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CHARACTERIZATION OF THE MECHANICAL AND PHYSICAL PROPERTIES OF TD-NiCr (Ni-20Cr-2ThO_2) ALLOY SHEET

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16. Abstract

Sheets of TD-NiCr processed using techniques developed to produce uniform material were tested to supply mechanical and physical property data. Two heats each of 0.025 and 0.051 cm thick sheet were tested.

Mechanical properties evaluated included tensile, modulus of elasticity, Poisson's Ratio, compression, creep-rupture, creep strength, bearing strength, shear strength, sharp notch and fatigue strength. Test temperatures covered the range from ambient to 1589K.

Physical properties were also studied as a function of temperature. The physical properties measured were thermal conductivity, linear thermal expansion, specific heat, total hemispherical emittance, thermal diffusivity, and electrical conductivity.

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SUMMARY

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Mechanical properties evaluated included tensile, modulus of elasticity, Poisson's Ratio, compression, creep-rupture, creep strength, bearing strength, shear strength, sharp notch, and fatigue. These tests were conducted at temperatures which covered the range from ambient to 1589K.

In general, the mechanical property tests indicated that properties were dependent both on thickness and test direction. Usually the 0.051 cm thick sheet was stronger than the 0.025 cm thick sheet and the strength of specimens taken parallel to the sheet rolling direction was, in general, greater than the strength of specimens taken normal to the rolling direction. For either sheet thickness (0.025 or 0.051 cm), the heat-to-heat variations in mechanical properties were usually small.

With regard to the actual mechanical property measurements, several interesting observations were made:

a) Thin sheet TD-NiCr has, in general, little tensile ductility at elevated temperatures ($T \geq 922K$).

b) The severe microstructural damage observed in many creep-rupture tested TD-NiCr specimens may limit the usefulness of the creep-rupture data.

c) The stresses necessary to produce 0.1 and 0.2% creep in 100 hours in thin sheet TD-NiCr were similar.

d) Thin sheet TD-NiCr does not appear to be notch sensitive.

Additionally, physical properties were studied as a function of temperature on one heat of 0.103 cm thick TD-NiCr sheet. The properties measured included linear thermal expansion, thermal conductivity,

specific heat, total hemispherical emittance, thermal diffusivity, and electrical resistivity. The physical properties were independent of testing direction. For example, the linear thermal expansion and thermal conductivity were found to be essentially equal for specimens taken either parallel or normal to the sheet rolling direction. Total hemispherical emittance was found to be quite dependent on the surface conditions. Unoxidized surfaces exhibited very unstable emittances at elevated temperatures in hard vacuums while oxidized surfaces exhibited much more stable emittances.

INTRODUCTION

The dispersion-strengthened Ni-20Cr-2ThO_2 alloy, commercially produced by Fansteel Inc. and designated TD-NiCr, has been considered for use in various high temperature applications requiring high strength and good oxidation resistance. One possible application would be as a portion of the thermal protection system for the space shuttle. This would entail use of the material at temperatures ranging from 1255K to 1477K.

While TD-NiCr has been available for several years, there has been no design-type data because material produced under a standardized technique has not been available. The mechanical properties of TD-NiCr have been found to be quite dependent on thermomechanical processing techniques and these techniques have varied giving rise to material with resultant variations in properties.

A separate NASA contract to Fansteel Inc. has provided sufficient material produced with standardized processing techniques for thorough evaluation of mechanical and physical properties of thin sheet material (0.025 and 0.051 cm). Manufacturing process details are given in Ref. 1.

The intention of the program is to provide design-allowable data for use of the material as a heat shield for space shuttle vehicles. This consisted of tensile, compression, bearing, creep-rupture, creep strength, modulus of elasticity, Poisson's Ratio, shear strength, sharp notch, and fatigue evaluations. In general, the mechanical properties were measured as functions of temperature (room temperature to 1589K), sheet direction (parallel, 45°, and/or normal to the sheet rolling direction), and thickness (0.025 cm and/or 0.051 cm). All mechanical property tests were conducted at Metcut Research Associates Inc., Cincinnati, Ohio.

Physical properties (linear thermal expansion, thermal conductivity, thermal diffusivity, electrical resistivity, specific heat and total hemispherical emittance) were evaluated from ambient to 1589K. Characterization of the physical properties was accomplished under a subcontract to Thermophysical Properties Research Center, West Lafayette, Indiana.

