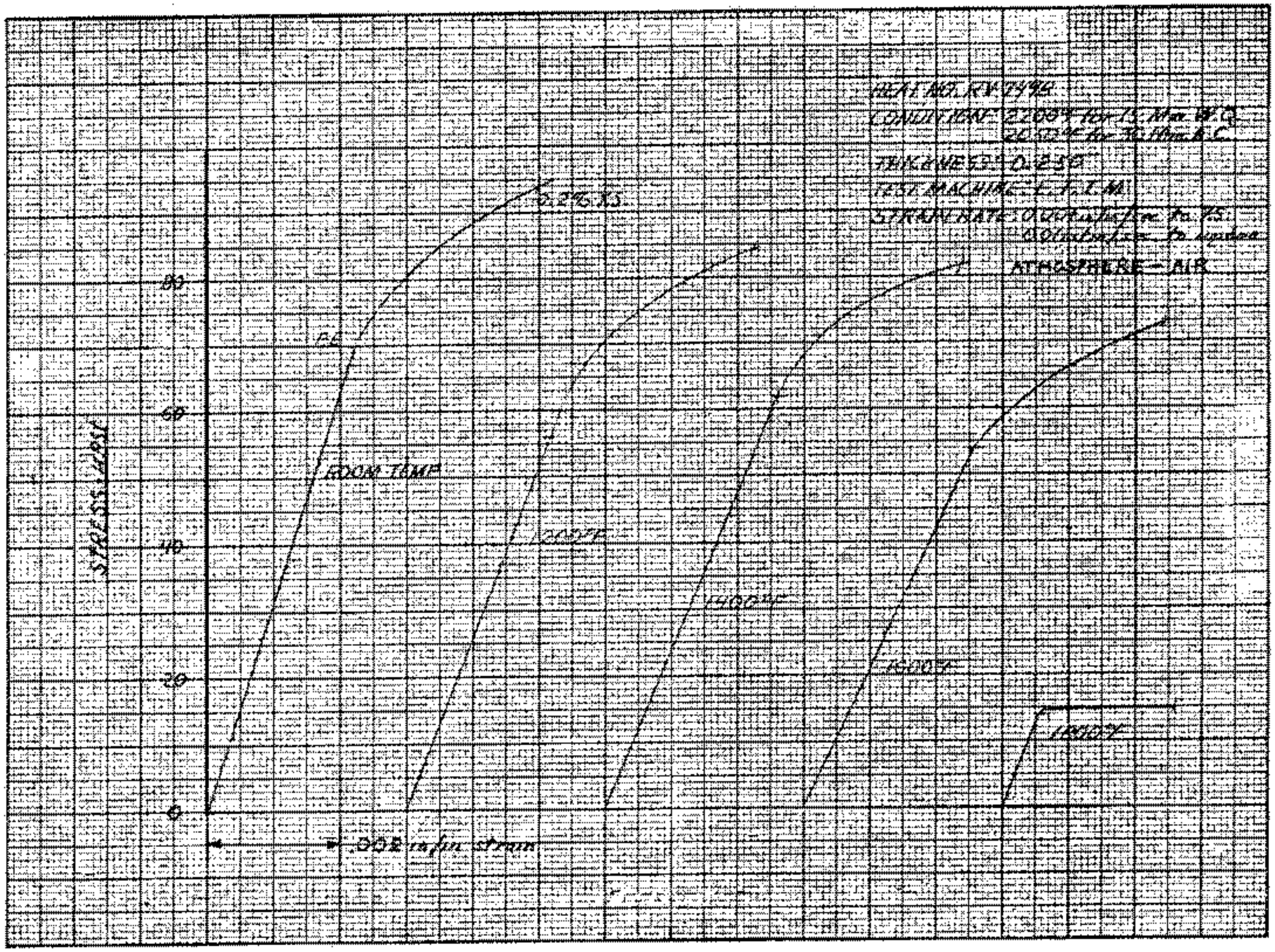
FIGURE 10 - Comparison of Tensile Properties of Vacuum Melted Hastelloy C Plate for Parent Metal and Welds



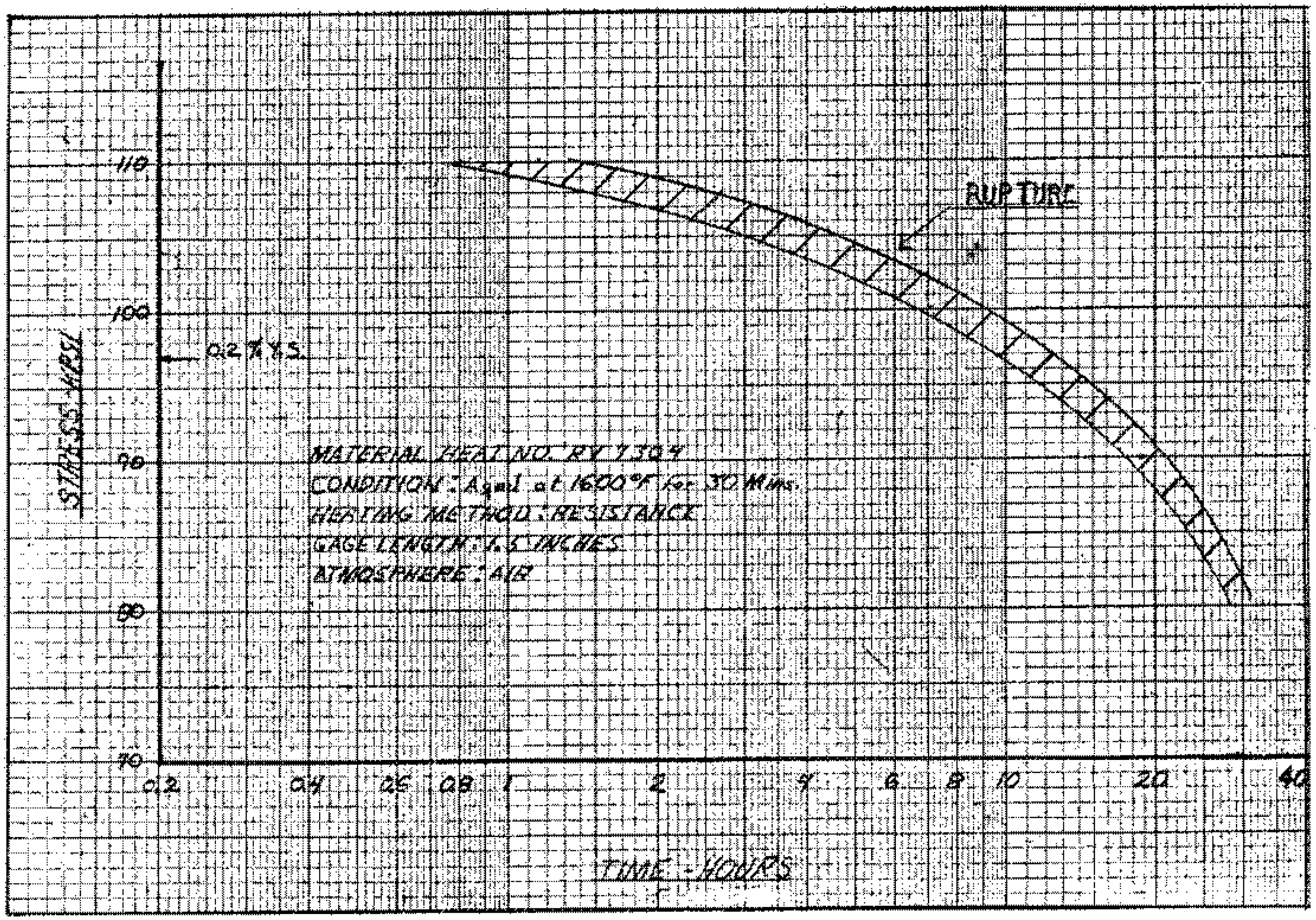
RUPTURE
1.0 % CREEP
0.1 % CREEP
0.2 % CREEP
0.5 % CREEP
CREEP
0.05 %
0.1 %
0.2 %
0.5 %
1.0 %
X RUPTURE
STRESS - KPSI
TIME - HOURS
30
25
20
15
10
5
0
.2
.4
.6
.8
1.0
2
4
6
8
10
20
40

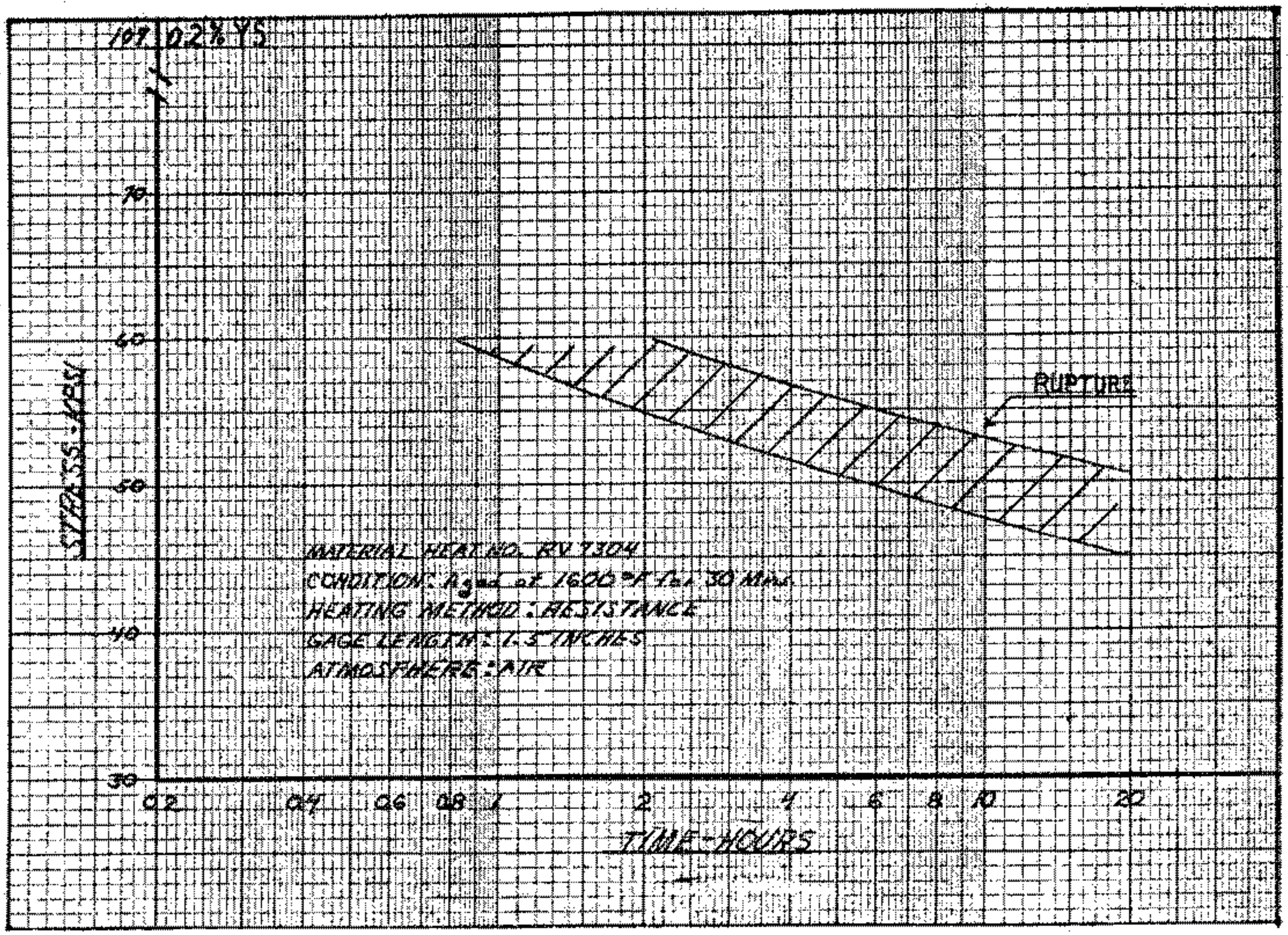


THICKNESS: 0.092"
TEST MACHINE: E.T.T.M.
STRAIN RATE: 0.001 in/in/sec
0.01 in/in/sec
ATMOSPHERE - AIR
120
100
80
60
40
20
0
STRESS - KPSI
0.2% Y.S.
PL
ROOM TEMP
1200°F
1500°F
1800°F
.002 in/in strain



ATMOSPHERE — AIR
0.2% YS
ROOM TEMP
1200°F
1400°F
1600°F
1800°F
0
20
40
60
80
.002 in/in strain


RUPTURE
0.2 % Y.S.
MATERIAL HEAT NO. RY 7304
CONDITION: Aged at 1600°F for 30 Mins.
HEATING METHOD: RESISTANCE
GAGE LENGTH: 1.5 INCHES
ATMOSPHERE: AIR
STRESS-KSI
110
100
90
80
70
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
40
TIME - HOURS



107 0.2% YS
70
60
50
40
30
STRESS - KPSI
RUPTURE
MATERIAL HEAT NO. RV 7304
CONDITION: Aged at 1600°F for 30 Min.
HEATING METHOD: RESISTANCE
GAGE LENGTH: 1.5 INCHES
ATMOSPHERE: AIR
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
TIME - HOURS

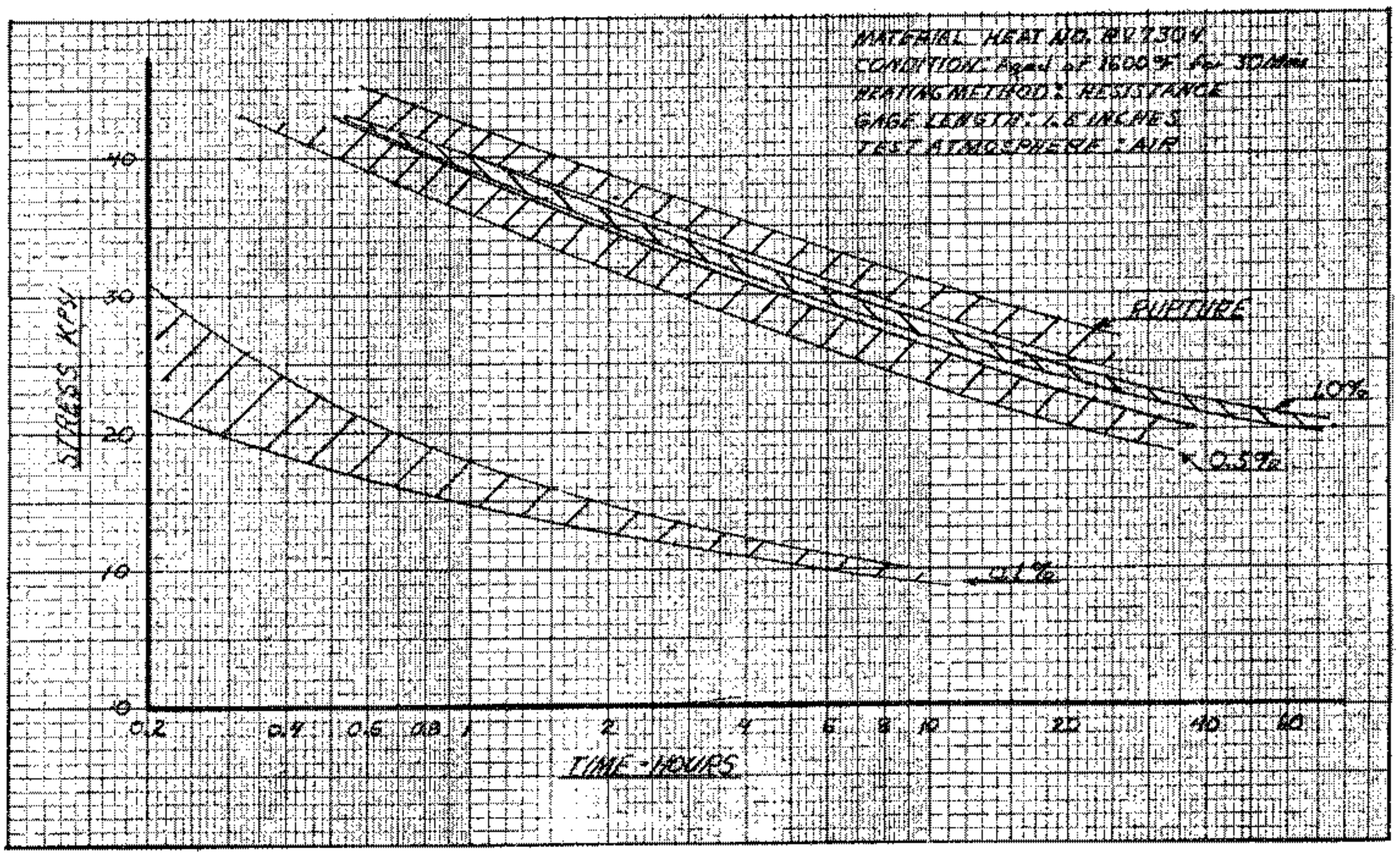
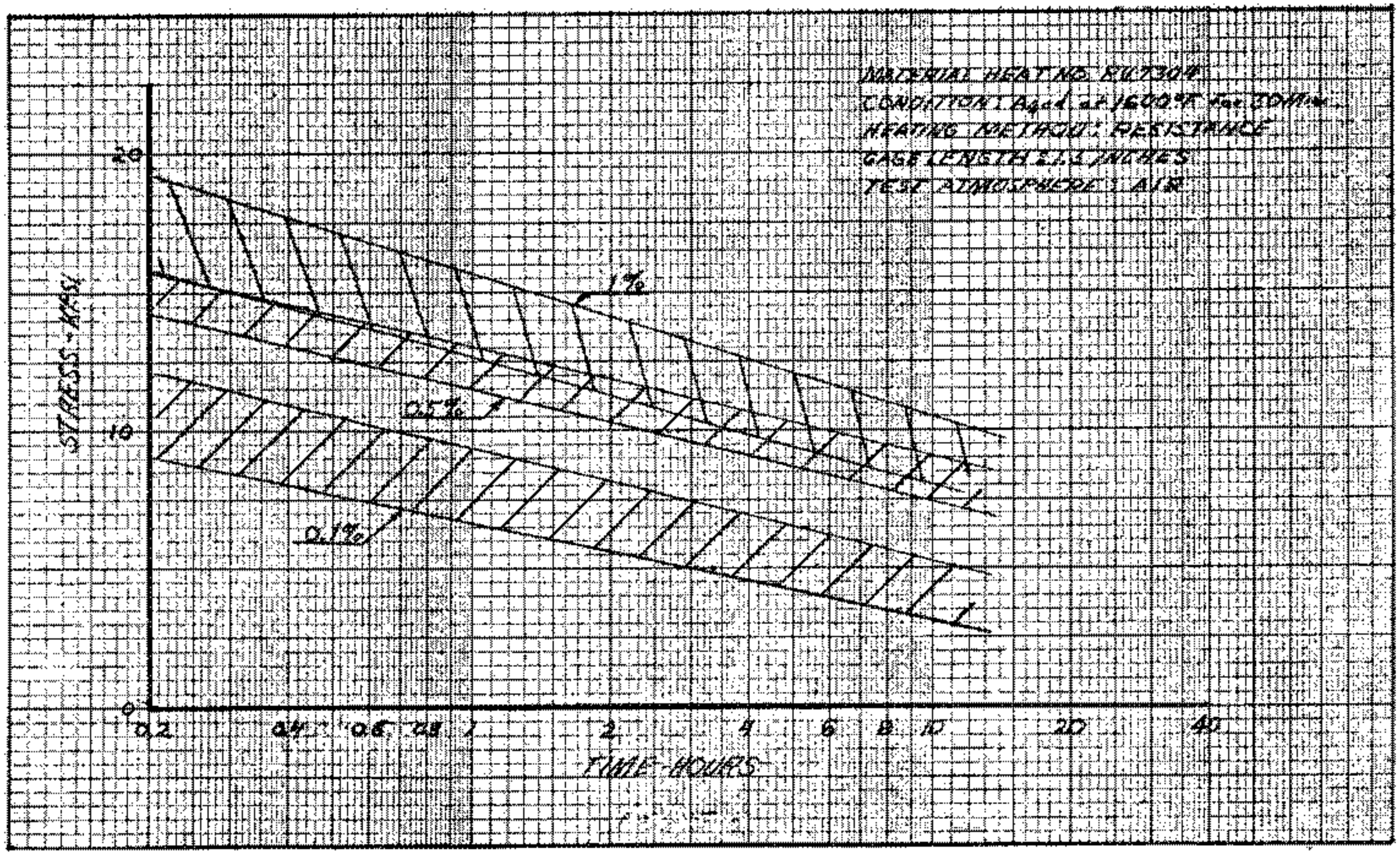
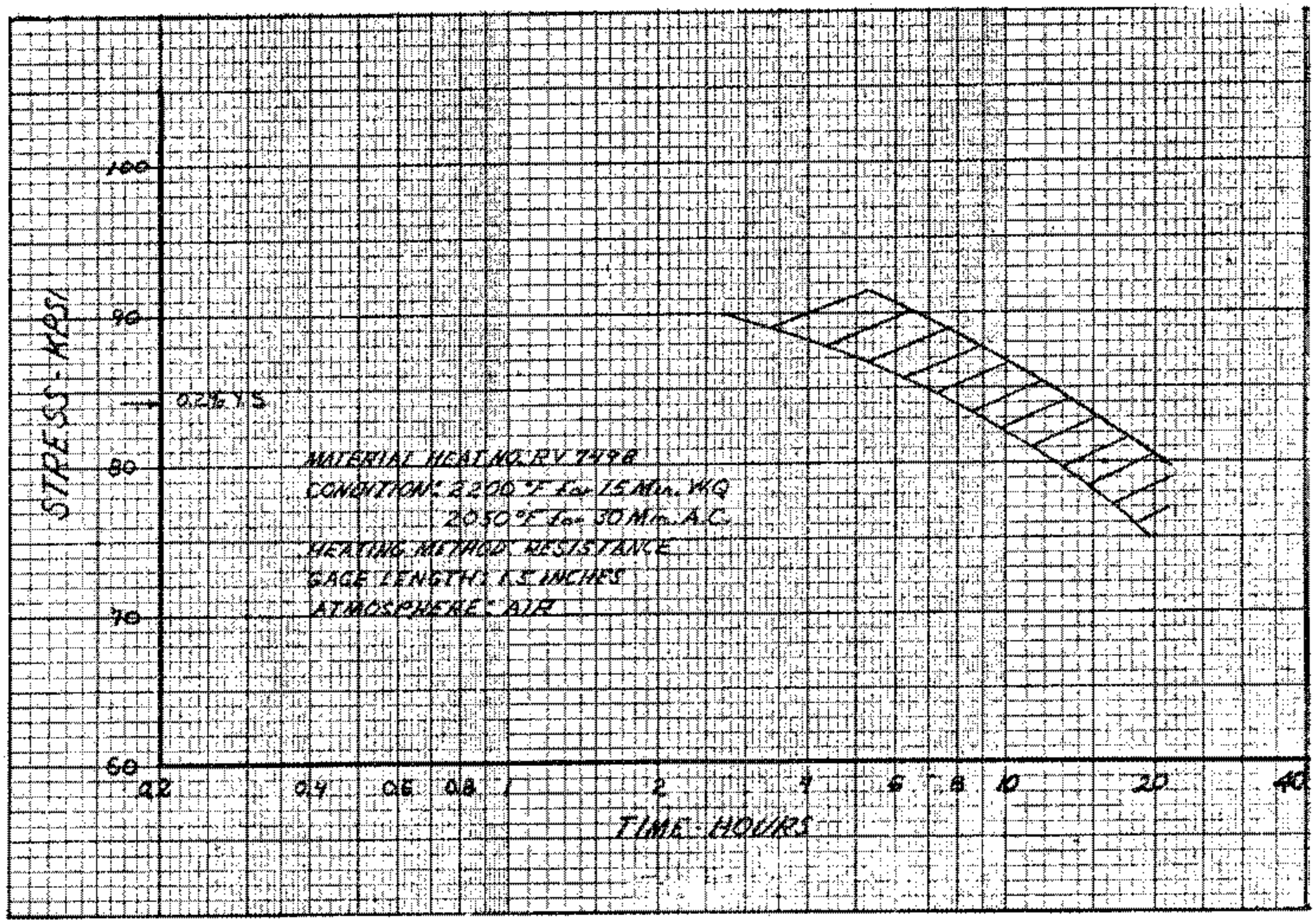