GENERAL BACKGROUND

Characterization of the TD-NiCr Alloy Sheet

The sheet to be tested in this program was typical of the sheet product produced by Fansteel, Inc. following the standard practice established for thin TD-NiCr sheet. (Ref. 1) The physical parameters of the TD-NiCr sheet obtained are listed in Table A. The first four heats in Table A were used for the mechanical property experiments while the last heat was used for characterization of the physical properties. In accordance with standard practice thin TD-NiCr sheet (sheet thickness ≤ 0.038 cm) was belt sanded and then cold rolled a few percent; the cold rolling is designed to improve the sheet flatness. Thicker TD-NiCr sheet (sheet thickness > 0.038 cm) is simply belt sanded.

TABLE A

PHYSICAL PARAMETERS OF TD-NiCr ALLOY SHEET

Heat No.	Nominal Thickness (cm)	Surface Finish	Nominal Sheet Size (m)	No. of Sheets
3636	0.051	ground	.5 x .9	5
3637	0.025	ground-cold rolled	.45 x .9	8
3697	0.025	ground-cold rolled	.45 x .9	8
3712	0.051	ground	.45 x 1.05	8
3715	0.103	ground	.45 x 1.2	1

All TD-NiCr sheet used in this program met or exceeded the minimum standards listed in Fansteel Product Specification: Thoriated Nickel Base Alloy, Composition and Properties, TD Nickel Chromium Sheet, Nickel - 20 Chromium - 2 Thoria, dated December 1, 1969. The chemistry of the alloy sheet and mechanical properties of the transverse sheet direction are shown in Tables B and C. The data in these tables was determined by Fansteel, Inc.

TABLE B

ALLOY CHEMISTRY AS REPORTED BY FANSTEEL, INC.

Heat No.	Composition, wt. percent				
	Cr	C	S	ThO_2	Ni
3636	20.16	.0214	.0021	2.17	bal
3637	19.8	.0194	.0019	2.14	bal
3697	20.07	.0248	.0055	2.10	bal
3712	19.77	.025	.003	2.10	bal
3715	19.65	.0226	.0036	1.93	bal

Additional characterization of the sheet used for the mechanical property studies was carried out at NASA/Lewis Research Center. The microstructure of the alloy sheet is shown in Figures 1 through 4. Both etchants (100 cm^3 H_2O, 10 cm^3 H_2SO_4, and 2 gms. chromic acid, or 90 cm^3 H_2O and 10 cm^3 H_2SO_4 at 3-5 volts dc) reveal the grain structure of TD-NiCr. With the exception of Heat 3636, all microstructures in Figures 1 through 4 are for the as-received material. Heat 3636 would not properly etch in the as-received condition; however, after a 50-hour anneal at 1589K in air, the grain structure could be seen. In general, such an annealing treatment does not affect the grain structure, but the anneal does affect the chromia particles in that they are preferentially attacked during etching; hence, the large number of voids in Figure 1. The average grain thickness, grain length, grain size, and grain aspect ratio are listed in Table D as a function of heat and sheet direction. Grain lengths, grain sizes, and grain aspect ratios could not be determined for Heat 3697 as only a few grains were seen in the microstructure (Figure 3), hence the average length of the grains in Heat 3697 is quite large, on the order of millimeters. Comparison of the data in Table D to similar data obtained by Fansteel, Inc. (Ref. 1) during the reproducibility studies for thin TD-NiCr sheet reveals: the average grain size and the grain aspect ratio of the TD-NiCr tested in this program are larger than values obtained from material used for the reproducibility studies.

The (111) pole figures for the alloy sheet used in the mechanical property tests are shown in Figures 5 and 6. All heats possessed an approximate (210) [001] texture with the [001] direction parallel to the sheet rolling direction.

Finally, neither the average thoria particle size nor average intraparticle spacing was determined during the course of the study.

Specimen Preparation

As each heat of material was received, the sheets were covered with an adhesive tape to protect the surface during the layout and shearing procedures. The specimen layout (inked on the taped surfaces) was made in such a way as to accomplish a somewhat random specimen location from the available stock. After inking, the sheets were photographed to supply a permanent record of specimen location. Figure 7 shows a photograph of a typical sheet layout.