FIGURE 16 - 1600°F Creep and Stress-Rupture Data for R-235 Alloy, 0.072-inch Sheet


MATERIAL HEAT NO. RU7304
CONDITION: Aged at 1600°F for 30 Min
HEATING METHOD: RESISTANCE
GAGE LENGTH INCHES
TEST ATMOSPHERE: AIR
1%
0.5%
0.1%
STRESS - KSI
20
10
0
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
40
TIME - HOURS



STRESS - KPSI
100
90
0.2% Y.S
80
70
60
MATERIAL HEAT NO. RV 7498
CONDITION: 2200 °F for 15 Min. WQ
2050 °F for 30 Min. A.C.
HEATING METHOD: RESISTANCE
GAGE LENGTH: 1.5 INCHES
ATMOSPHERE: AIR
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
40
TIME - HOURS

MAC A673

28B312

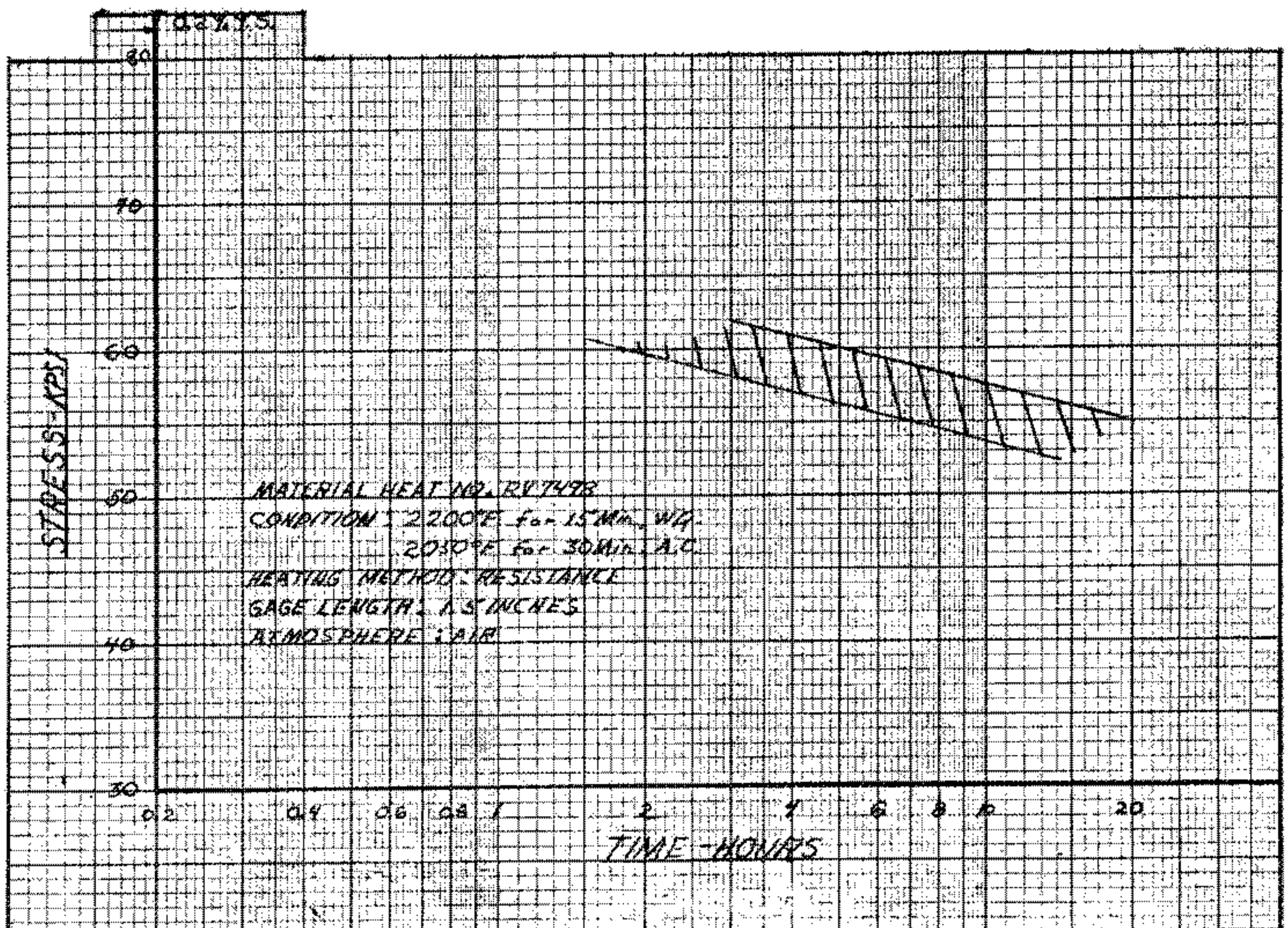


FIGURE 19 - 1400°F Stress-Rupture Data for R-235 Alloy, 0.250-inch Plate

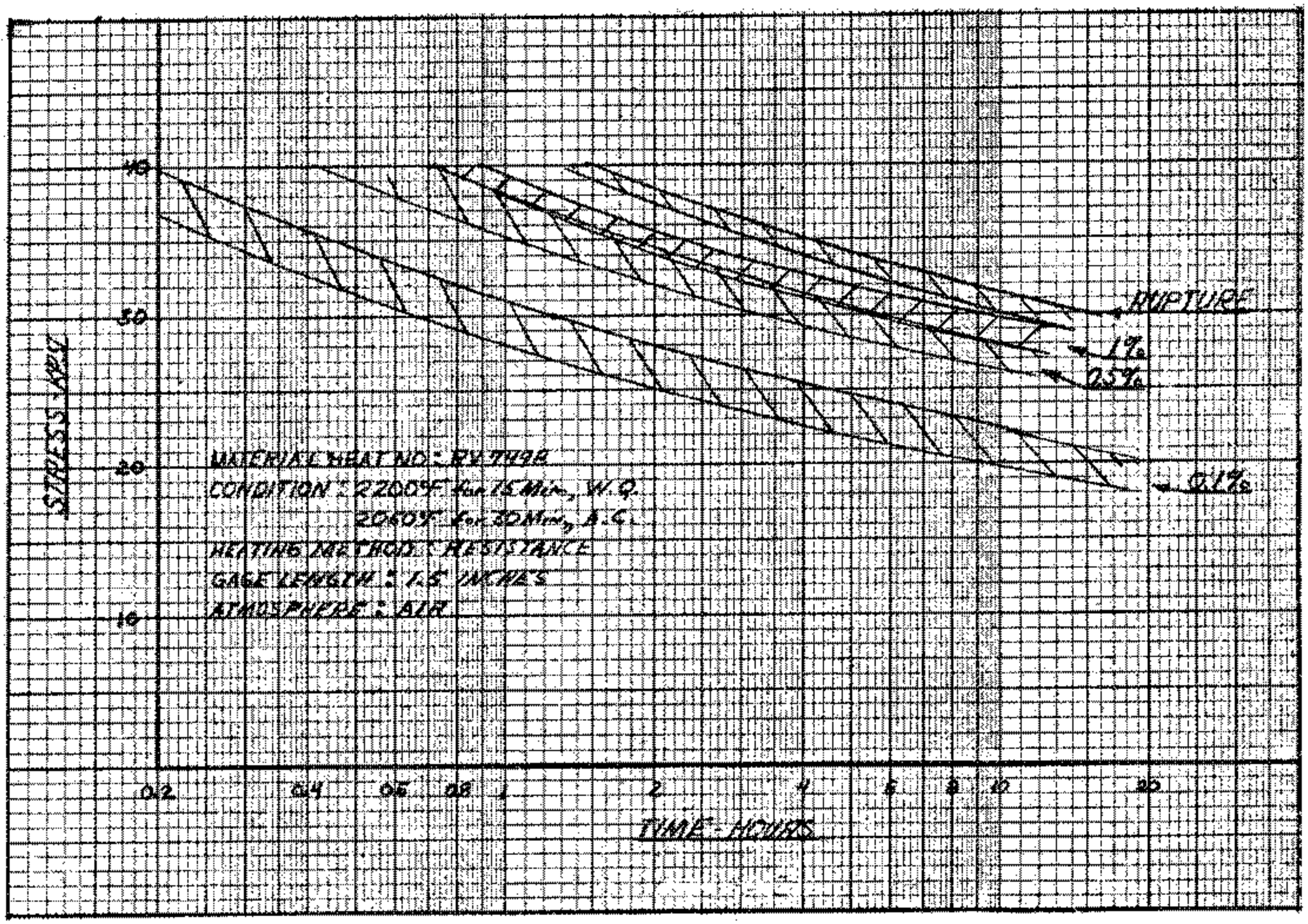


FIGURE 20 - 1600°F Creep and Stress-Rupture Data for R-235 Alloy, 0.250-inch Plate

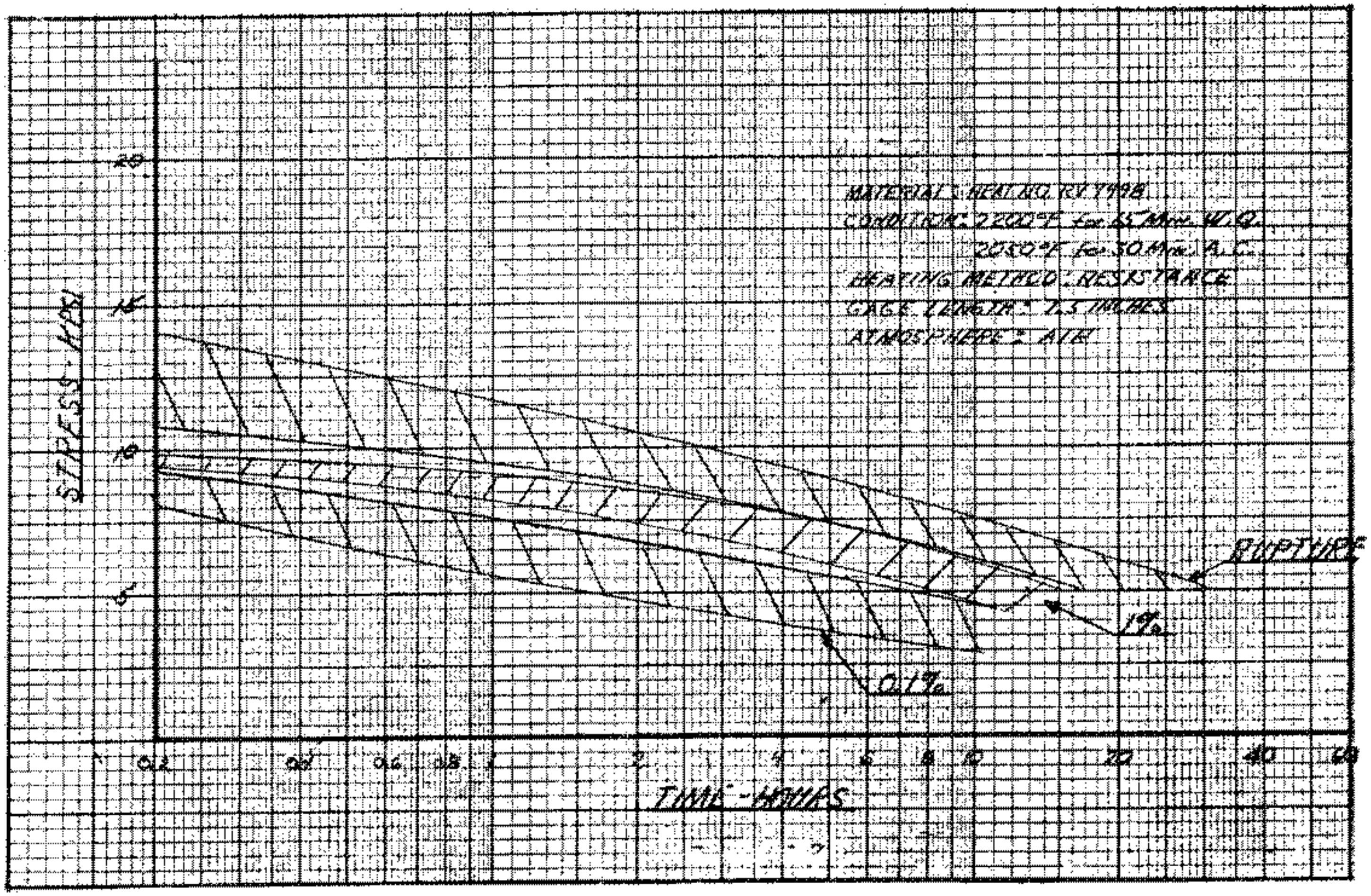


FIGURE 21 - 1800°F Creep and Stress-Rupture Data for A-235 Alloy, 0.250-inch Plate

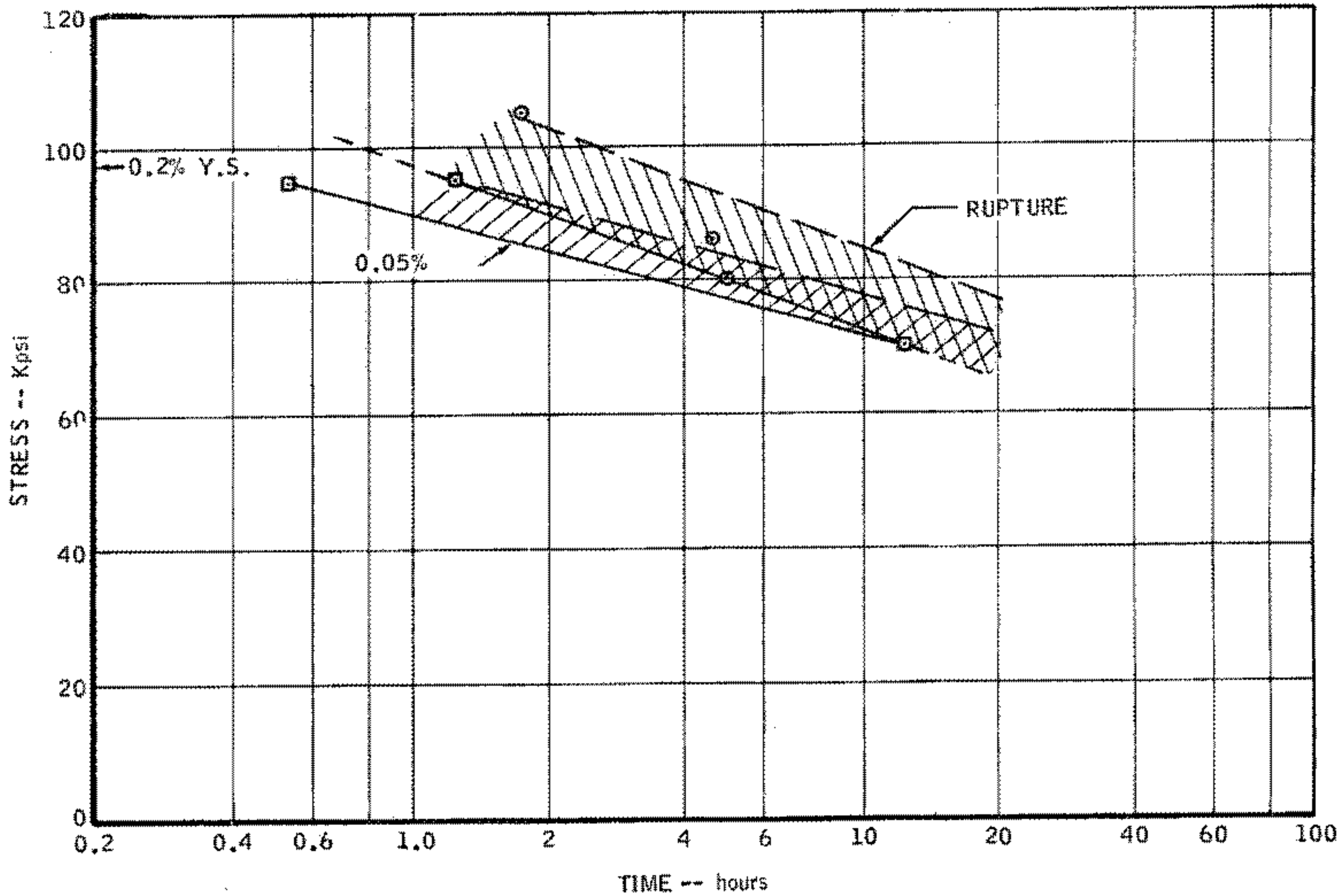


FIGURE 22 - Stress-Rupture Properties at 1200°F of 0.063-inch R-235 Sheet Welded Transverse without Filler Metal

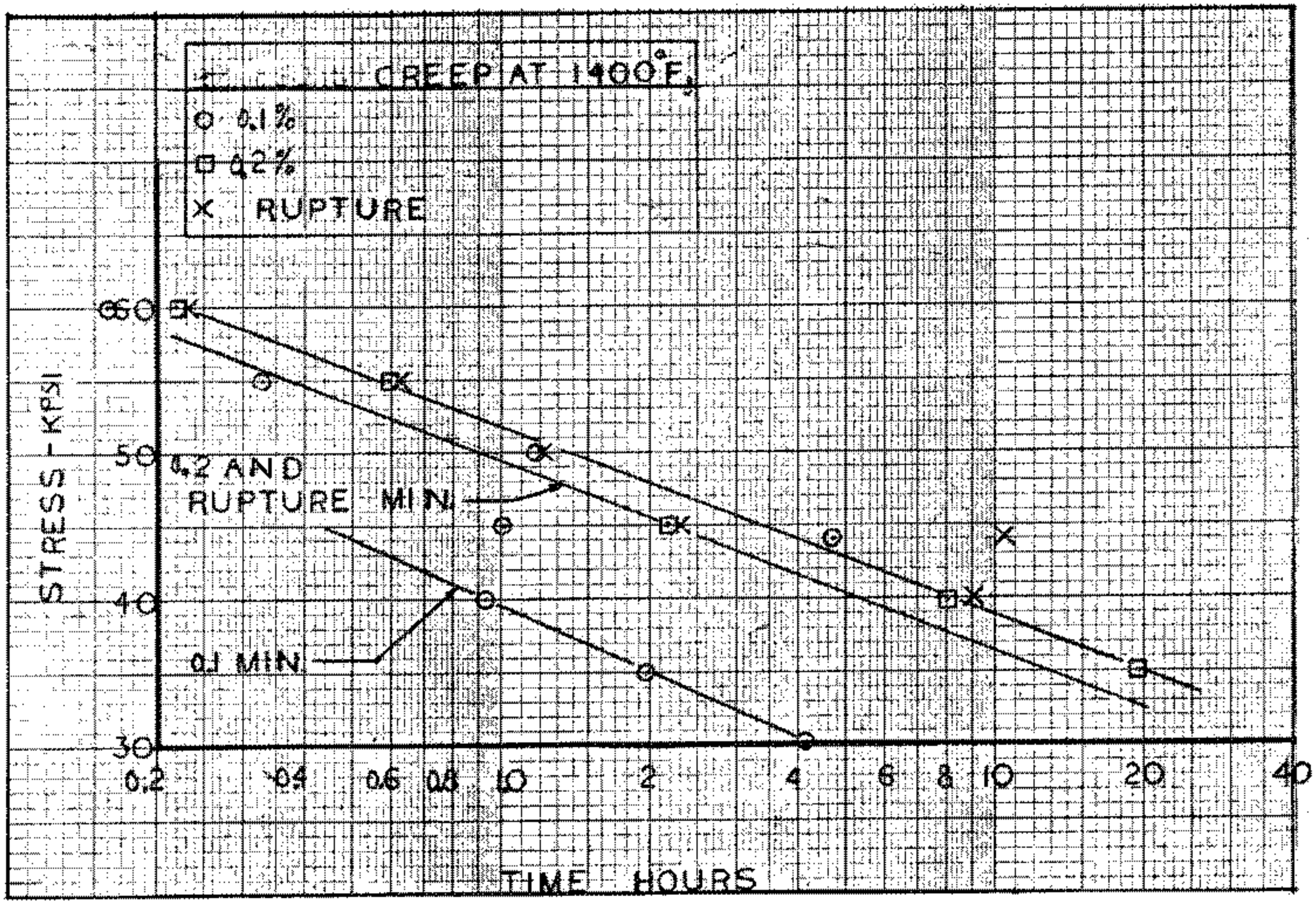


FIGURE 23 - Stress-Rupture Properties at 1400°F of 0.063-inch R-235 Sheet Welded Transverse without Filler Metal