Because of the need to have specimens taken parallel, normal, and at 45° to the rolling direction and also the need for a large number of specimens from a limited amount of material, it was impossible to have a truly random specimen location. The "somewhat random" refers to the fact that certain groups or clusters of specimens of certain sizes and directions were obtained at random locations on the sheets.

Following the layout, the specimen blanks were sheared to the approximate length and width. Groups of specimens were then rough milled to the required overall sizes. Where required, loading holes for the test specimens were then drilled and reamed using soluble oil as a cutting fluid.

Finishing of the specimen edges was accomplished using low stress grinding or milling procedures.

The test specimens used for mechanical testing are shown in Figures 8 through 13. Figure 8 shows the specimen configuration used for tensile, modulus of elasticity, Poisson's Ratio, creep-rupture, and creep-strength testing. Figures 9 through 13 show compression, bearing, shear, sharp-notch, and fatigue specimens, respectively.

The test specimens for physical testing were from Heat 3715 (0.102 cm thick). The rectangular coupons and discs required for these tests were machined at Metcut to the dimensions requested by R. Taylor at TPRC. Exact descriptions of the specimen are contained in the various sections covering the physical testing procedures.

TABLE C

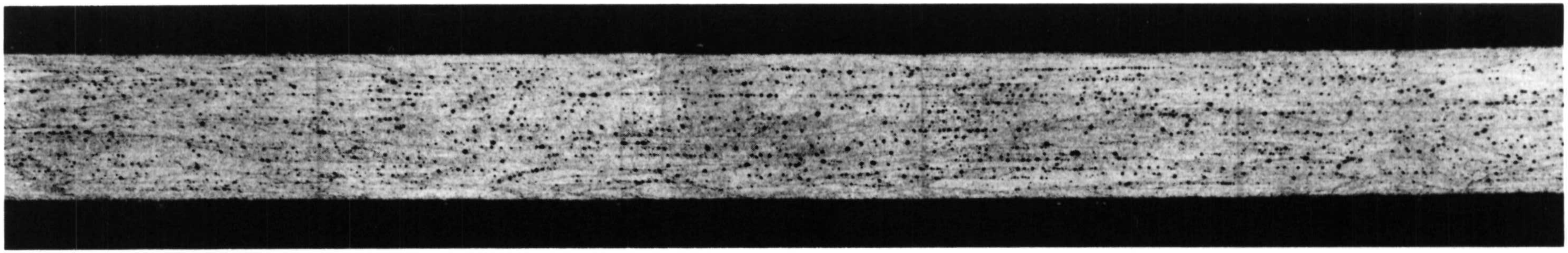
MECHANICAL PROPERTIES OF ALLOY SHEET AS REPORTED BY FANSTEEL, INC. TRANSVERSE SHEET DIRECTION

	Room Temperature Properties				1366K Properties			
Heat No.	0.2% Y.S. (MN/m^2)	U.T.S. (MN/m^2)	Elong. (%)	105° 3T Bend Test	0.2% Y.S. (MN/m^2)	U.T.S. (MN/m^2)	Elong. (%)	Stress Rupture Life
3636	578.8	815.8	19.	passed	136.4	136.4	2.	Exceeds 20h at 37.8 MN/m^2
3637	563.6	799.9	23.	passed	102.	102.	2.	Exceeds 20h at 31. MN/m^2
3697	554.	742.7	15.5	passed	89.6	89.6	2.	Exceeds 20h at 31. MN/m^2
3712	578.1	765.5	25.	passed	128.8	128.8	3.5	Exceeds 20h at 37.8 MN/m^2
3715	547.8	821.3	17.	passed	121.2	122.6	2.9	Exceeds 20h at 37.8 MN/m^2

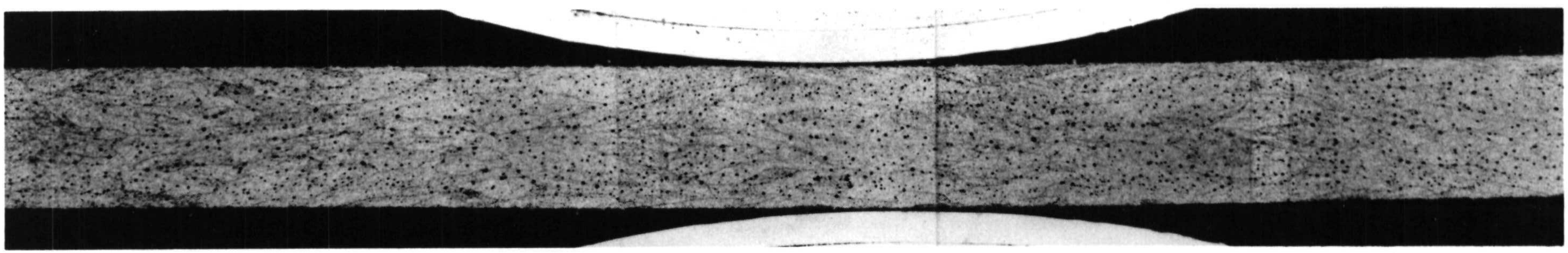
TABLE D

AVERAGE GRAIN SIZE PARAMETERS FOR ALLOY SHEET

Heat No.	Specimen Direction	Grain Thickness, D (μm)	Grain Length, L (μm)	Average Grain Size $\sqrt{LD}$ (μm)	Grain Aspect Ratio, L/D	Nom. Sheet Thickness / Avg. Grain Thickness
3636	Parallel	50	290	120	5.7	10.2
	Normal	50	230	110	4.4	10.2
3637	Parallel	50	390	140	7.6	5.1
	Normal	55	290	130	5.0	4.6
3697	Parallel	250	--	--	--	1.0
	Normal	250	--	--	--	1.0
3712	Parallel	110	640	265	5.9	4.6
	Normal	90	360	180	4.0	5.6

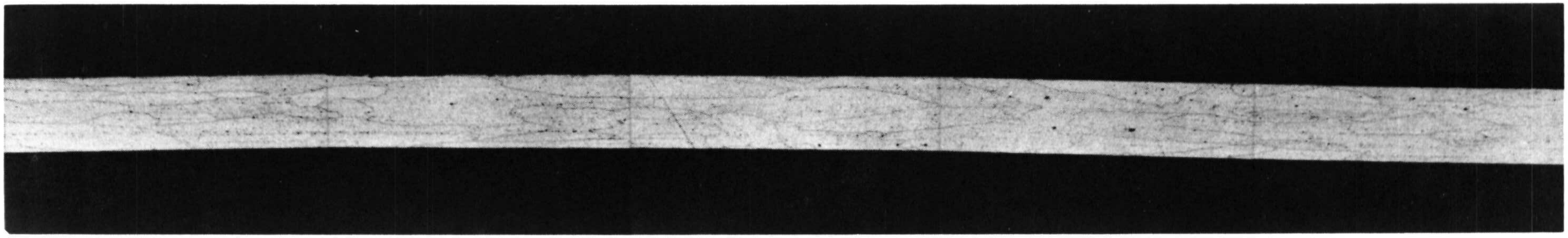


(a) Longitudinal Direction

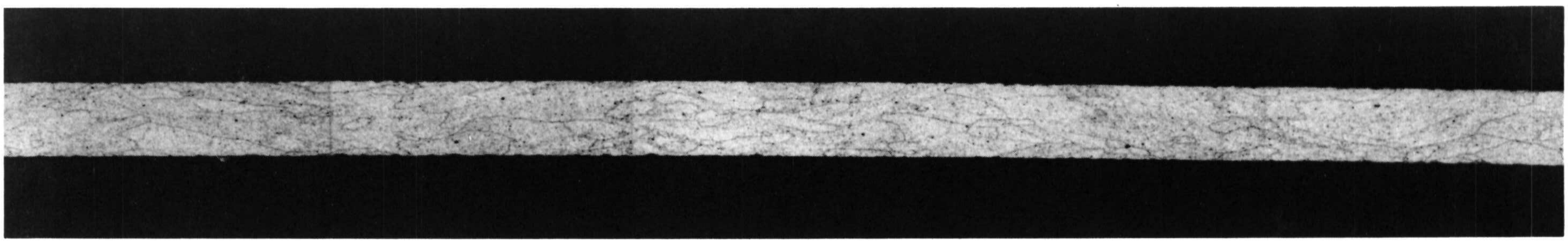


(b) Transverse Direction

Figure 1 - MICROSTRUCTURE OF TD-NiCr SHEET, HEAT 3636, ANNEALED. ETCHANT: $H_2SO_4 + H_2O$. MAGNIFICATION: 47X.