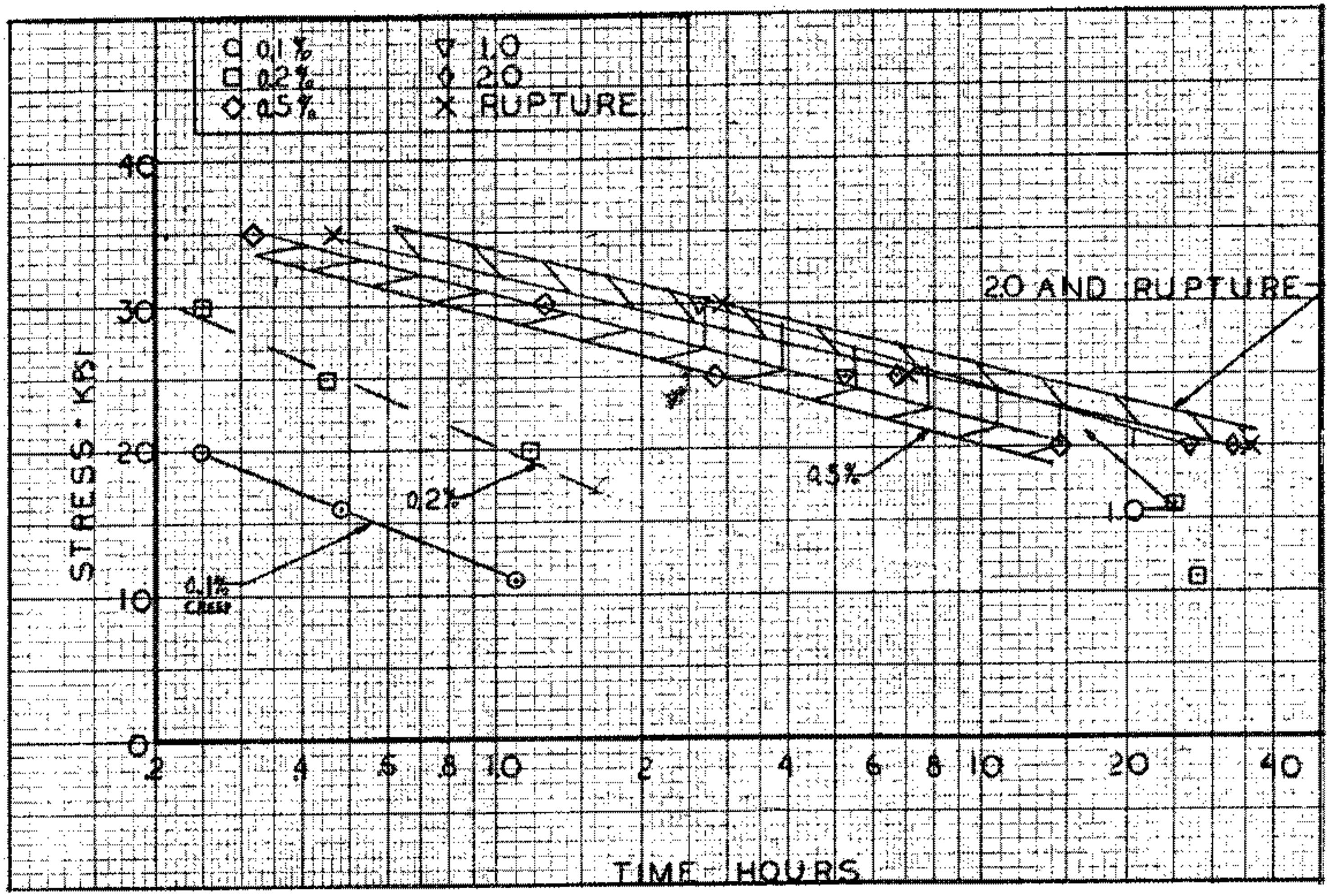
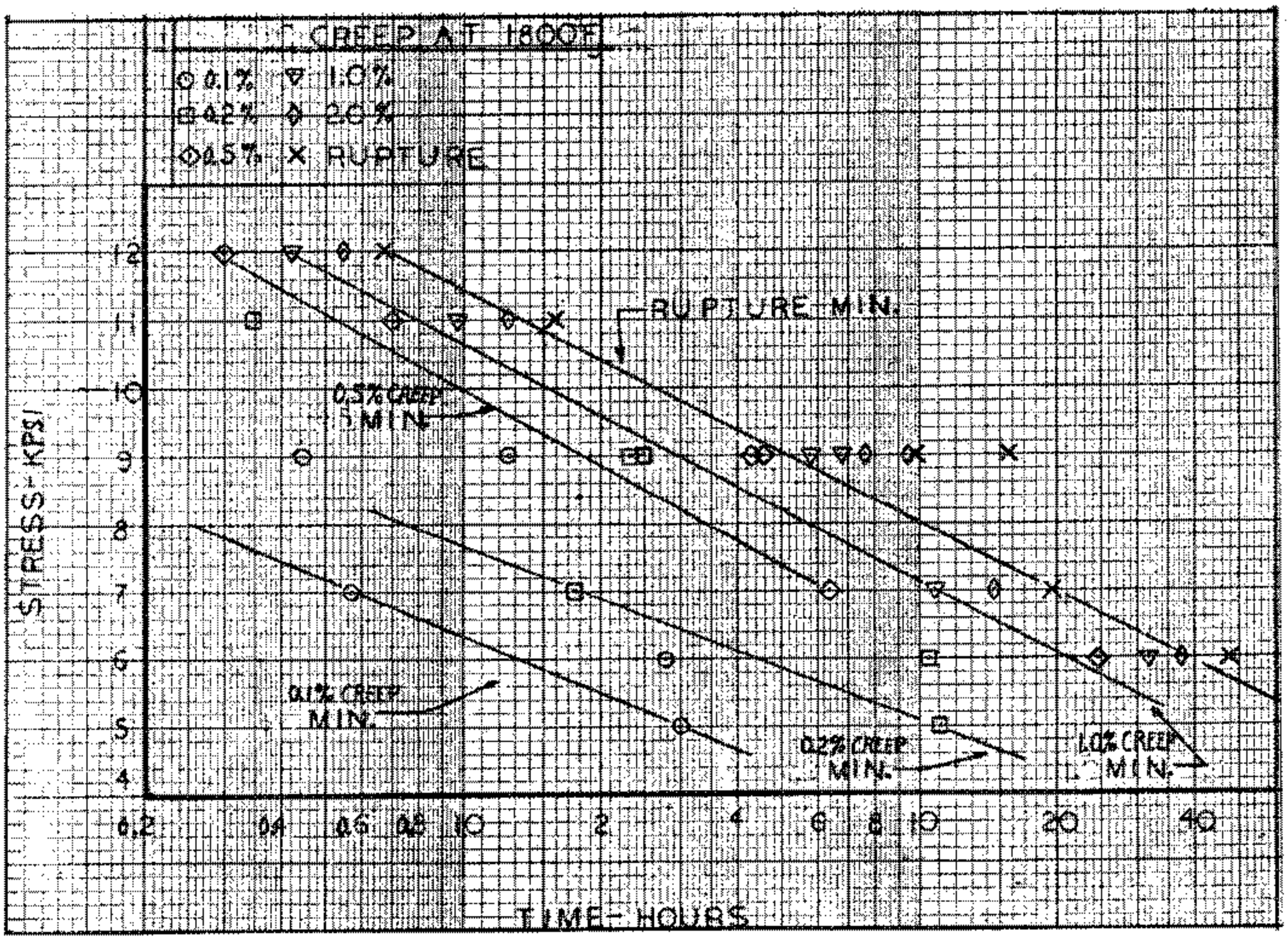
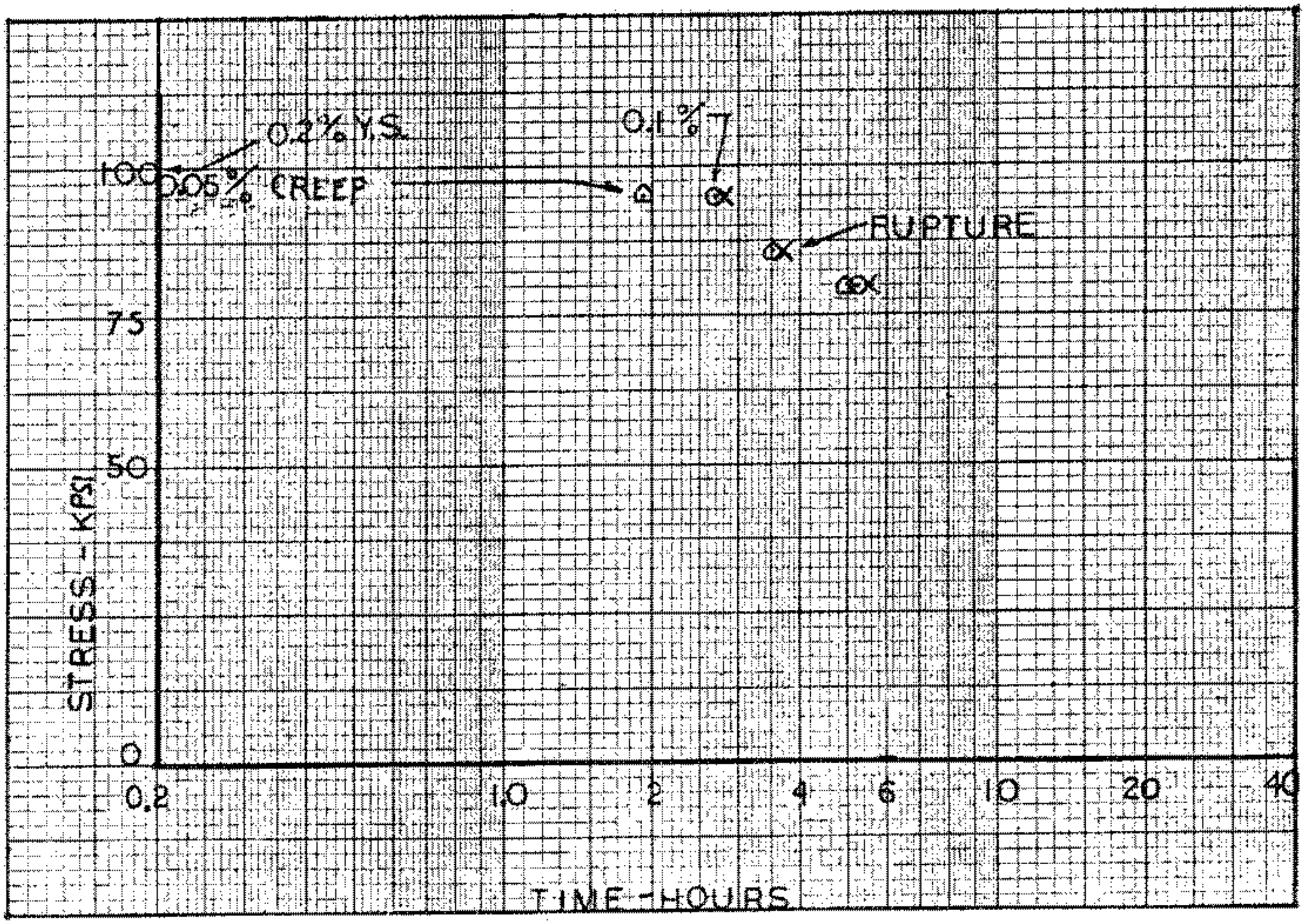


FIGURE 24 - Creep-Rupture Properties at 1600°F of 0.063-inch R-235 Sheet Welded Transverse without Filler Metal



CREEP AT 1800F
0.1%
1.0%
0.2%
2.0%
0.5%
RUPTURE
RUPTURE MIN.
0.5% CREEP MIN.
0.1% CREEP MIN.
0.2% CREEP MIN.
1.0% CREEP MIN.
STRESS - KPSI
TIME - HOURS
12
11
10
9
8
7
6
5
4
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
20
40


0.2% Y.S.
0.1%
100
0.05% CREEP
RUPTURE
75
50
0
STRESS - KPSI
0.2
1.0
2
4
6
10
20
40
TIME - HOURS

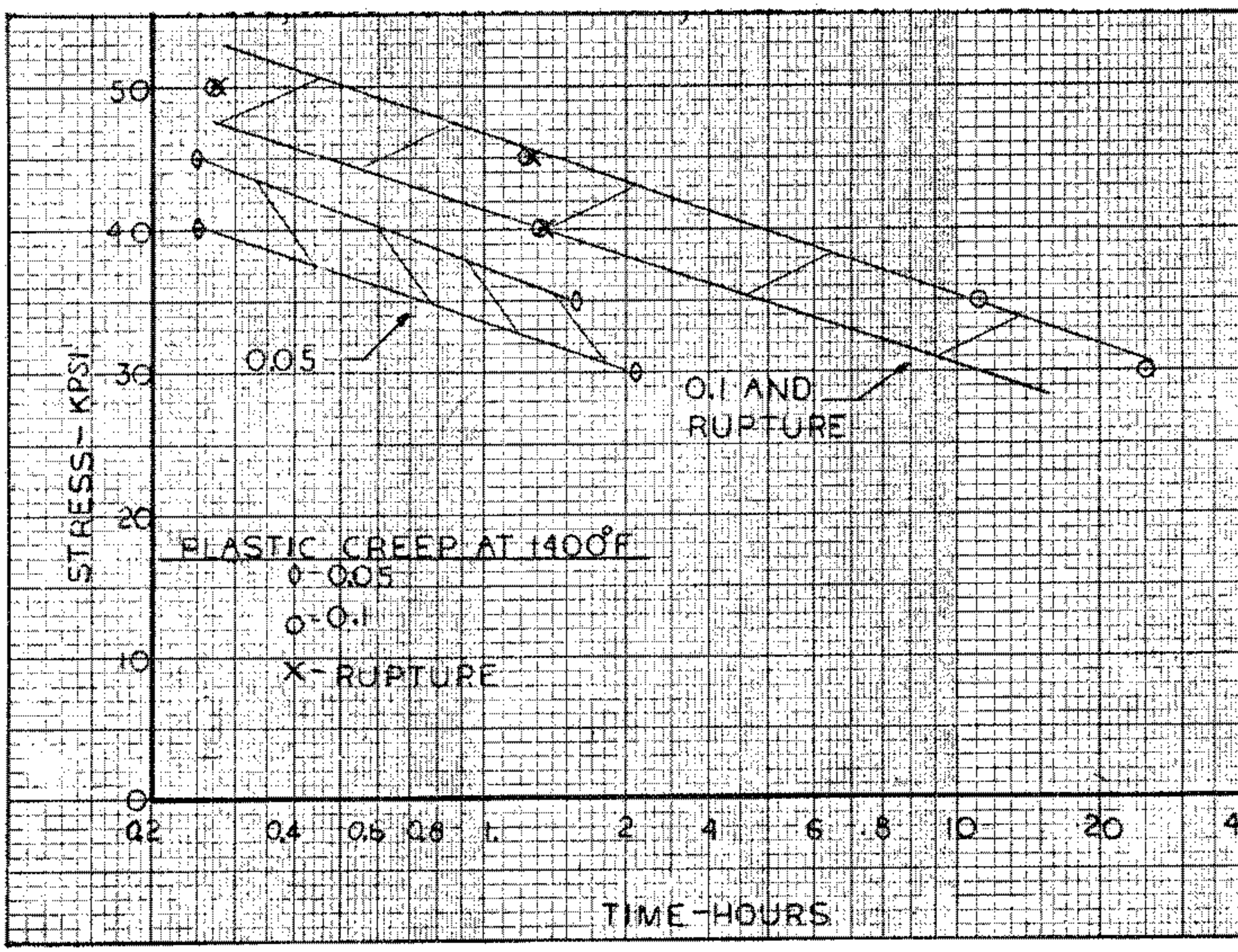
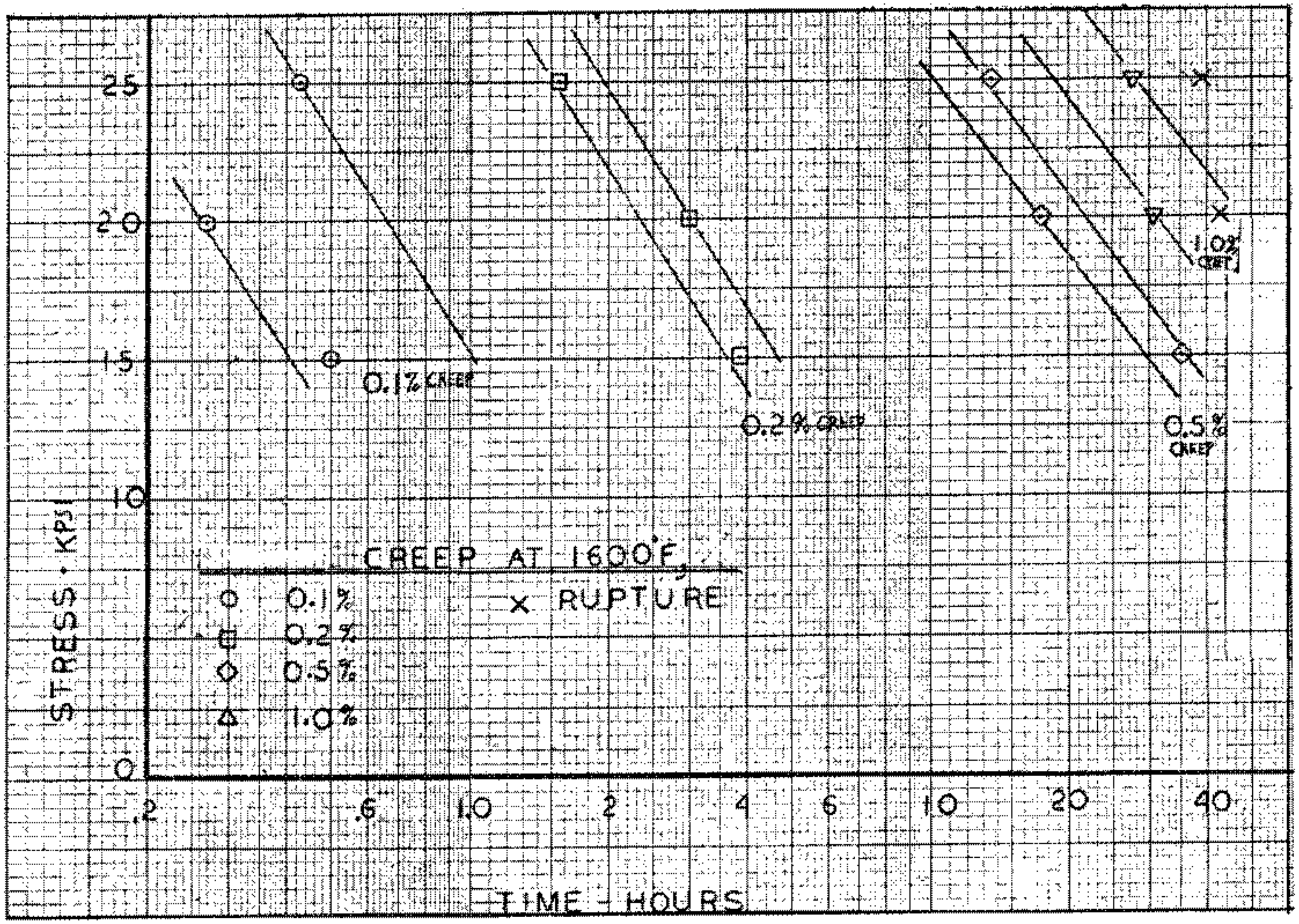


FIGURE 27 - Creep-Rupture Properties at 1400°F of 0.063-inch R-235 Sheet Welded Transverse with R-235 Filler Metal



25
20
15
10
0
STRESS - KPSI
.2
.6
1.0
2
4
6
10
20
40
TIME - HOURS
0.1% CREEP
0.2% CREEP
0.5% CREEP
1.0% CREEP
CREEP AT 1600°F
0.1%
0.2%
0.5%
1.0%
X RUPTURE

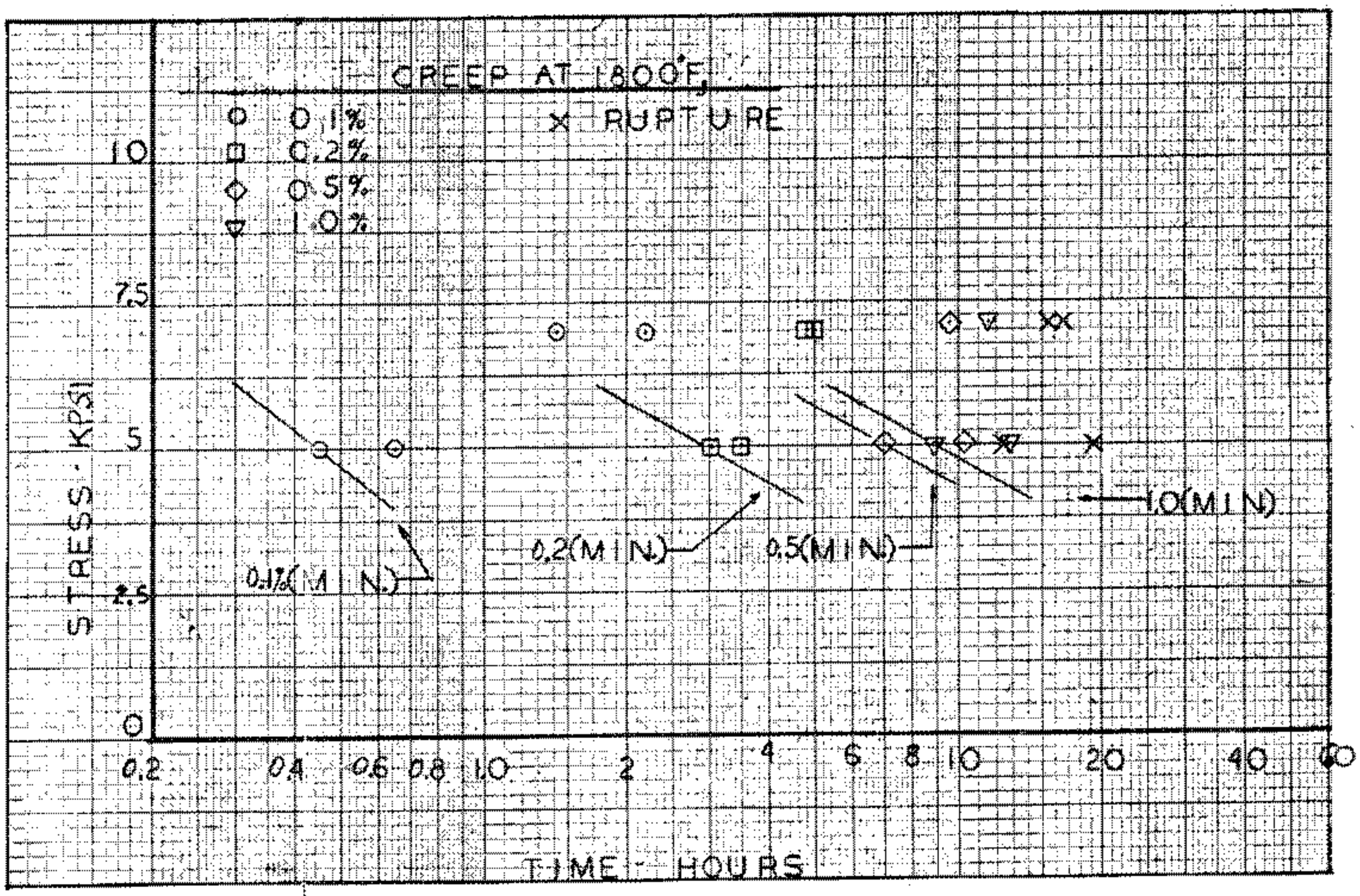


FIGURE 29 - Creep-Rupture Properties at 1800°F of 0.063-inch R-235 Sheet Welded with R-235 Filler Metal

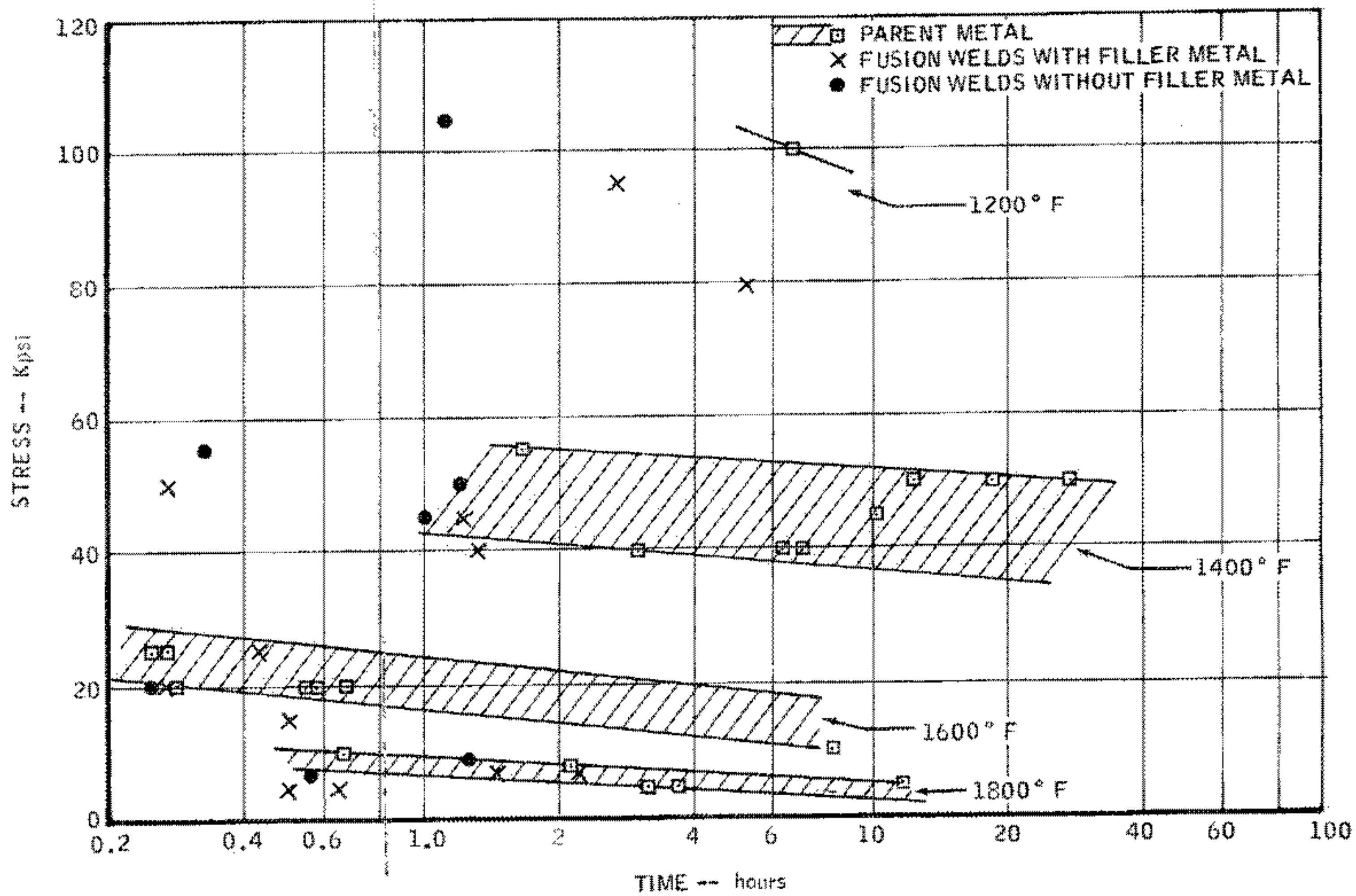


FIGURE 36 - 0.1% Creep of R-235 Nickel Base Alloy Sheet, Parent Metal vs. Fusion Welds

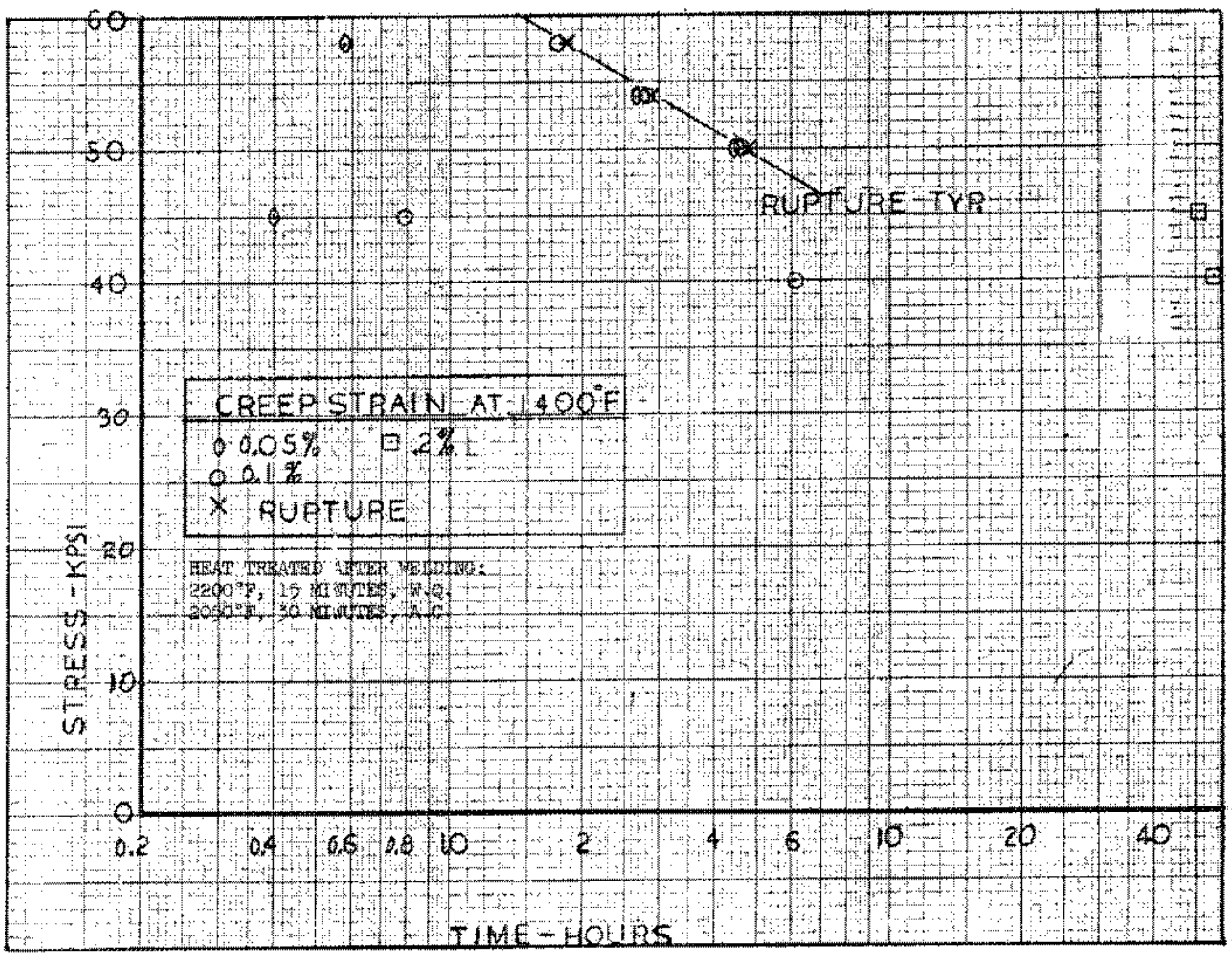
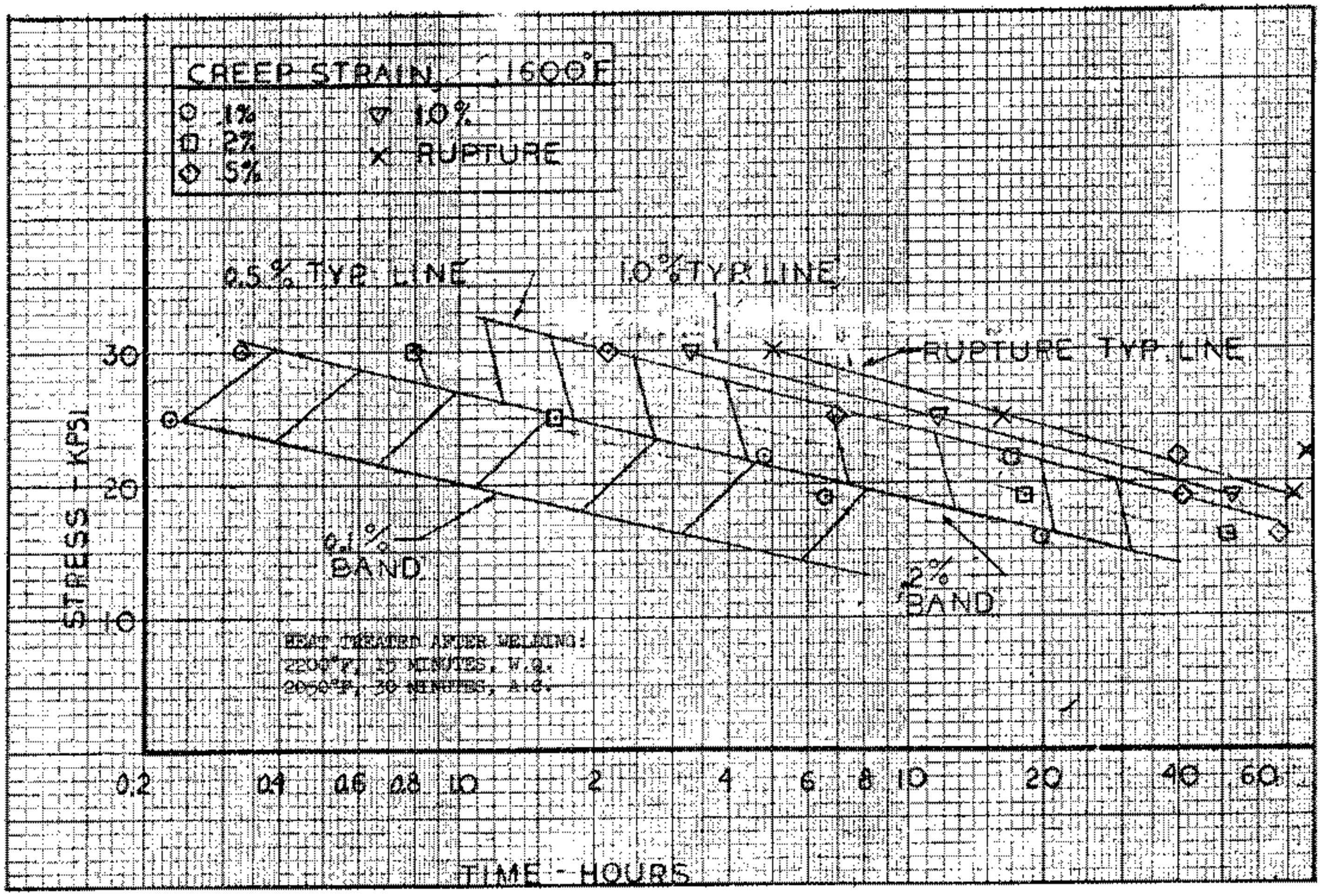


FIGURE 31 - Creep-Rupture Properties at 1400°F of 0.250-inch R-235 Plate Welded with R-235 Filler Metal



CREEP STRAIN, 1600°F
○ 1%
□ 2%
◇ 5%
▽ 10%
× RUPTURE
0.5% TYP LINE
1.0% TYP LINE
RUPTURE TYP LINE
0.1% BAND
2% BAND
HEAT TREATED AFTER WELDING:
2200°F, 15 MINUTES, W.Q.
2050°F, 30 MINUTES, A.C.
STRESS - KPSI
10
20
30
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
20
40
60
TIME - HOURS

MAC A472

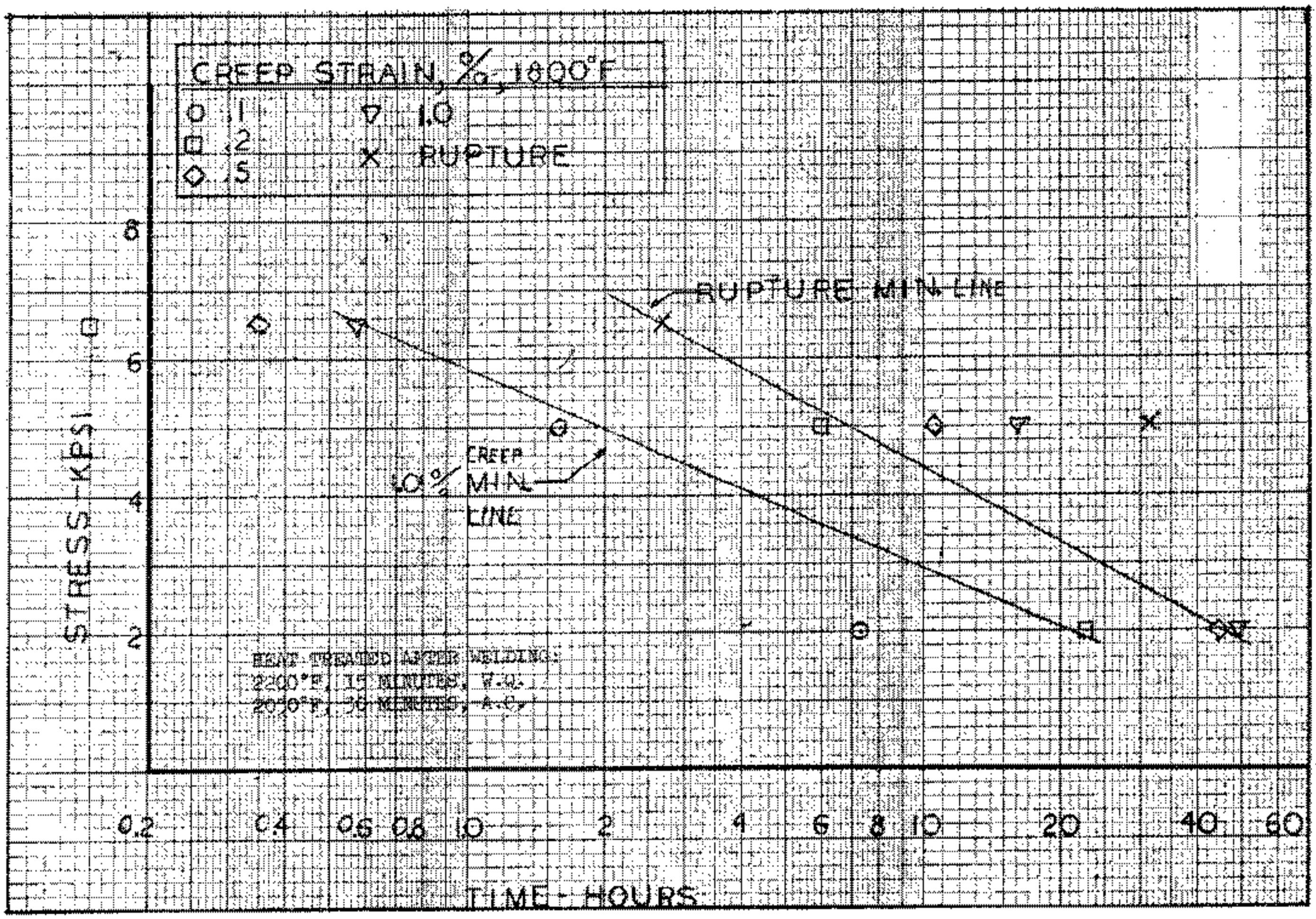


FIGURE 35 - Creep-Rupture Properties at 1800°F of 0.050-Inch R-235 Plate Welded with R-235 Filler Wire

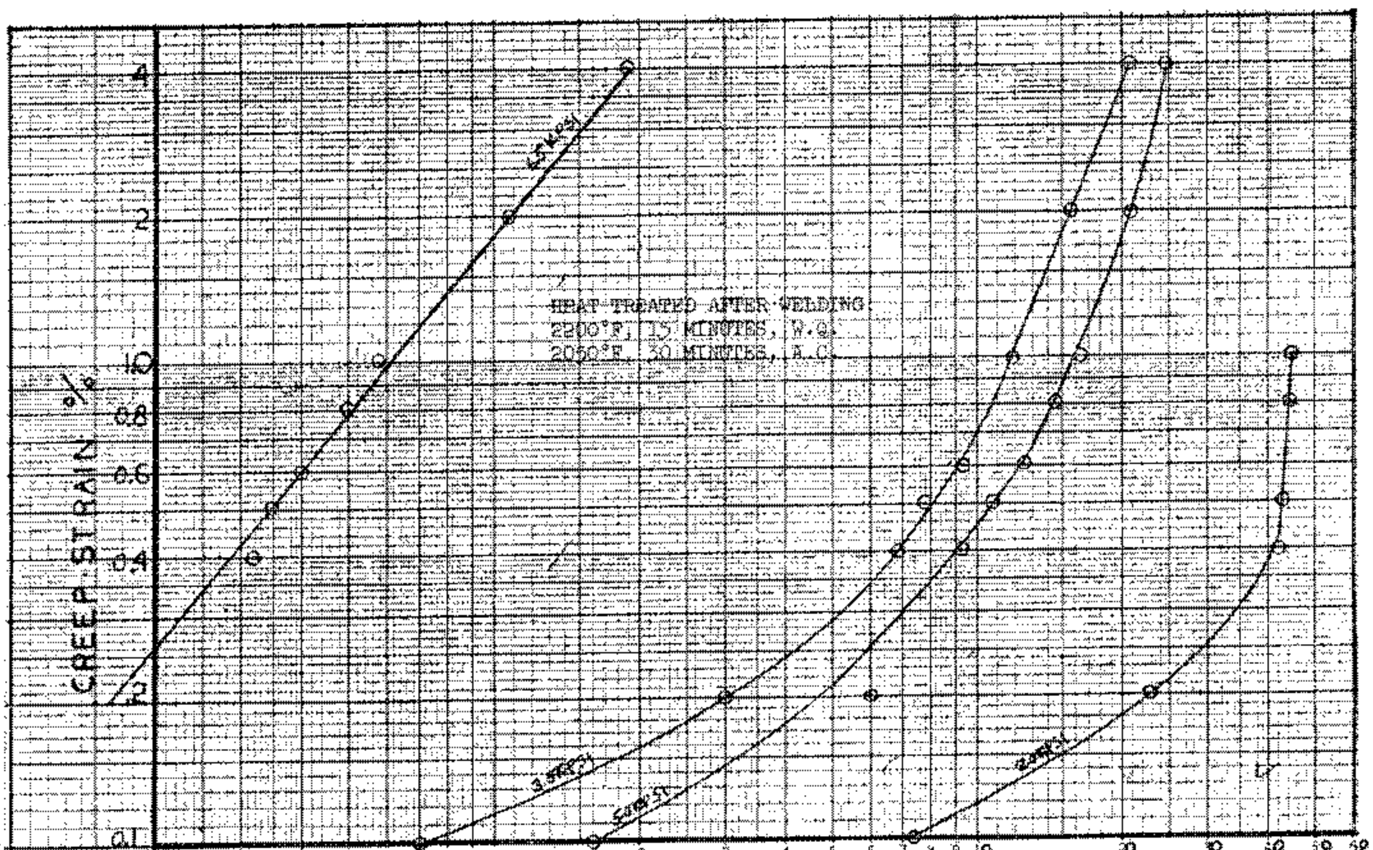


FIGURE 34 - Creep at 1500°F of 0.250-inch R-235 Plate Welded with R-235 Filler Wire