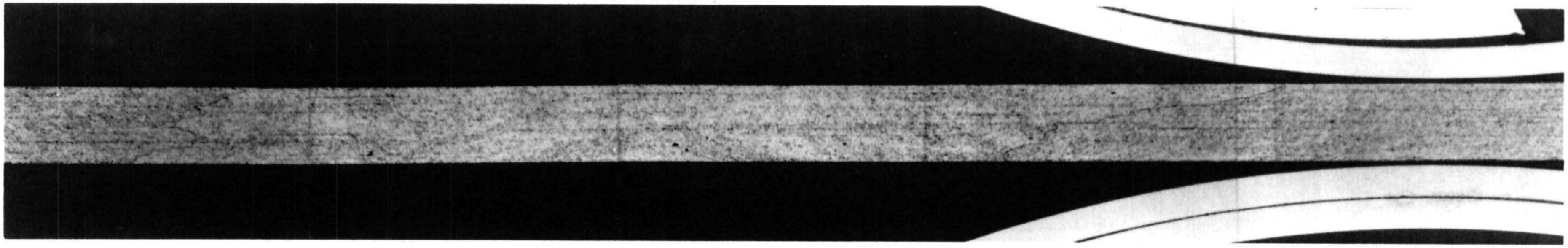


(a) Longitudinal Direction

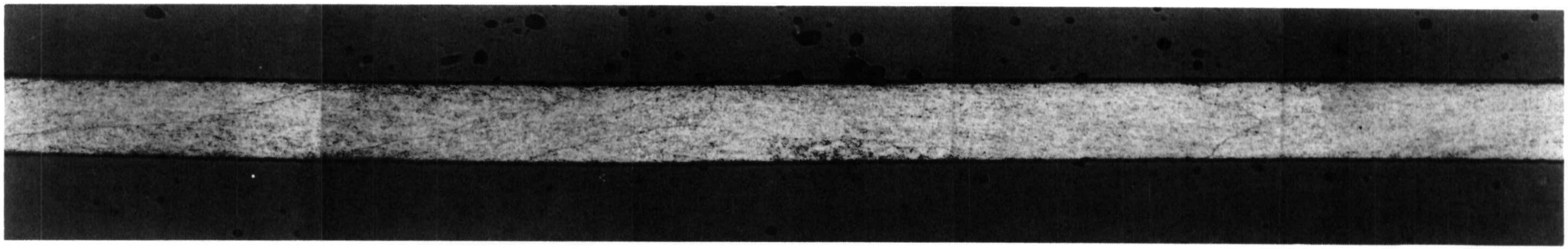


(b) Transverse Direction

Figure 2 - MICROSTRUCTURE OF TD-NiCr SHEET, HEAT 3637, AS RECEIVED. ETCHANT: CHROMIC ACID. MAGNIFICATION: 47X.