MAC A673

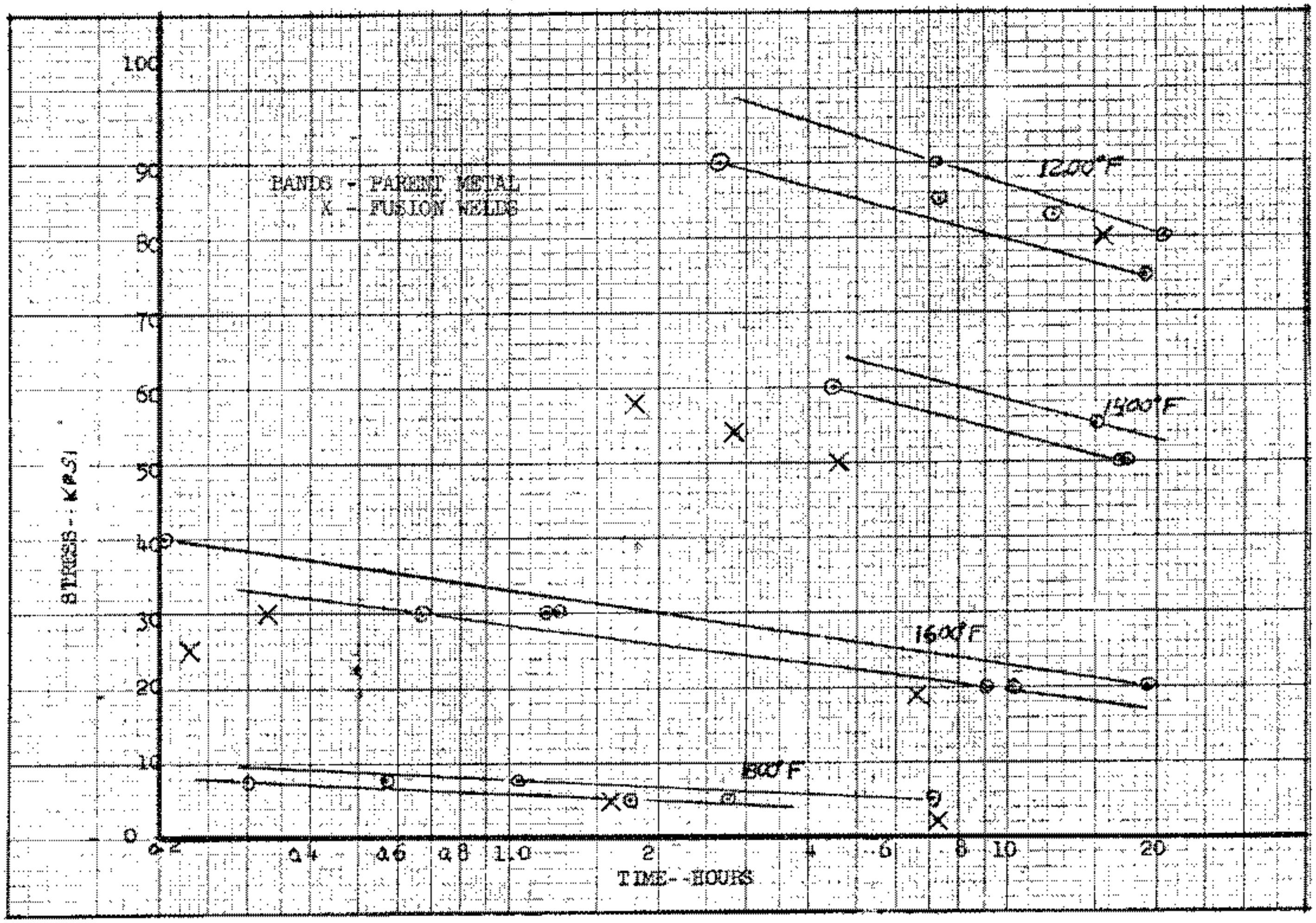


FIGURE 35 - 0.2% Creep of N-155 Plate, Parent Metal vs. Fusion Welds

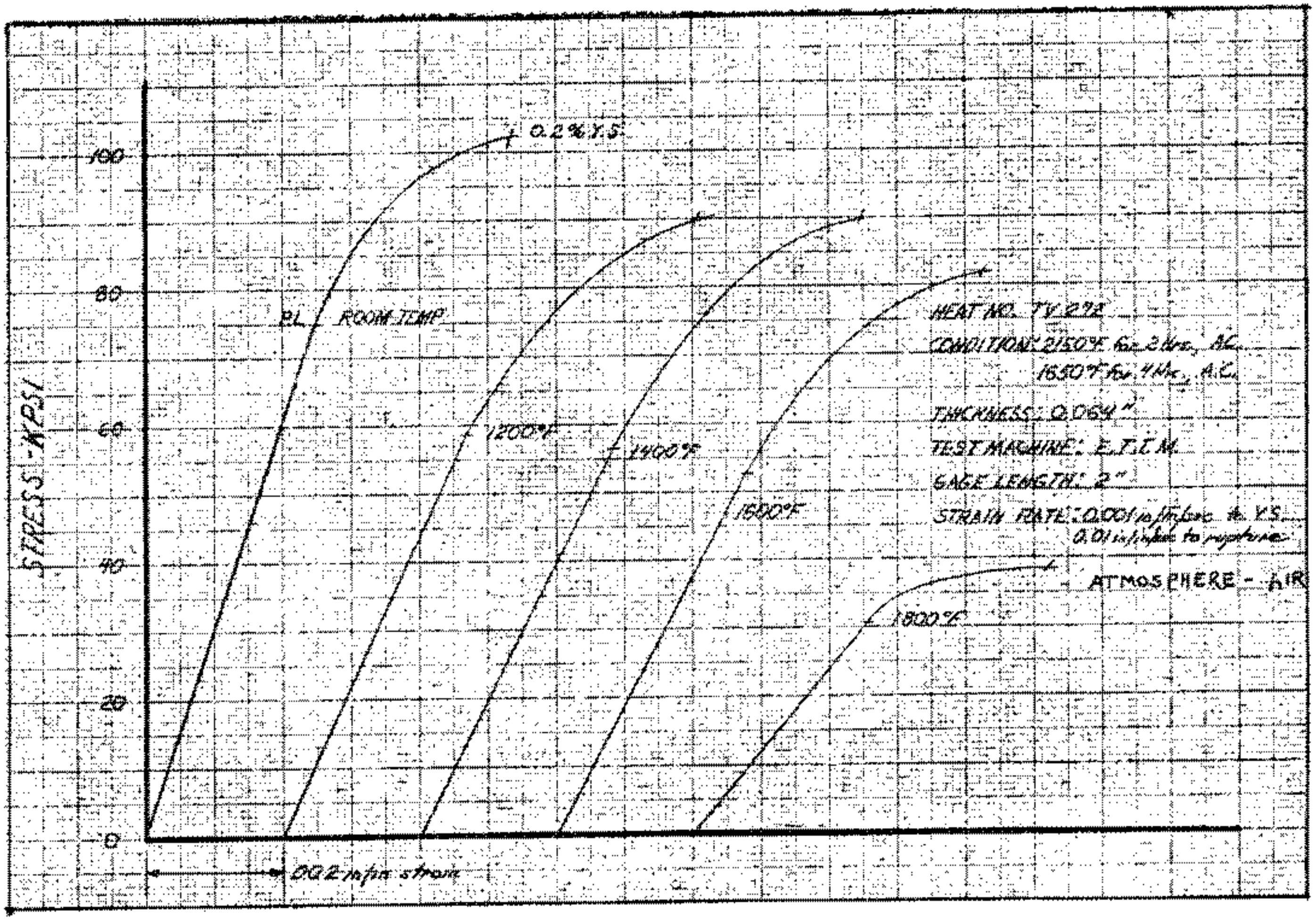


FIGURE 36 - Tensile Stress-Strain Curves for Rene' 41 Alloy Sheet

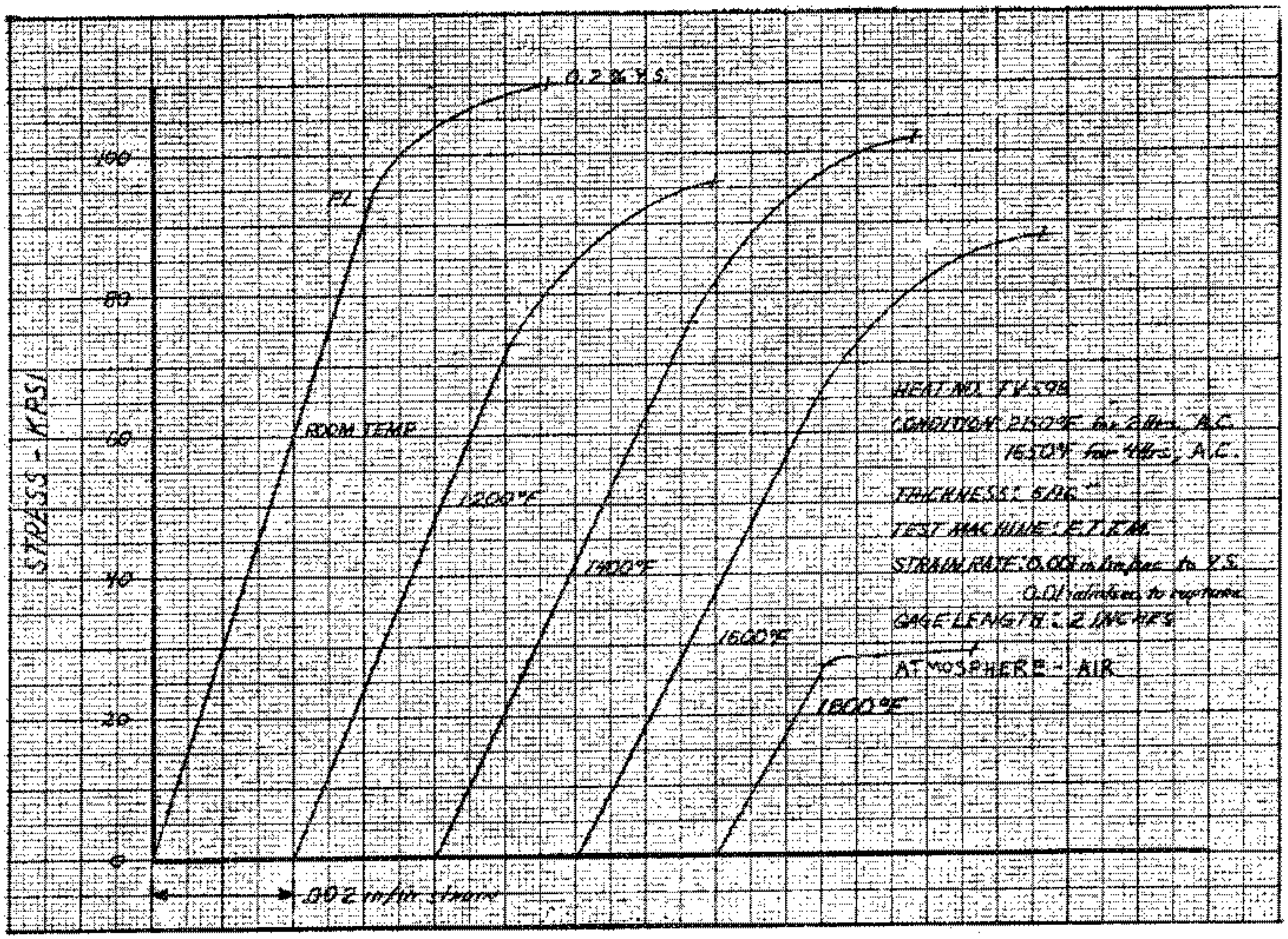


FIGURE 57 - Tensile Stress-Strain Curves for Rene' 41 Alloy Plate

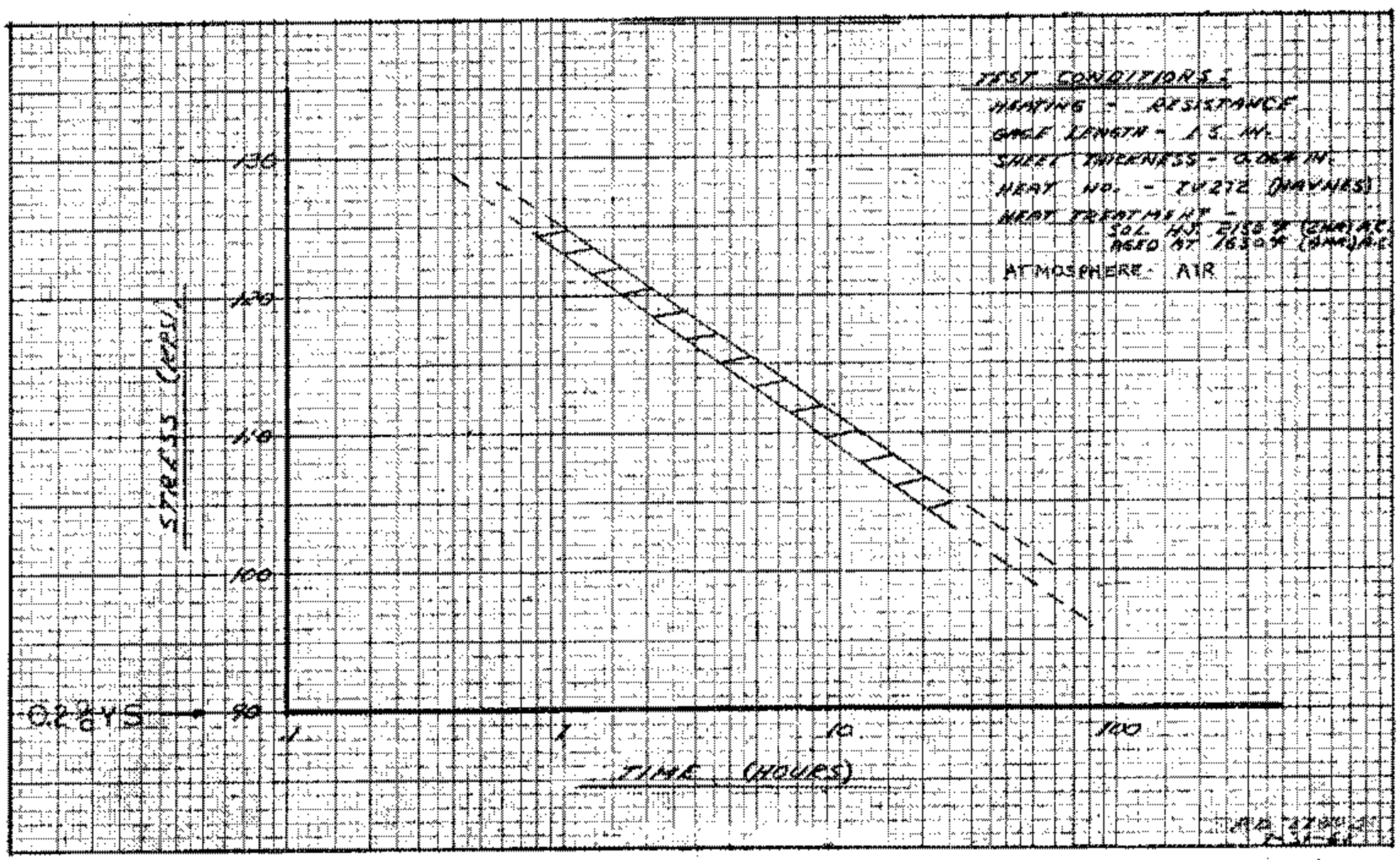
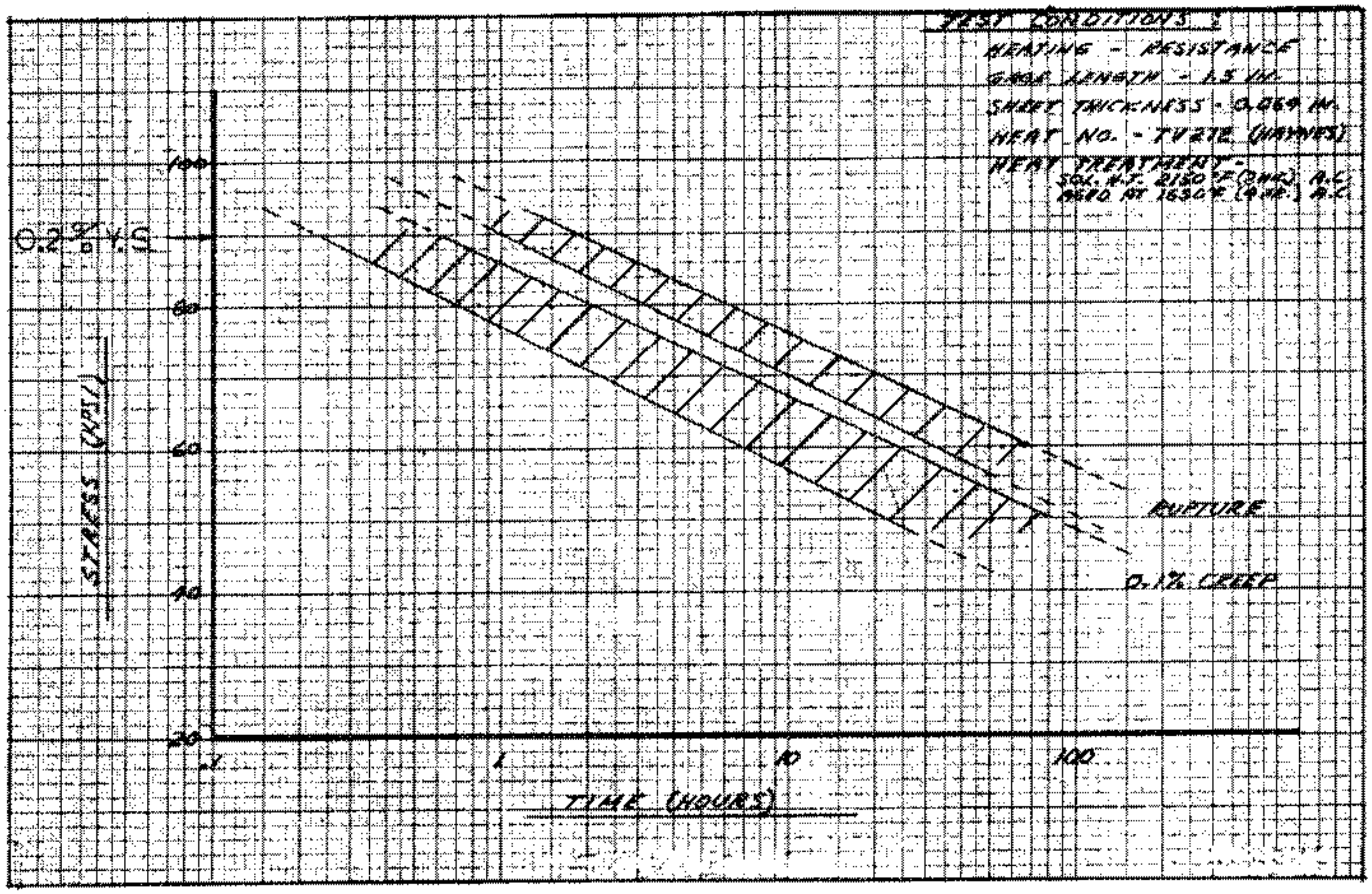
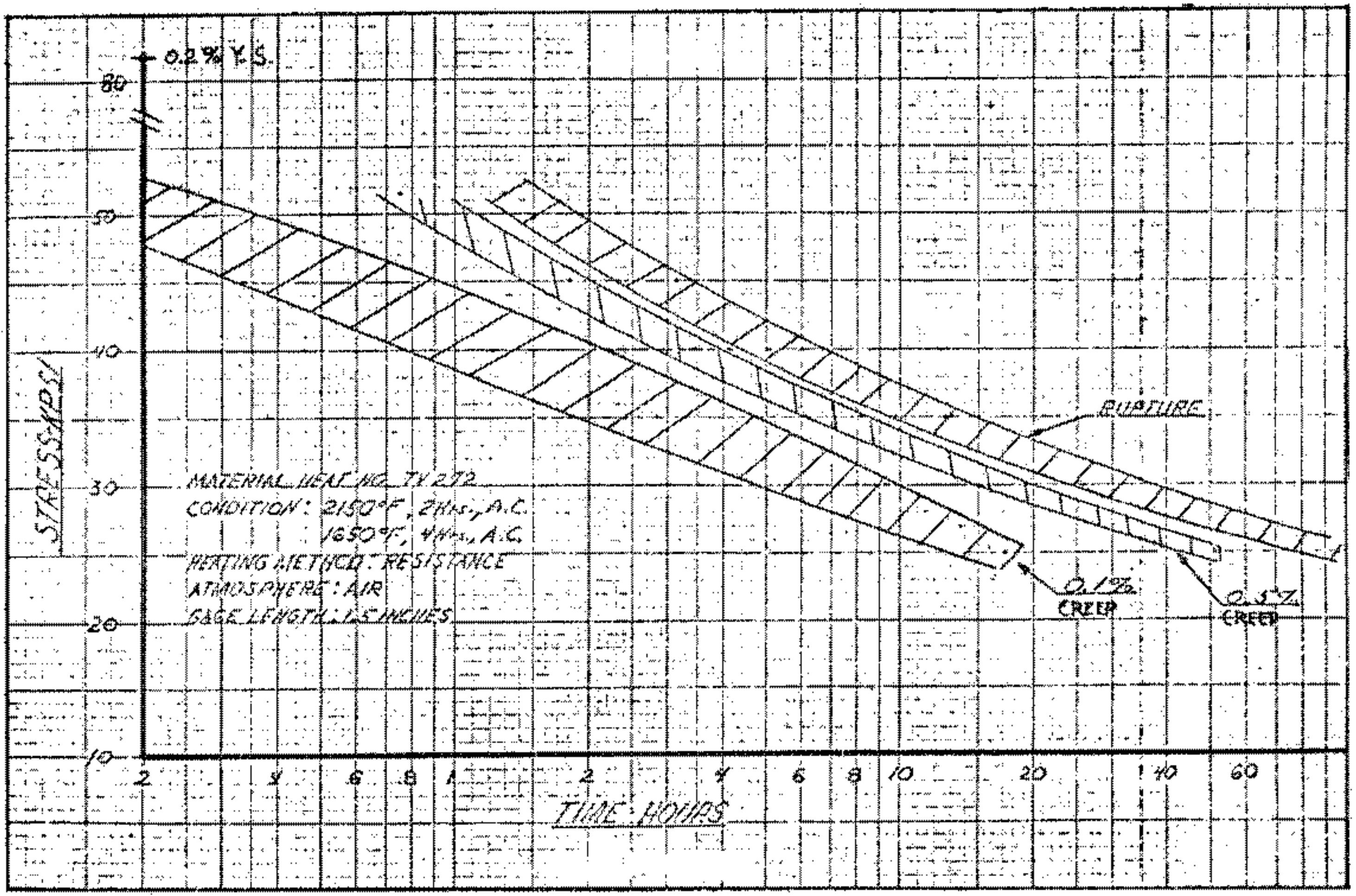


FIGURE 38 - Stress-Rupture Properties for René 41 Alloy Sheet at 1200°F


TEST CONDITIONS :
HEATING - RESISTANCE
GAGE LENGTH - 1.5 IN.
SHEET THICKNESS - 0.069 IN.
HEAT NO. - TV212 (HAYNES)
HEAT TREATMENT -
SOL. H.T. 2150 °F (2 HR.) A.C.
AGED AT 1650 °F (4 HR.) A.C.
0.2% Y.S.
RUPTURE
0.1% CREEP
STRESS (KSI)
100
80
60
40
20
.1
1
10
100
TIME (HOURS)


0.2% Y.S.
80
50
40
30
20
10
STRESS KPSI
MATERIAL HEAT NO. TY 272
CONDITION: 2150°F, 2Hrs., A.C.
1650°F, 4Hrs., A.C.
HEATING METHOD: RESISTANCE
ATMOSPHERE: AIR
GAGE LENGTH: 1.5 INCHES
RUPTURE
0.1% CREEP
0.5% CREEP
2
.4
.6
.8
1
2
4
6
8
10
20
40
60
TIME HOURS

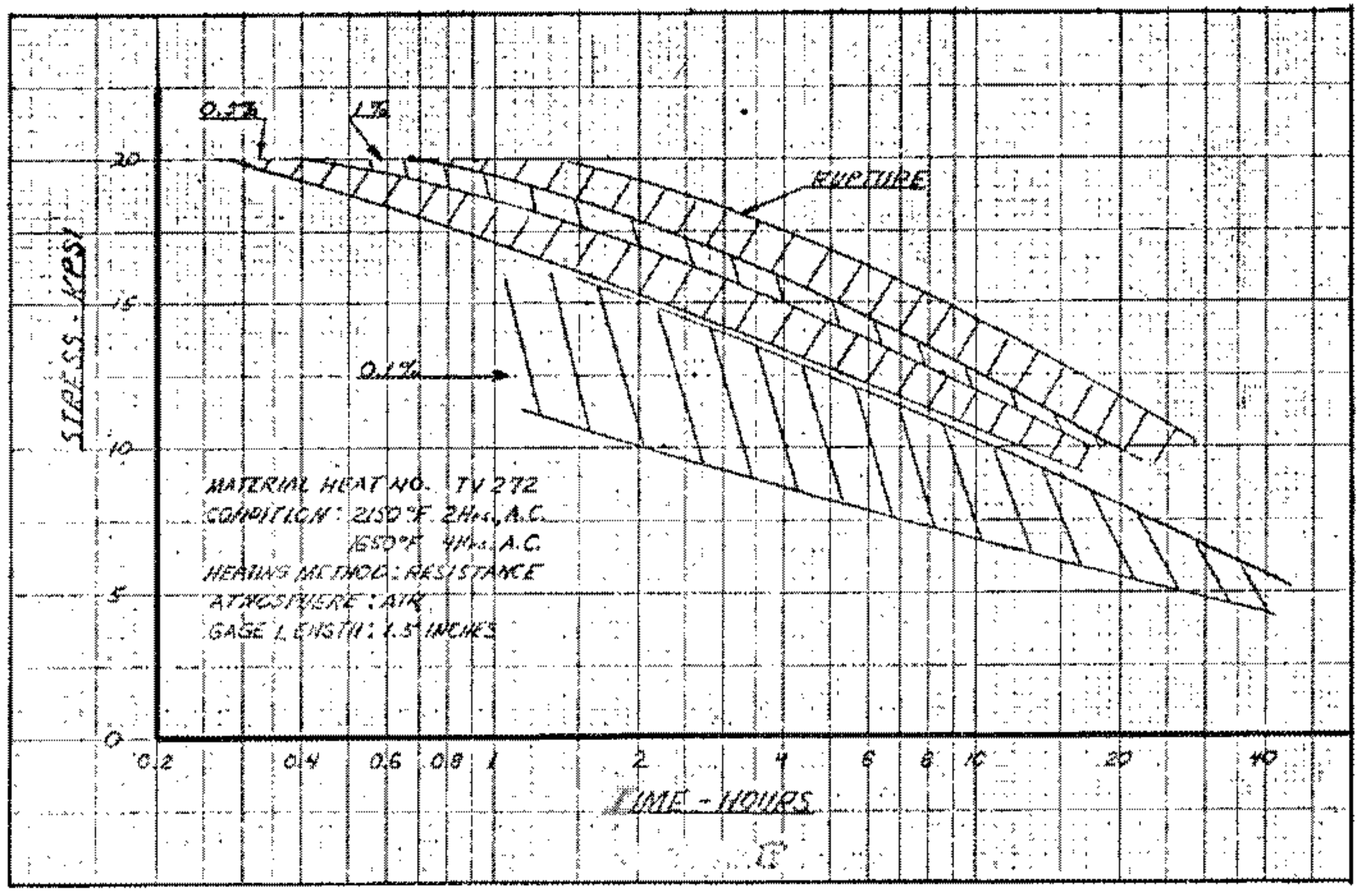
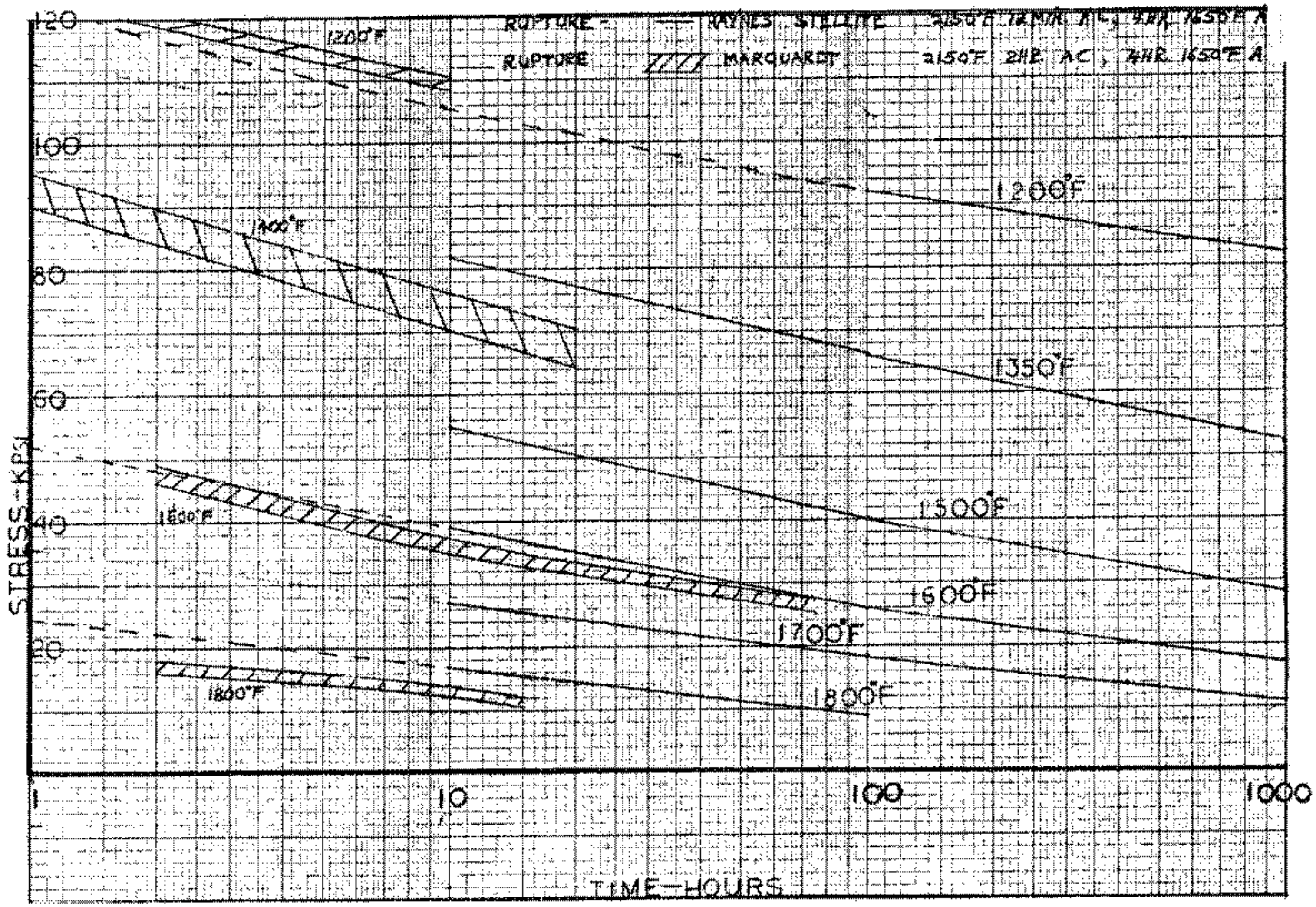


FIGURE 41 - 1800°F Creep and Stress-Rupture Data for Rene' 41 Alloy, 0.064-inch Sheet



RUPTURE HAYNES STELLITE
RUPTURE MARQUARDT 2150°F 2HR AC, 4HR 1650°F A
120
100
80
60
40
20
STRESS-KPSI
1
10
100
1000
TIME-HOURS
1200°F
1400°F
1600°F
1800°F
1200°F
1350°F
1500°F
1600°F
1700°F
1800°F

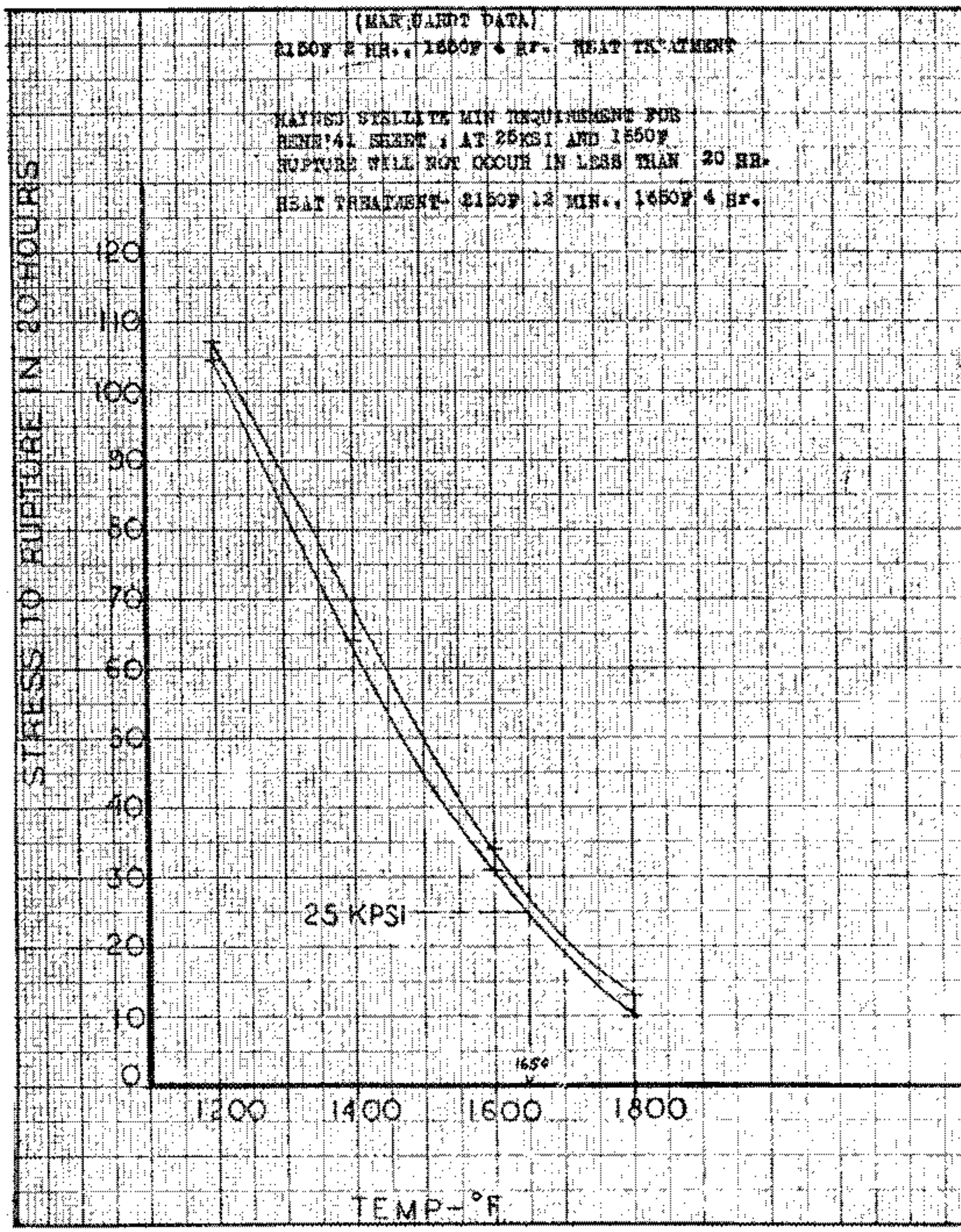


FIGURE [illegible] - Stress to Rupture in 20 hours for 0.065-inch Rene' 41 Sheet

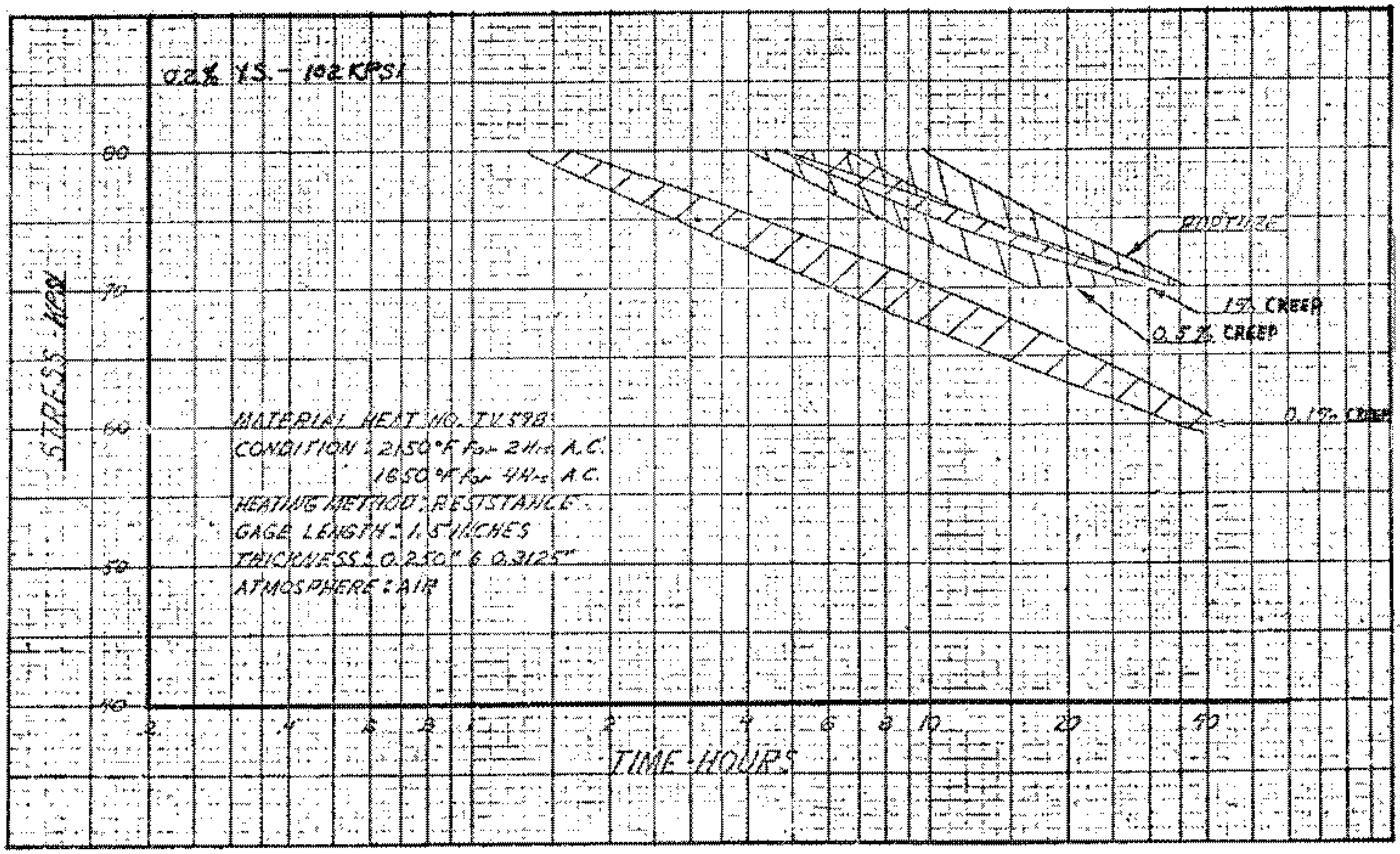


FIGURE 44 - 1400°F Creep and Stress-Rupture Data for Rene' 41 Alloy Plate

MAC A673

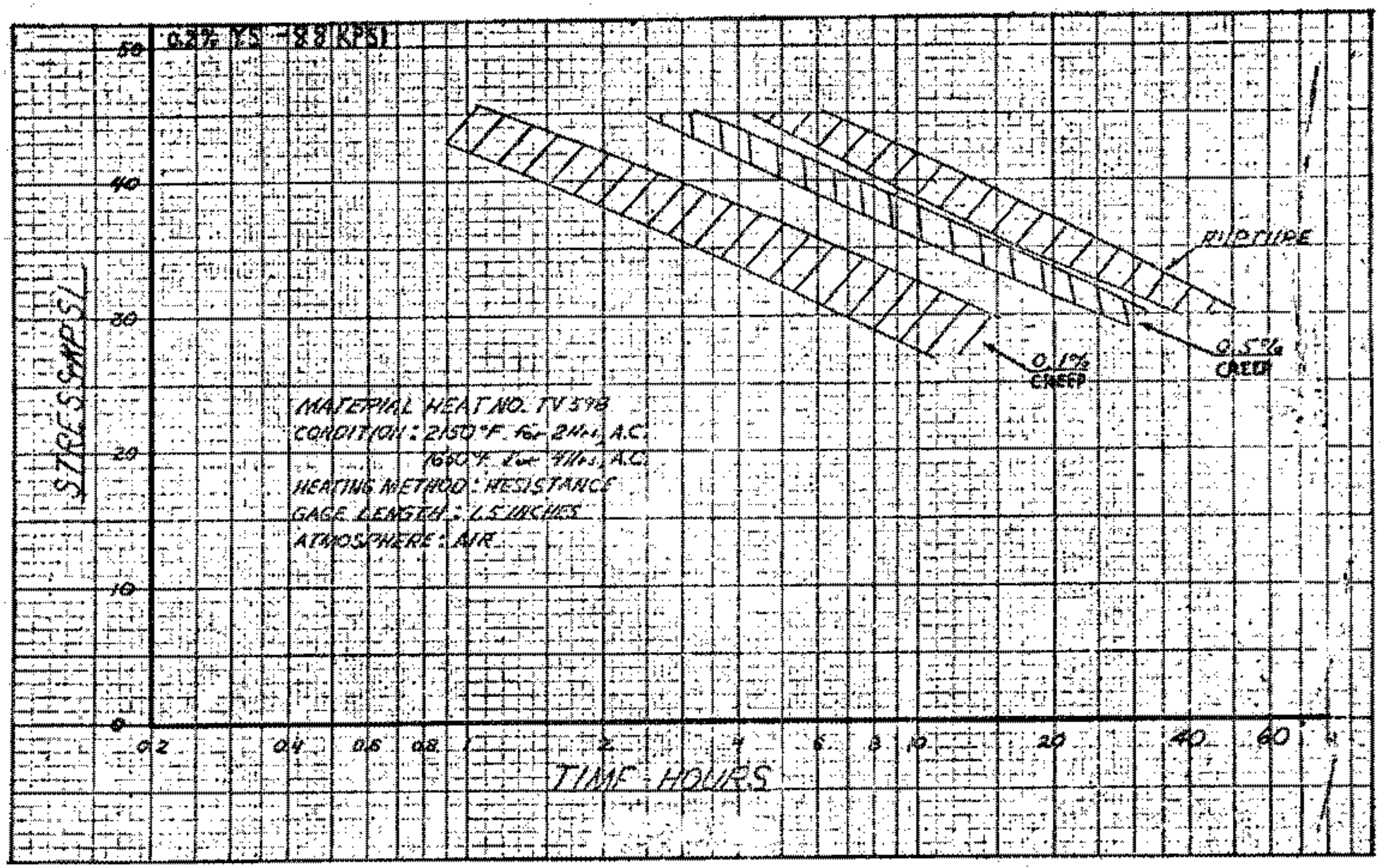


FIGURE 45 - 1600°F Creep and Stress-Rupture Data for Rene' 41 Alloy, 5/16 inch Plate

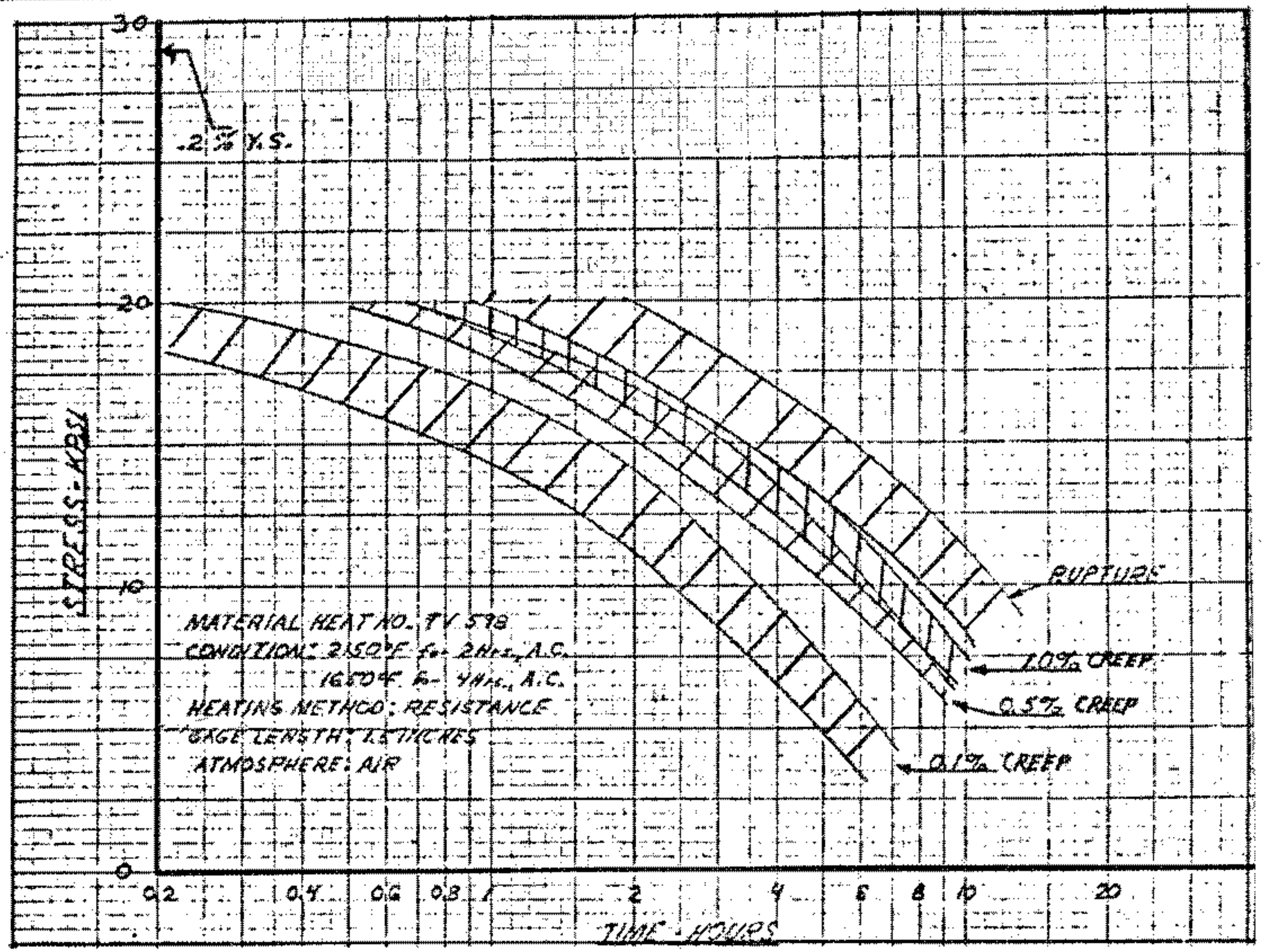


FIGURE 46 - 1800°F Creep and Stress-Rupture Data for Rene' 41 Alloy, 5/16 inch Plate

MAC A673

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ASD-TDR-63-277, Vol. II

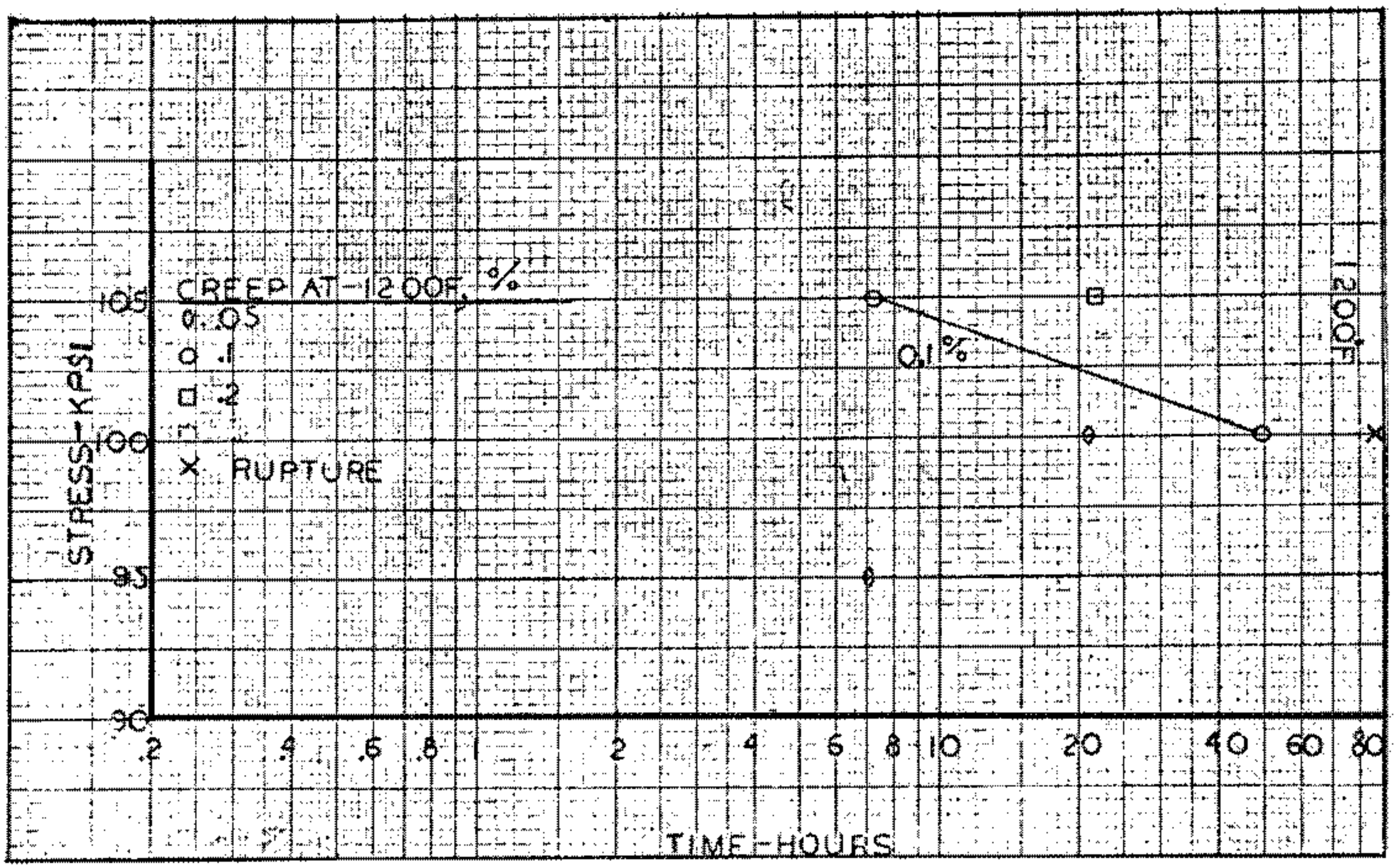
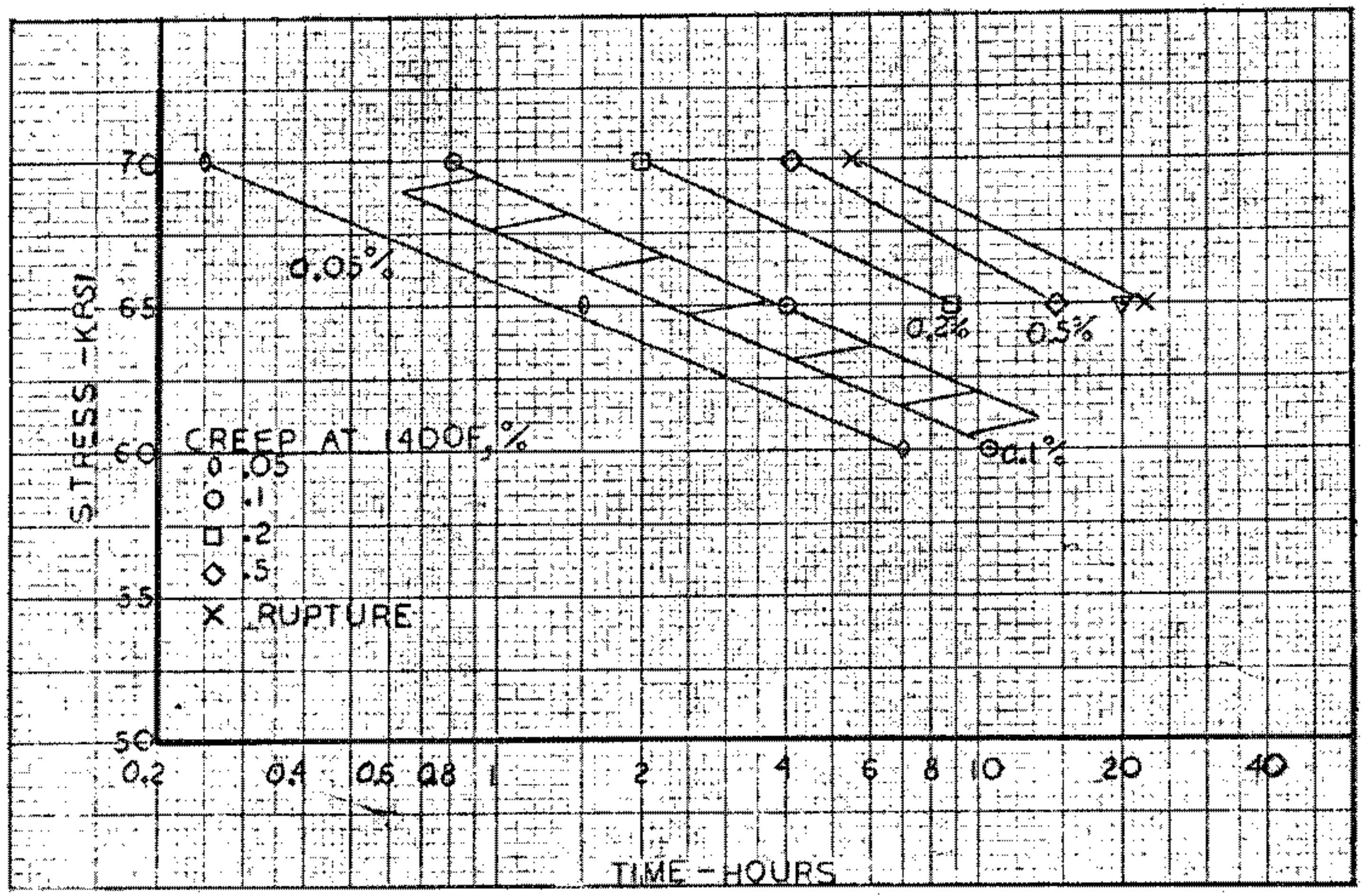


FIGURE 47 - Creep and Stress-Rupture for 0.064-inch Rene' 41 Sheet Welded without Filler Wire

REPORT 6009



STRESS - KSI
70
65
60
55
50
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
40
TIME - HOURS
0.05%
0.1%
0.2%
0.5%
CREEP AT 1400F, %
.05
.1
.2
.5
RUPTURE