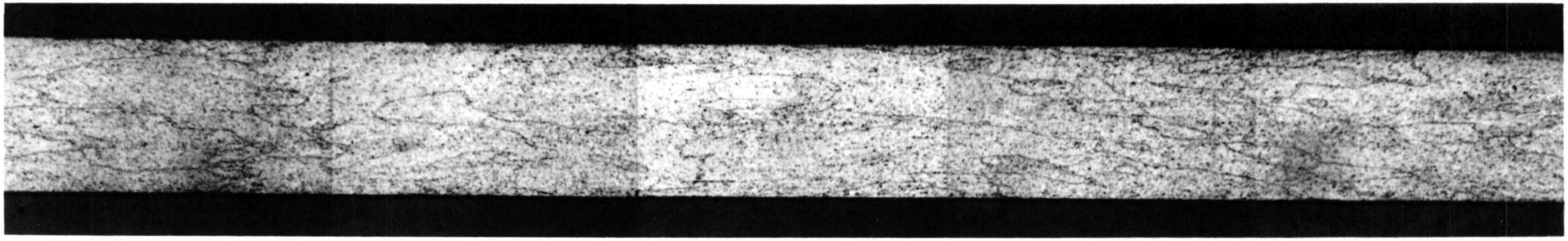


(a) Longitudinal Direction

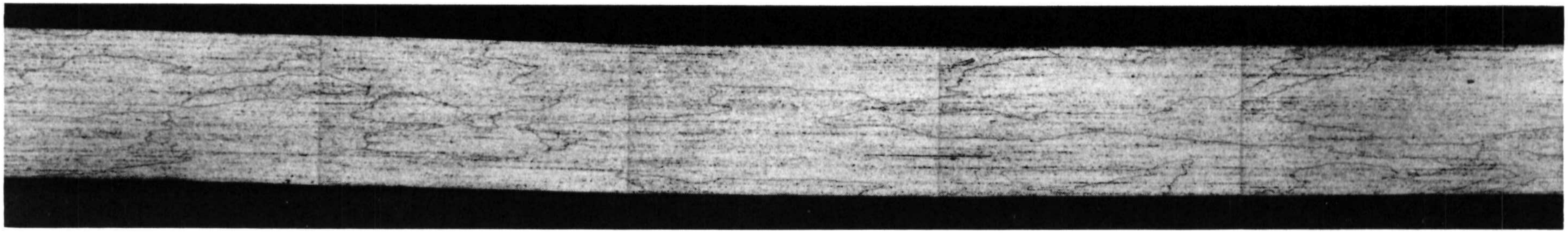


(b) Transverse Direction

Figure 3 - MICROSTRUCTURE OF TD-NiCr SHEET, HEAT 3697, AS RECEIVED. ETCHANT: CHROMIC ACID, MAGNIFICATION: 47X.



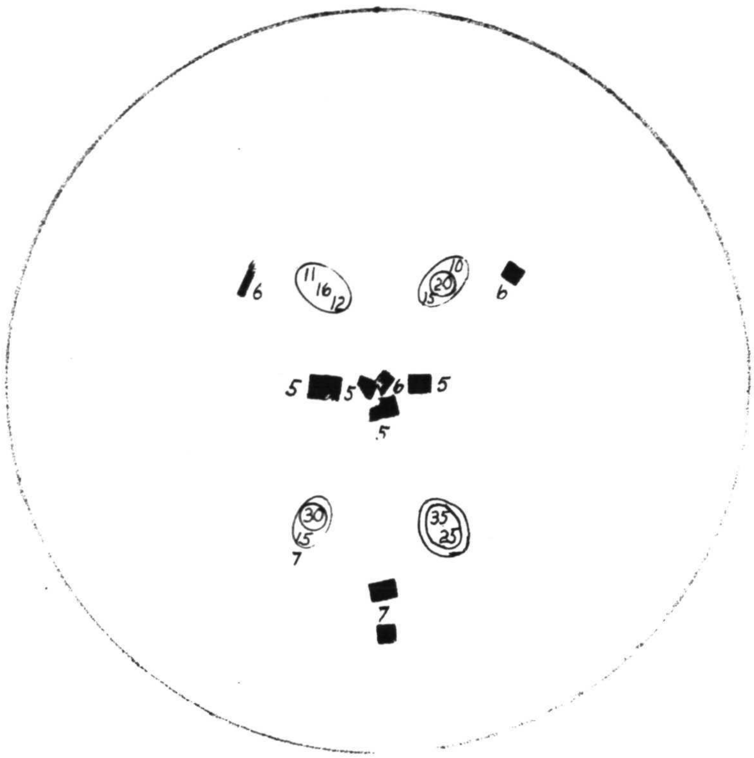
(a) Longitudinal Direction



(b) Transverse Direction

Figure 4 - MICROSTRUCTURE OF TD-NiCr SHEET, HEAT 3712, AS RECEIVED. ETCHANT: CHROMIC ACID. MAGNIFICATION: 47X.