MAC A672

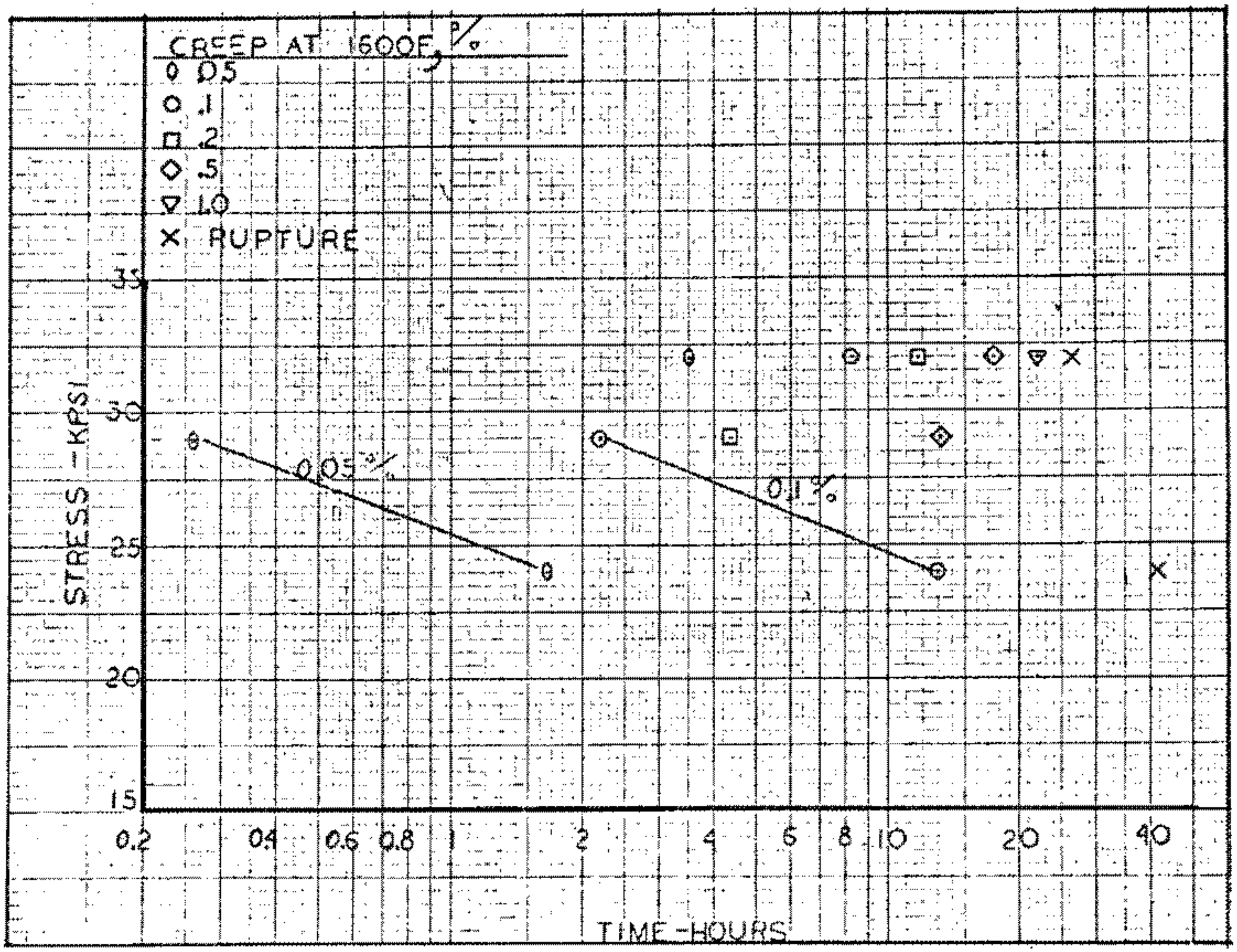


FIGURE 49 - Creep and Stress-Rupture for 0.064-inch Rene' 41 Sheet Welded without Filler Wire

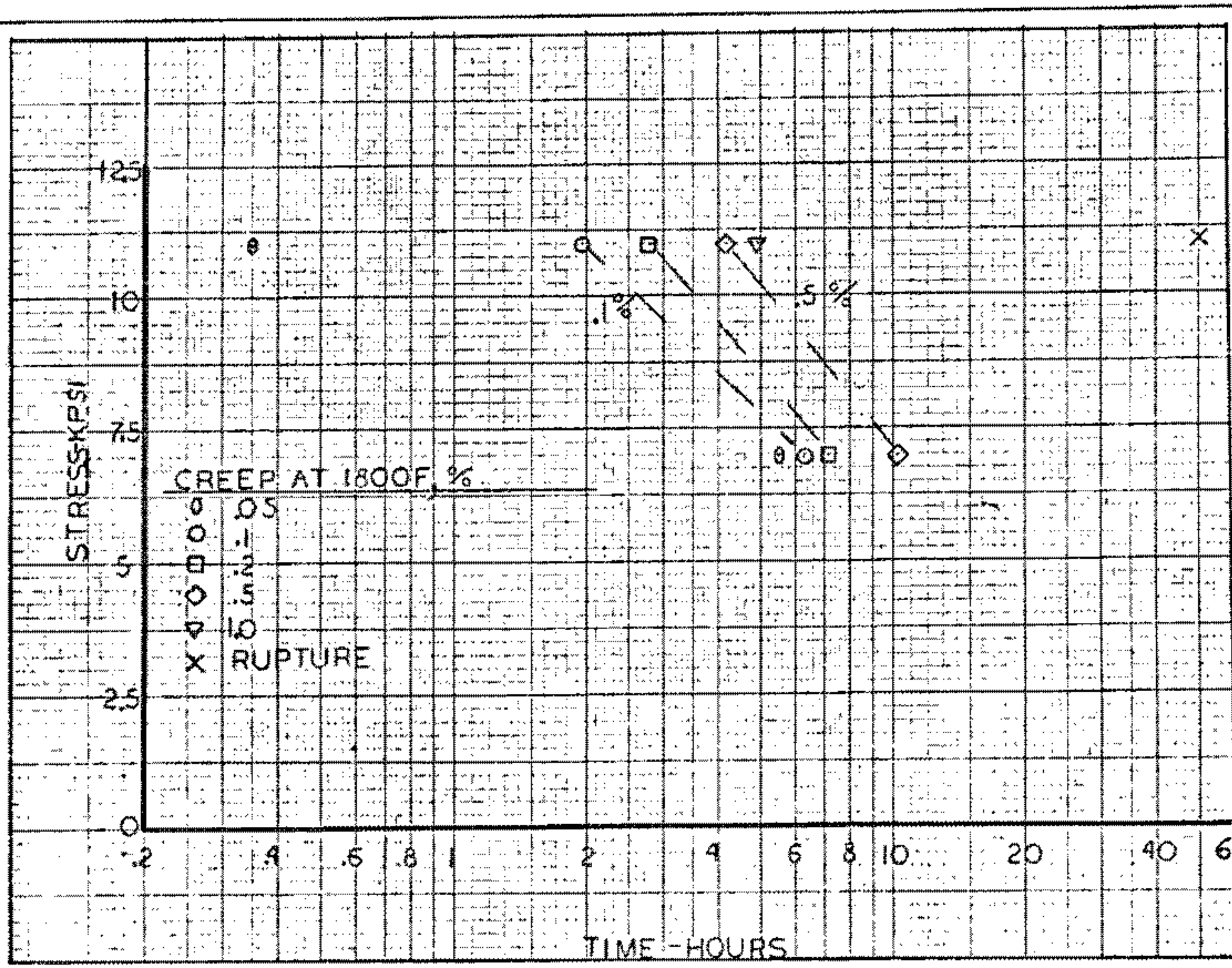


FIGURE 50 - Creep and Stress-Rupture for 0.064-inch Rene' 41 Sheet Welded without Filler Wire

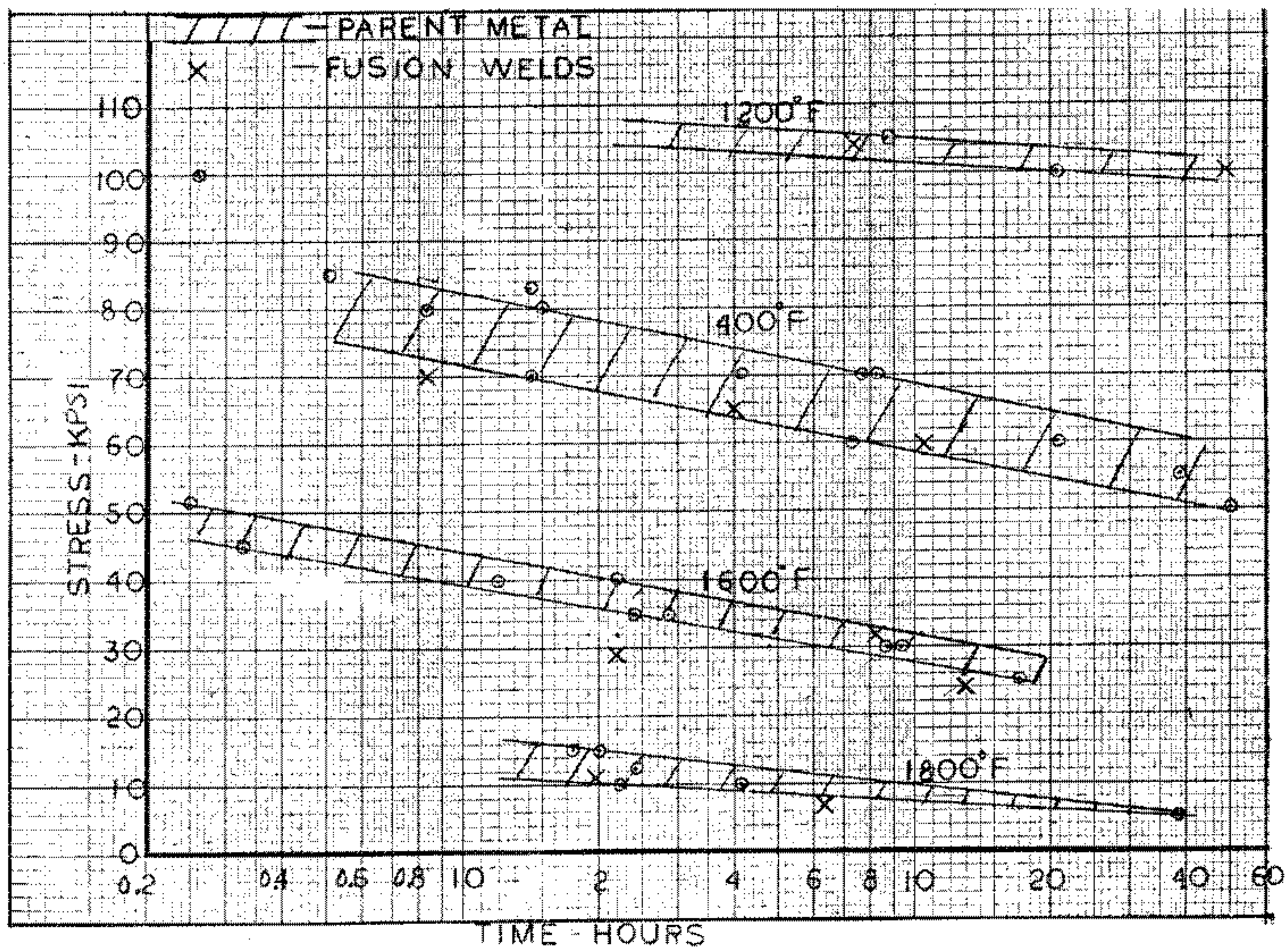


FIGURE 51 - 0.1% Creep of Rene' 41 Sheet, Parent Metal vs. Fusion Welds

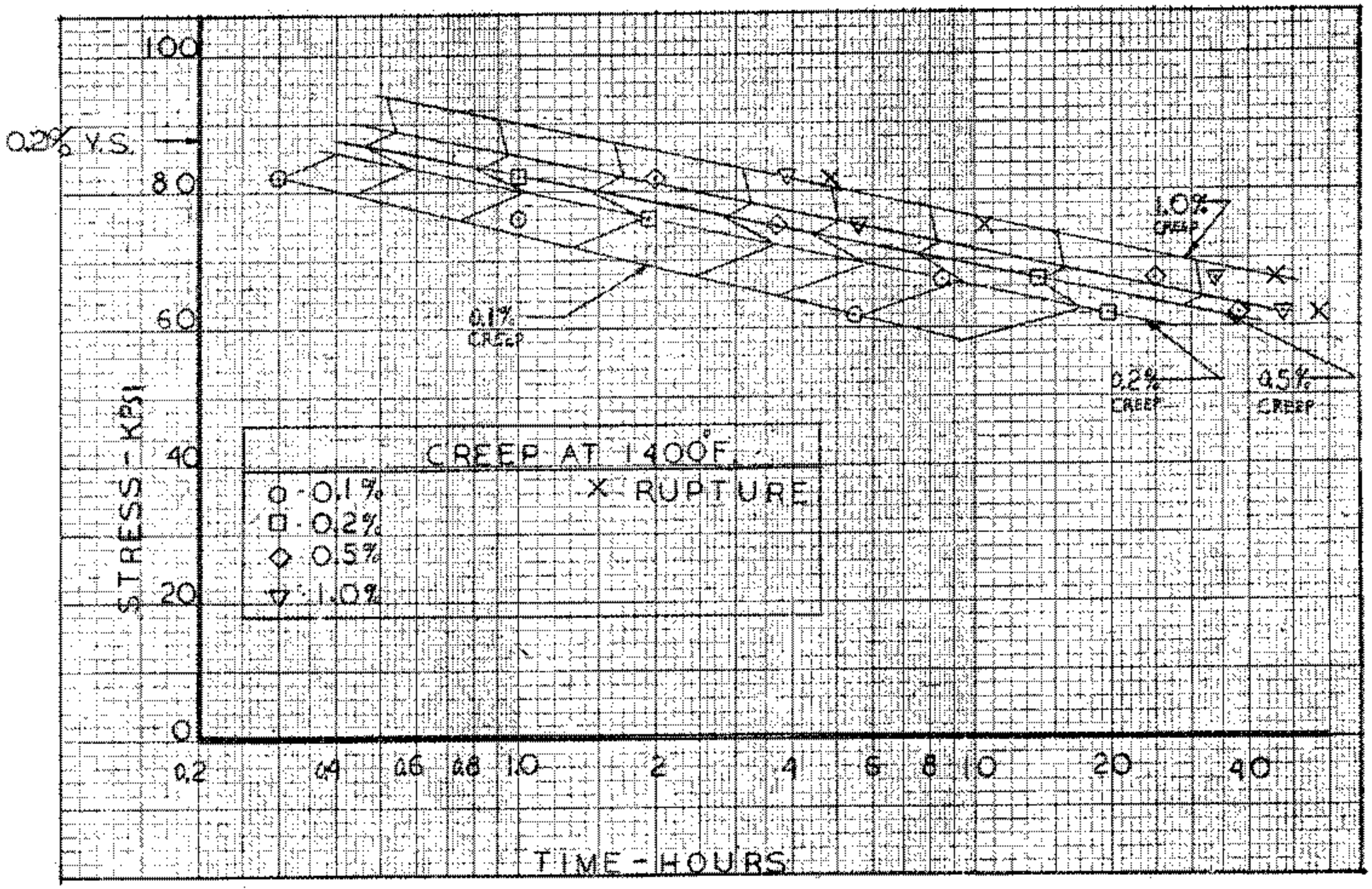
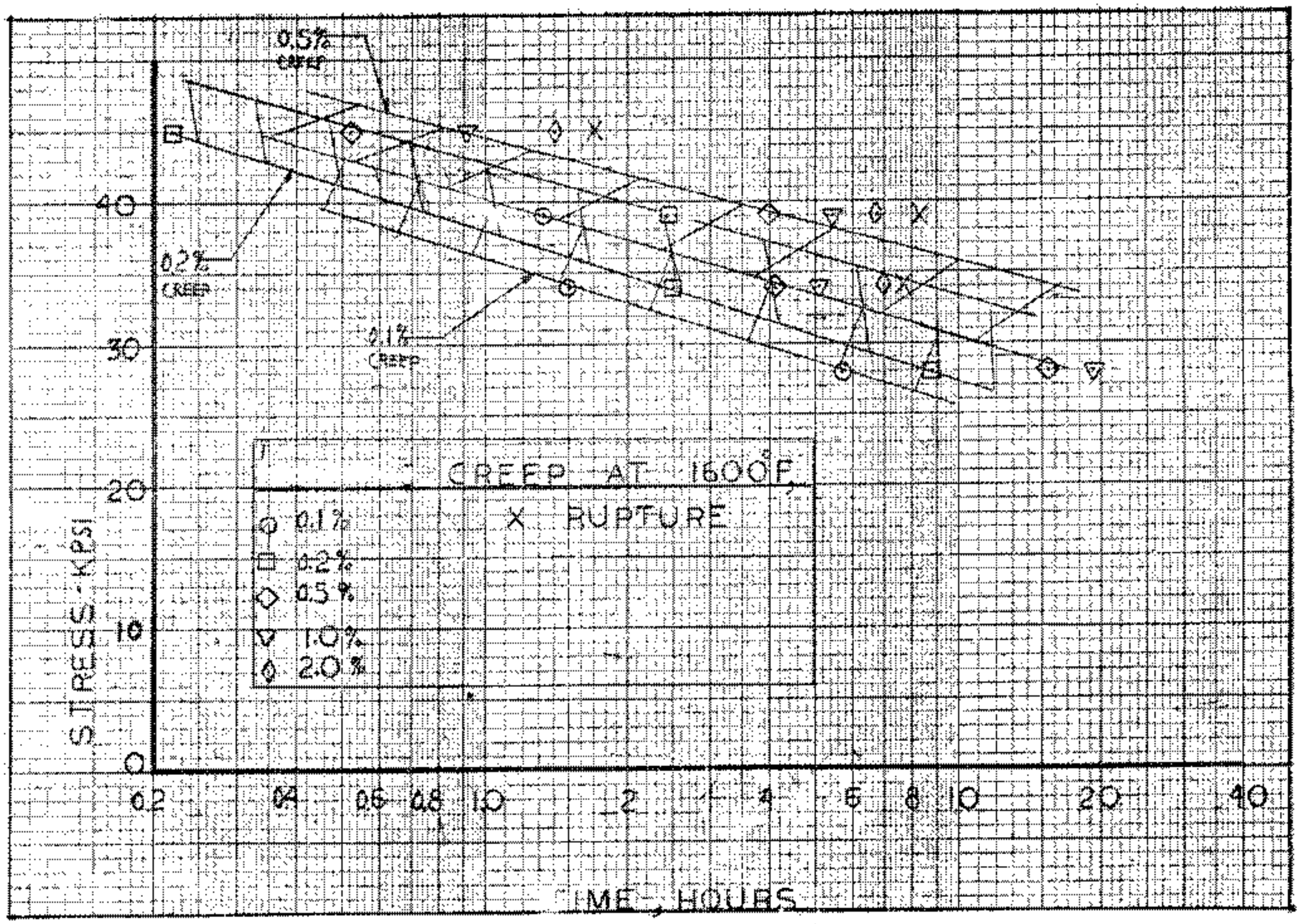


FIGURE 52 - Creep-Rupture Properties at 1400°F of Rene' 41 Plate Welded (Transverse) with Rene' 41 Filler Metal

MAC A673



[illegible] Creep-Rupture Properties at 1600°F of René 41 Plate Welded (Transverse) with René 41 Filler Metal

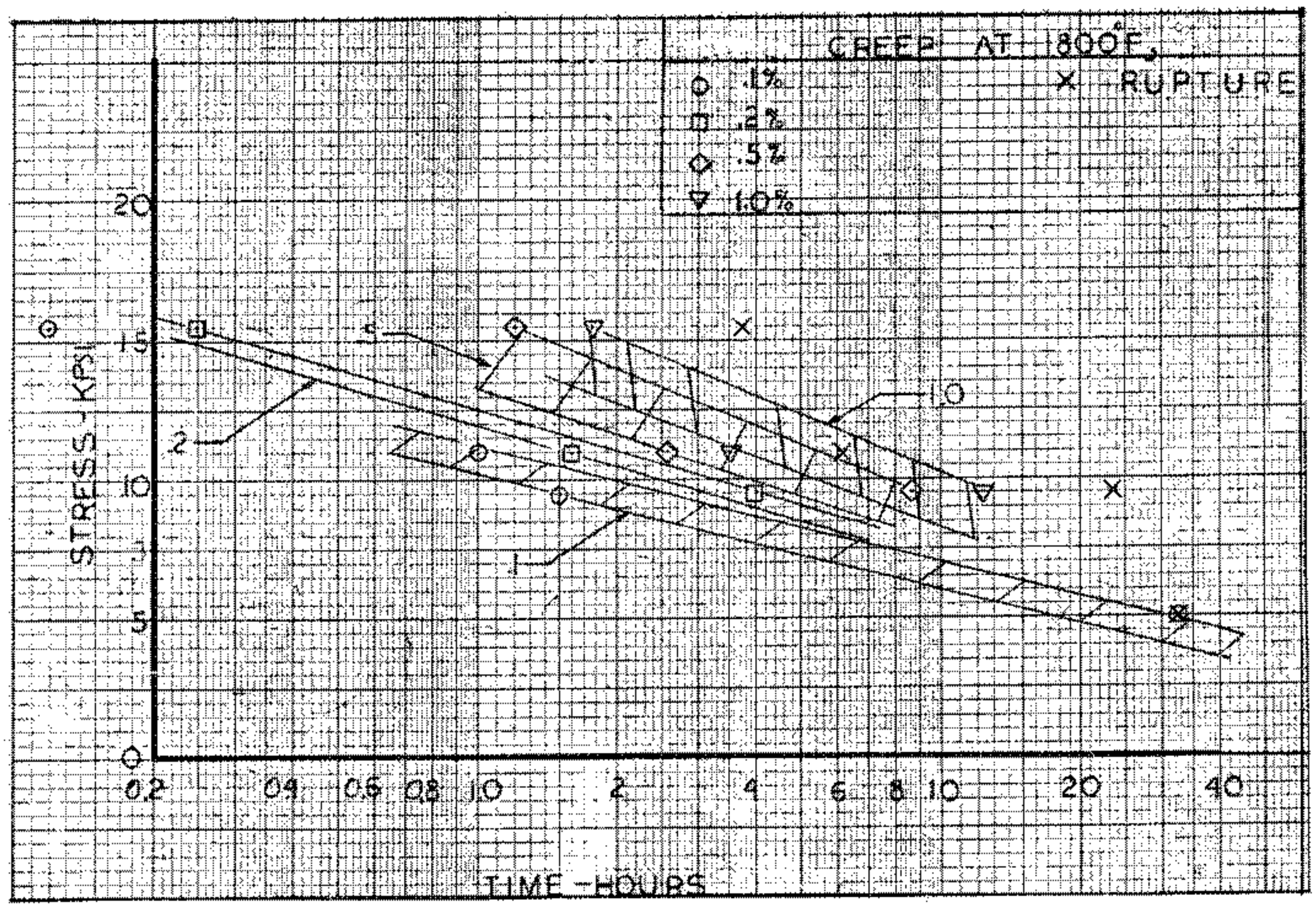


FIGURE 54 - Creep-Rupture Properties at 1800°F of Rene' 41 Plate Welded (Transverse) with Filler Metal