(a) Heat 3636



(b) Heat 3637

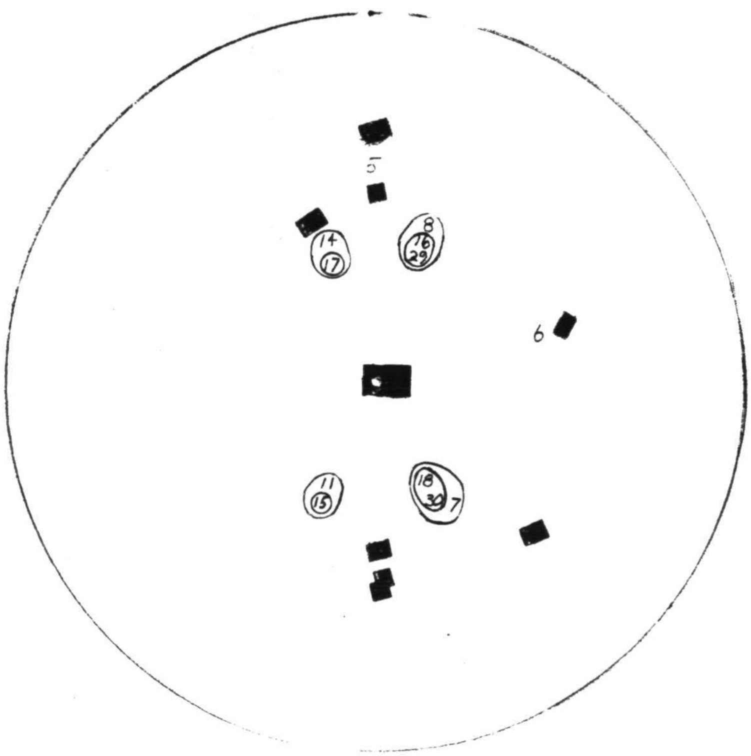
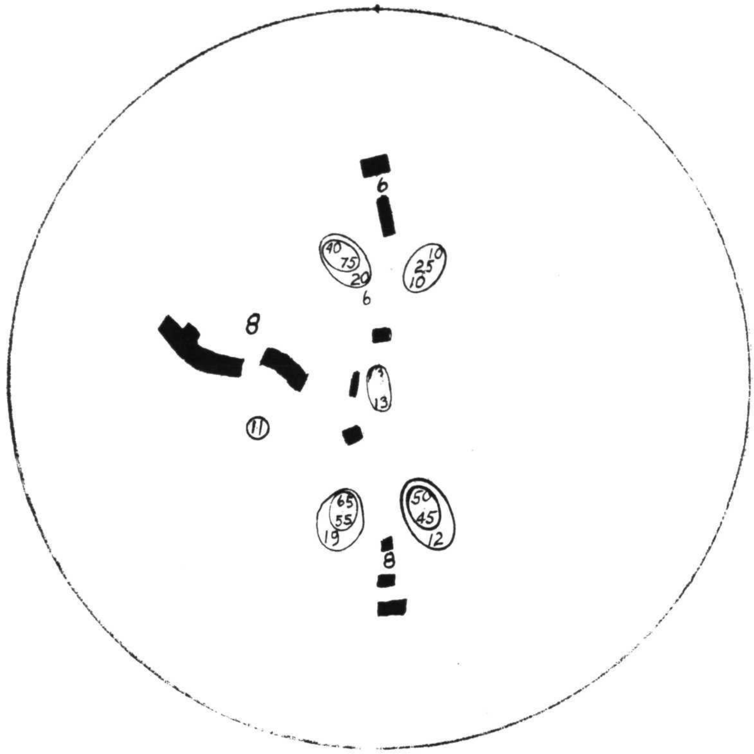