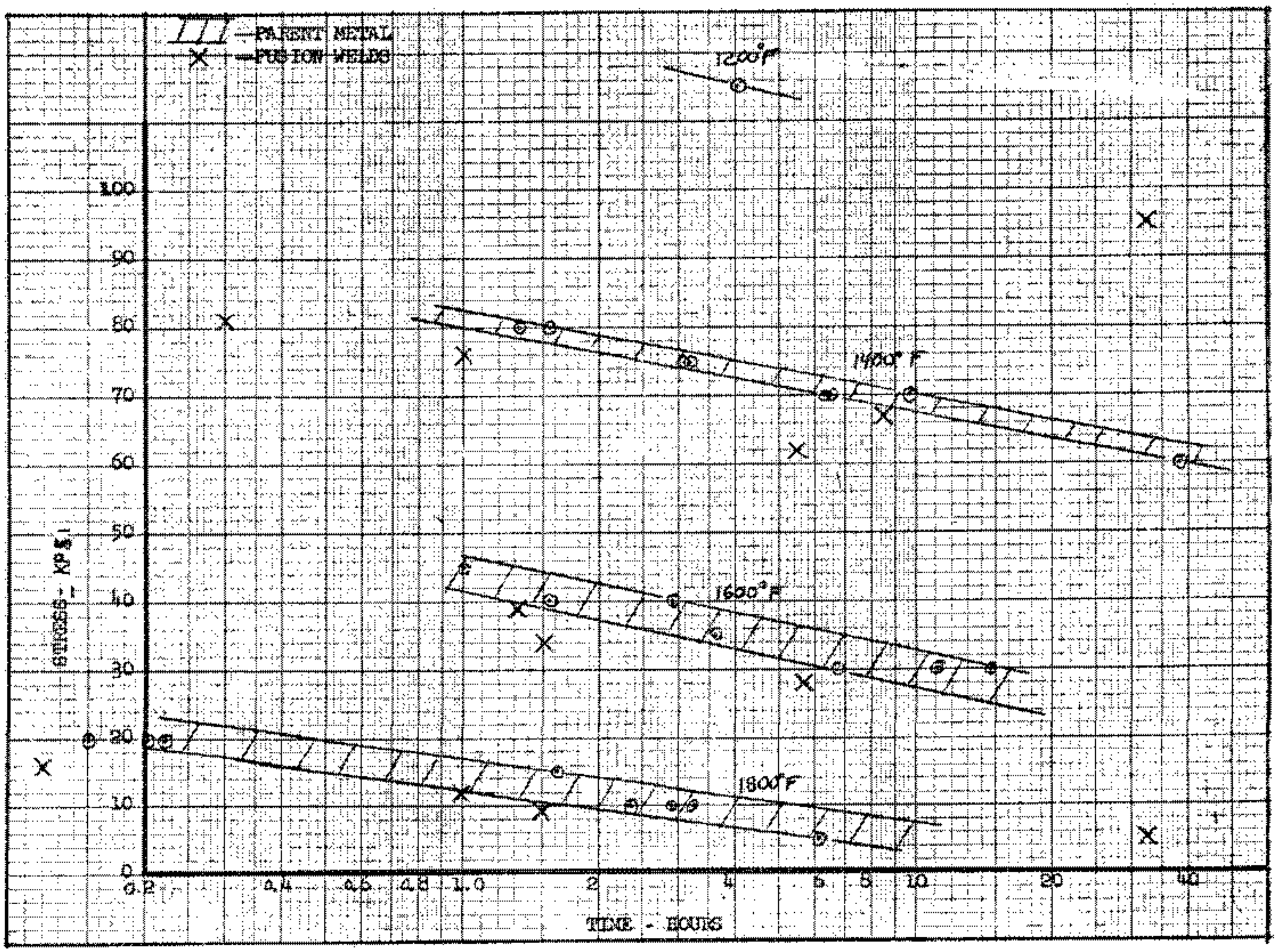
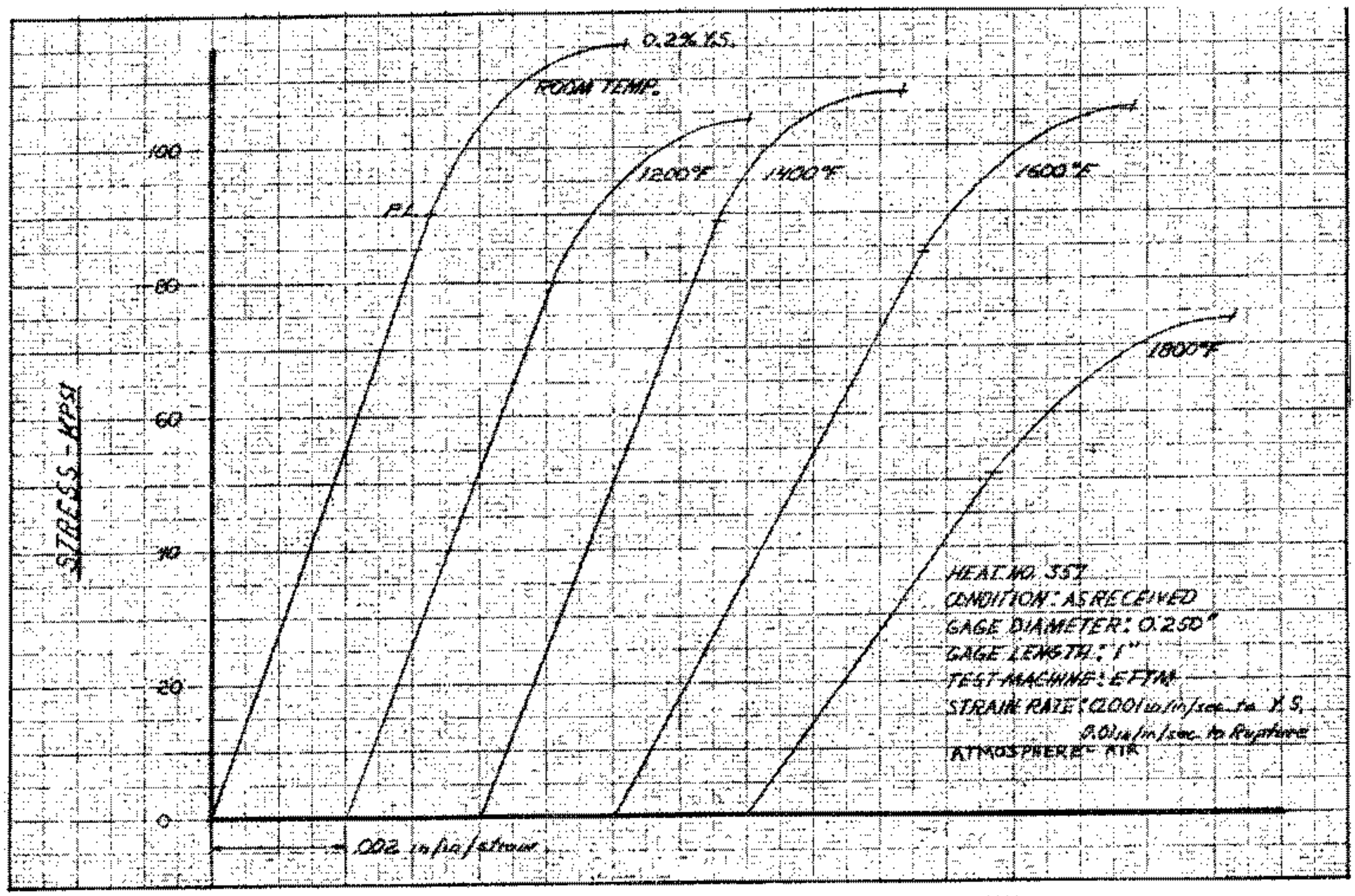
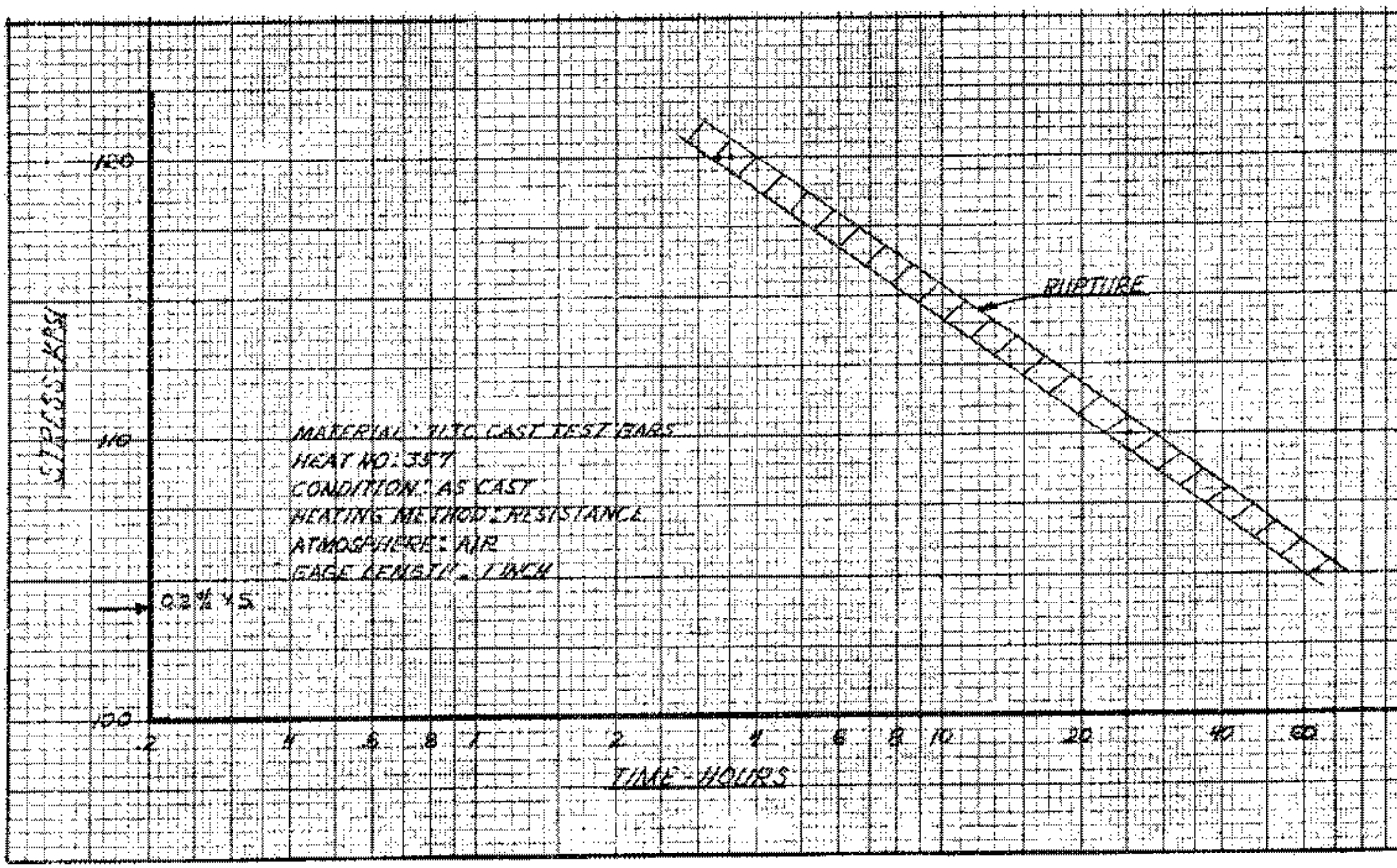


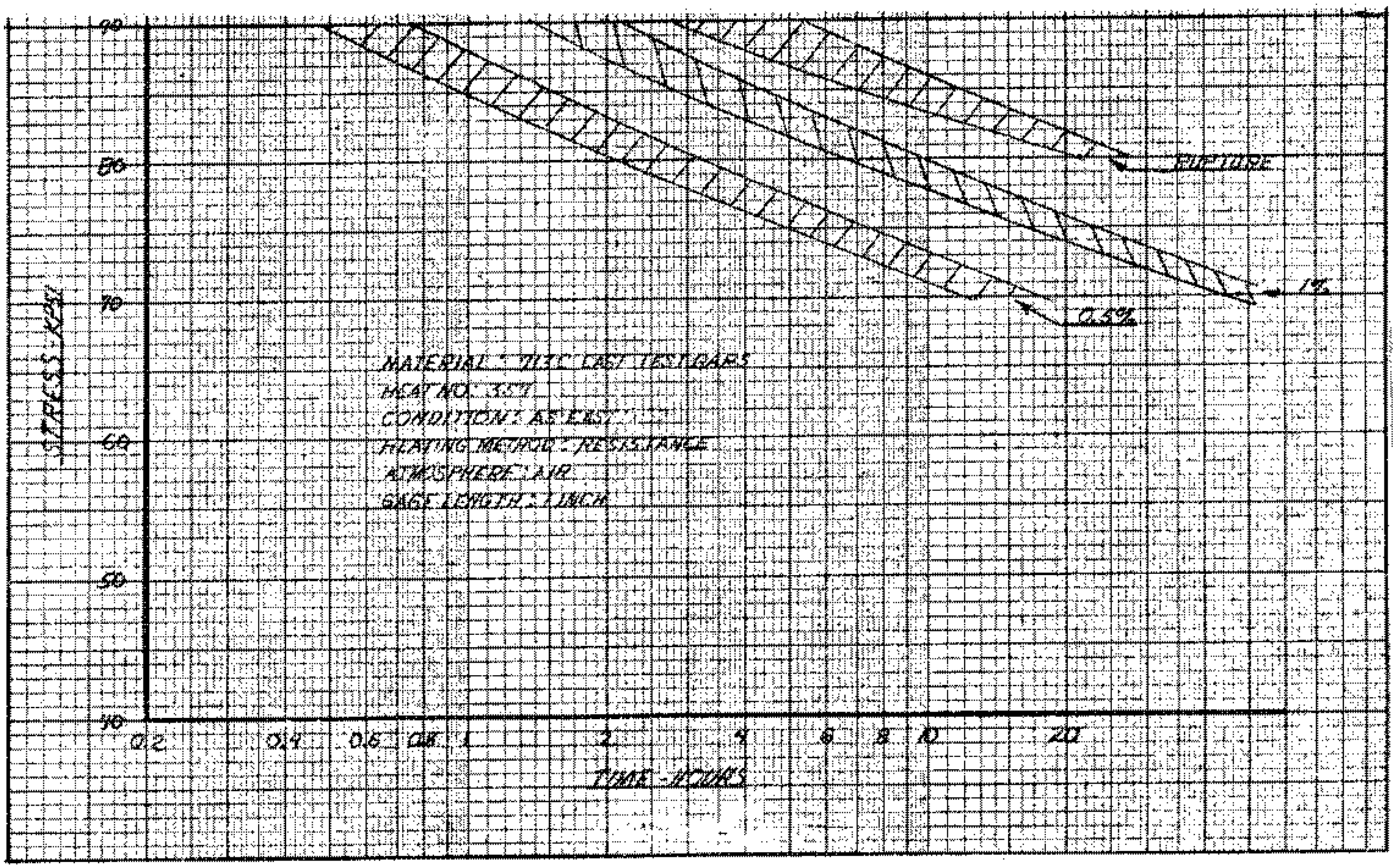
FIGURE 55 - 0.1% Creep of Rene' 41 Plate, Parent Metal vs Fusion Welds


0.2% Y.S.
ROOM TEMP.
P.L.
1200°F
1400°F
1600°F
1800°F
STRESS - KPSI
100
80
60
40
20
0
.002 in/in/strain
HEAT NO. 357
CONDITION: AS RECEIVED
GAGE DIAMETER: 0.250"
GAGE LENGTH: 1"
TEST MACHINE: EFTM
STRAIN RATE: 0.001 in/in/sec. to Y.S.
0.01 in/in/sec. to Rupture
ATMOSPHERE: AIR

MAC A673



[illegible] - [illegible] Stress-Rupture Data for Y130 Alloy



RUPTURE
1%
0.5%
MATERIAL: 713C CAST TEST BARS
HEAT NO. 357
CONDITION: AS CAST
HEATING METHOD: RESISTANCE
ATMOSPHERE: AIR
GAGE LENGTH: 1 INCH
STRESS - KPSI
90
80
70
60
50
40
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
TIME - HOURS

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28B302

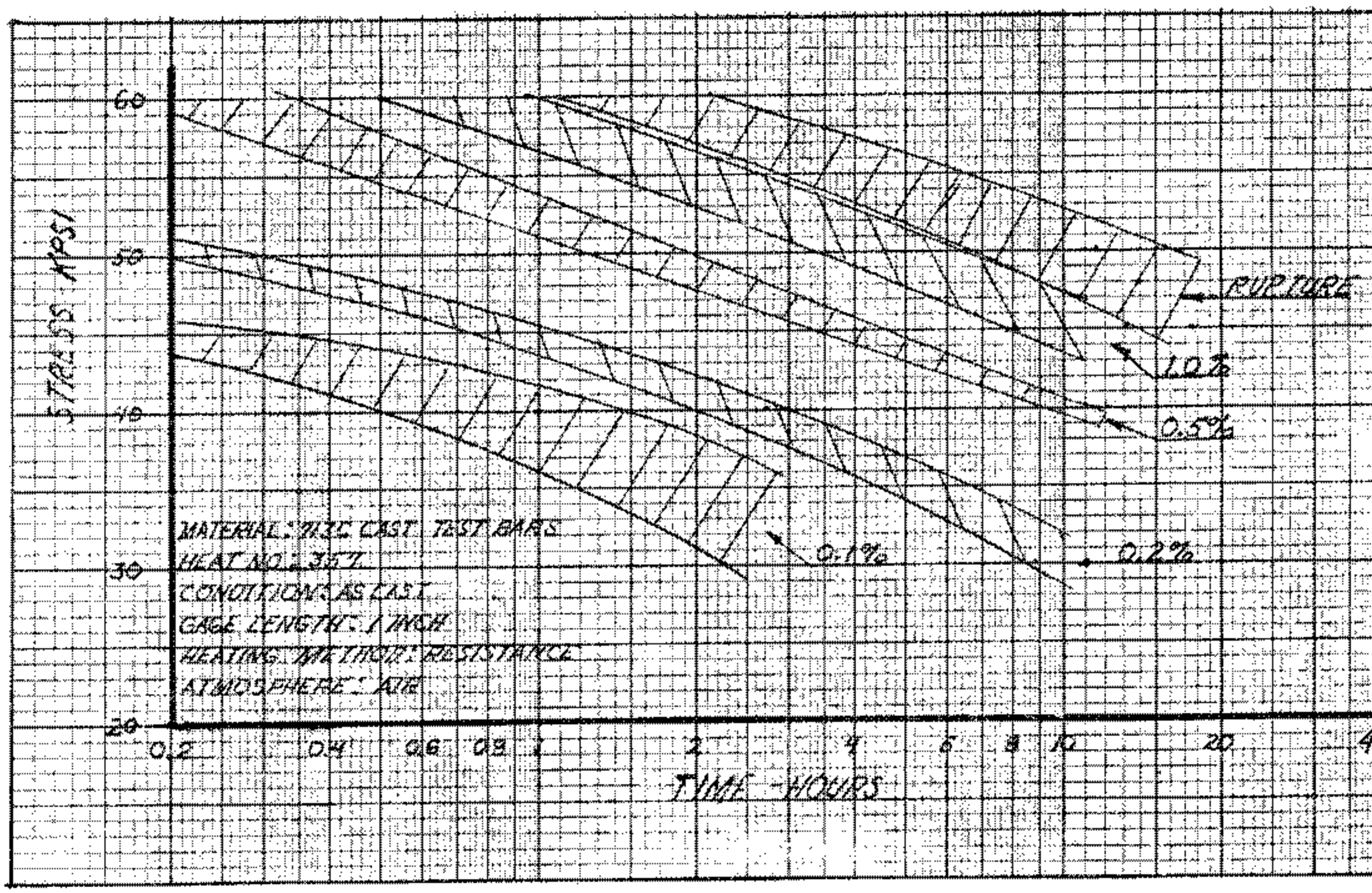

FIGURE 59 - 1600°F Creep and Stress-Rupture Data for 713C Alloy

REPORT 6695

MAC A673

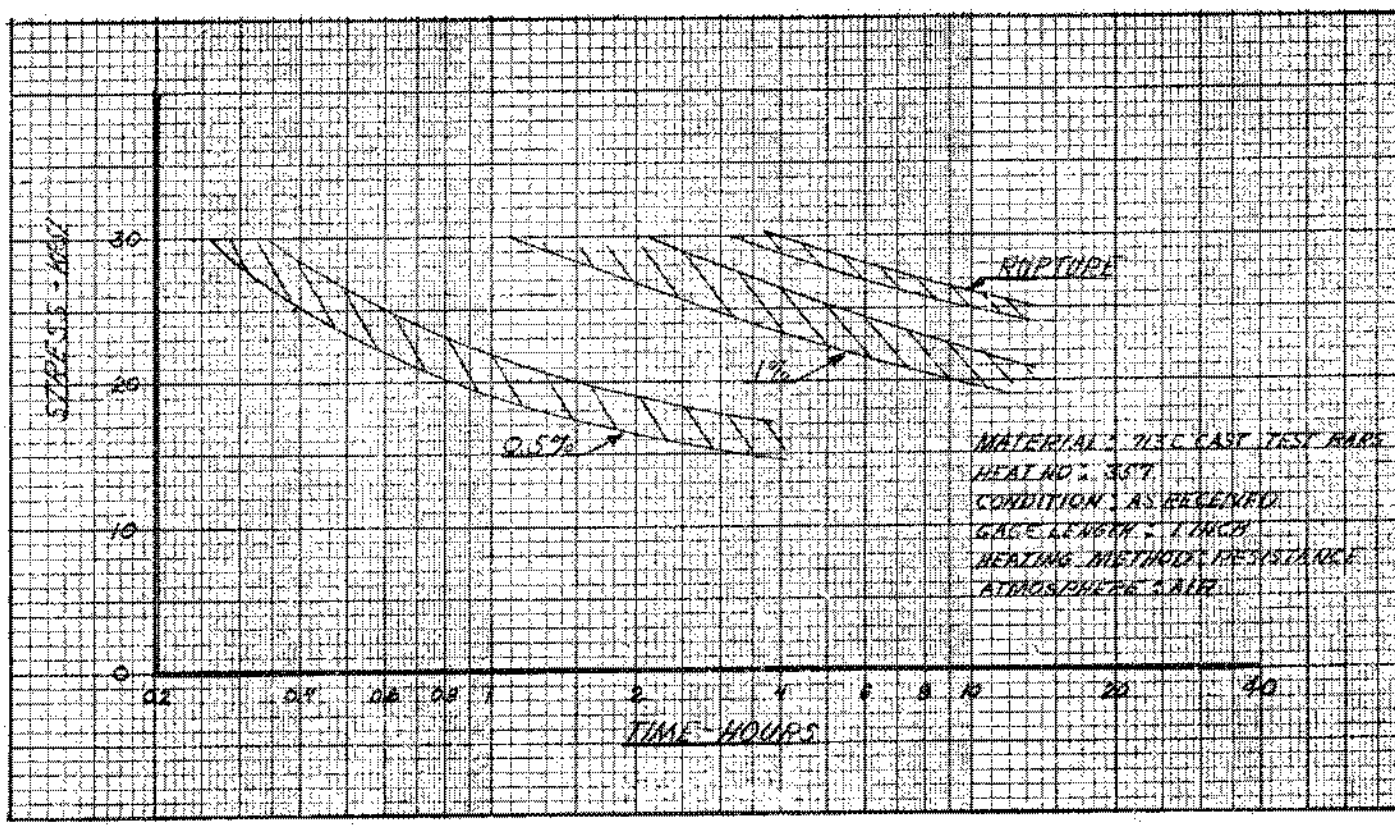

FIGURE 60 - 1800°F Creep and Stress Rupture Data for 713C Alloy

Aeronautical Systems Division, Dir/Aero-mechanics, Propulsion Lab., Wright-Patterson AFB, Ohio
Rpt Nr ASD-TDR-63-277, Vol. VI. NUCLEAR RAM-JET PROPULSION SYSTEM (PROJECT PLUTO): Structural Materials Investigations (U). Final Report, 15 February 1963, 161 p, incl. illus., tables, 0 refs.

Unclassified Report

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Unclassified Abstract

1. Nuclear ramjet propulsion system
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3. Materials
4. Heat resistant alloys
5. Welding

I. AFSC Project 655A, Tasks 1 & 5
II. Contract AF 33 (657)-8123
III. The Marquardt Corp., Van Nuys, Calif.
IV. R.D. Grossman
V. TMC Rpt. 6005
VI. Not aval for OTS

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