Figure 5 - (111) Pole Figures for Heats 3636 and 3637

(c) Heat 3697



(d) Heat 3712

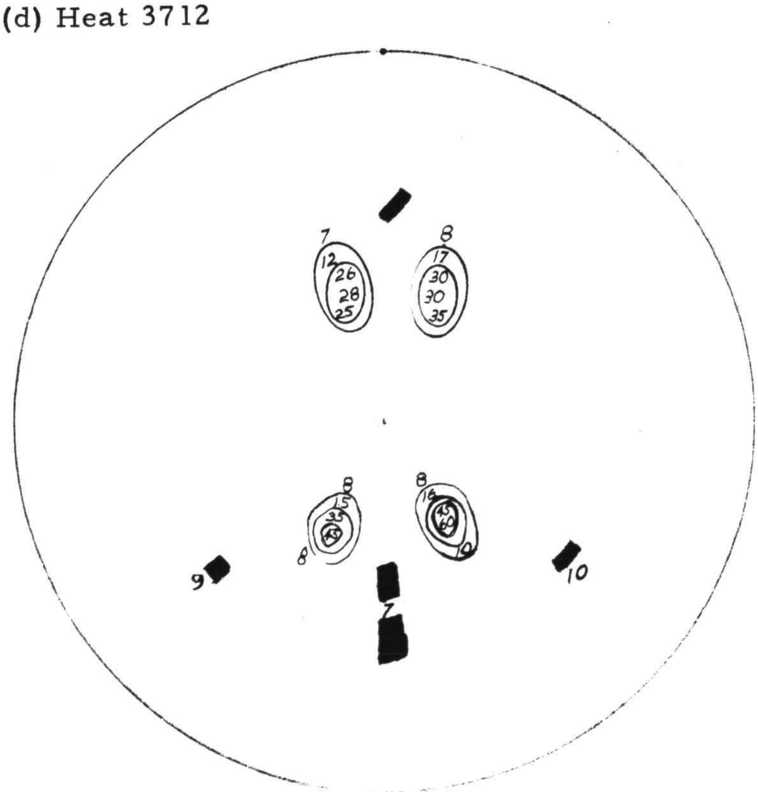


Figure 6 - (111) Pole Figures for Heats 3697 and 3712

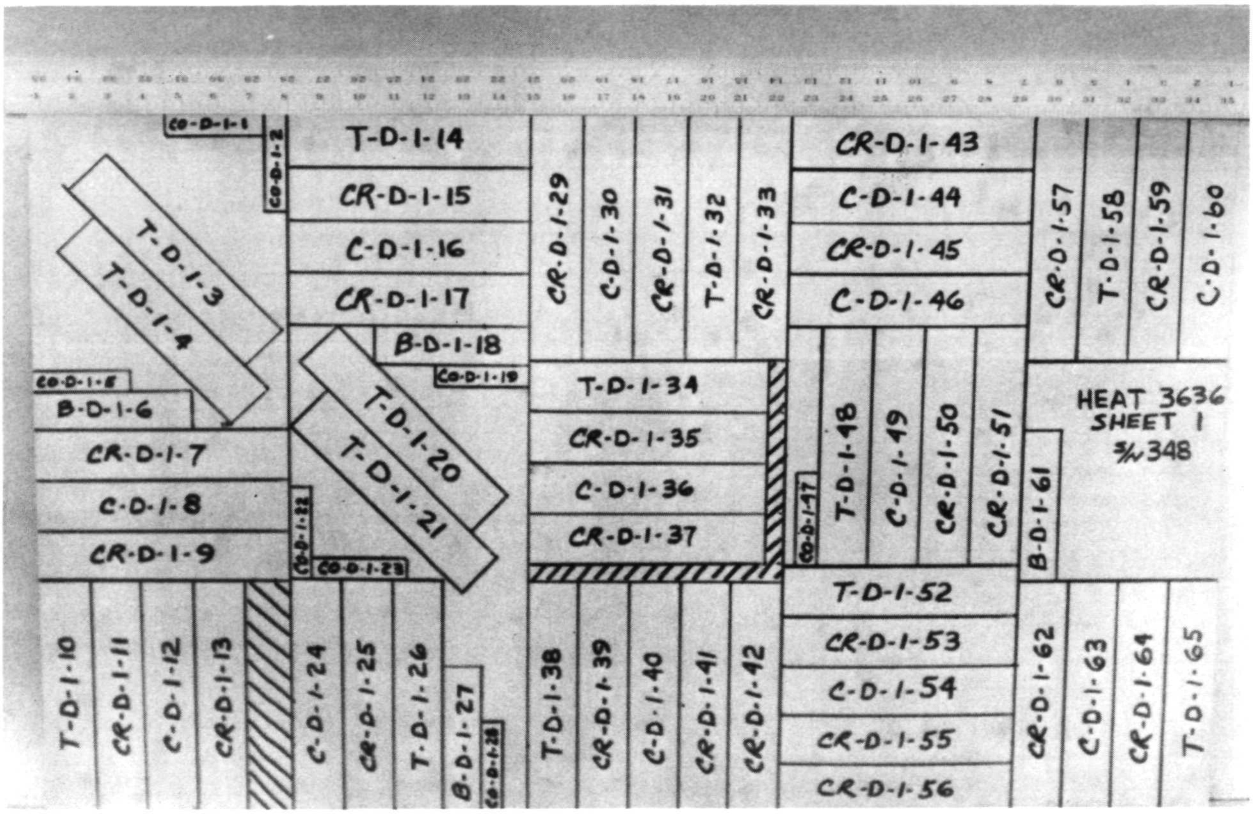


Figure 7 - Typical Specimen Layout, Heat 3636, Sheet 1, S/N 348.

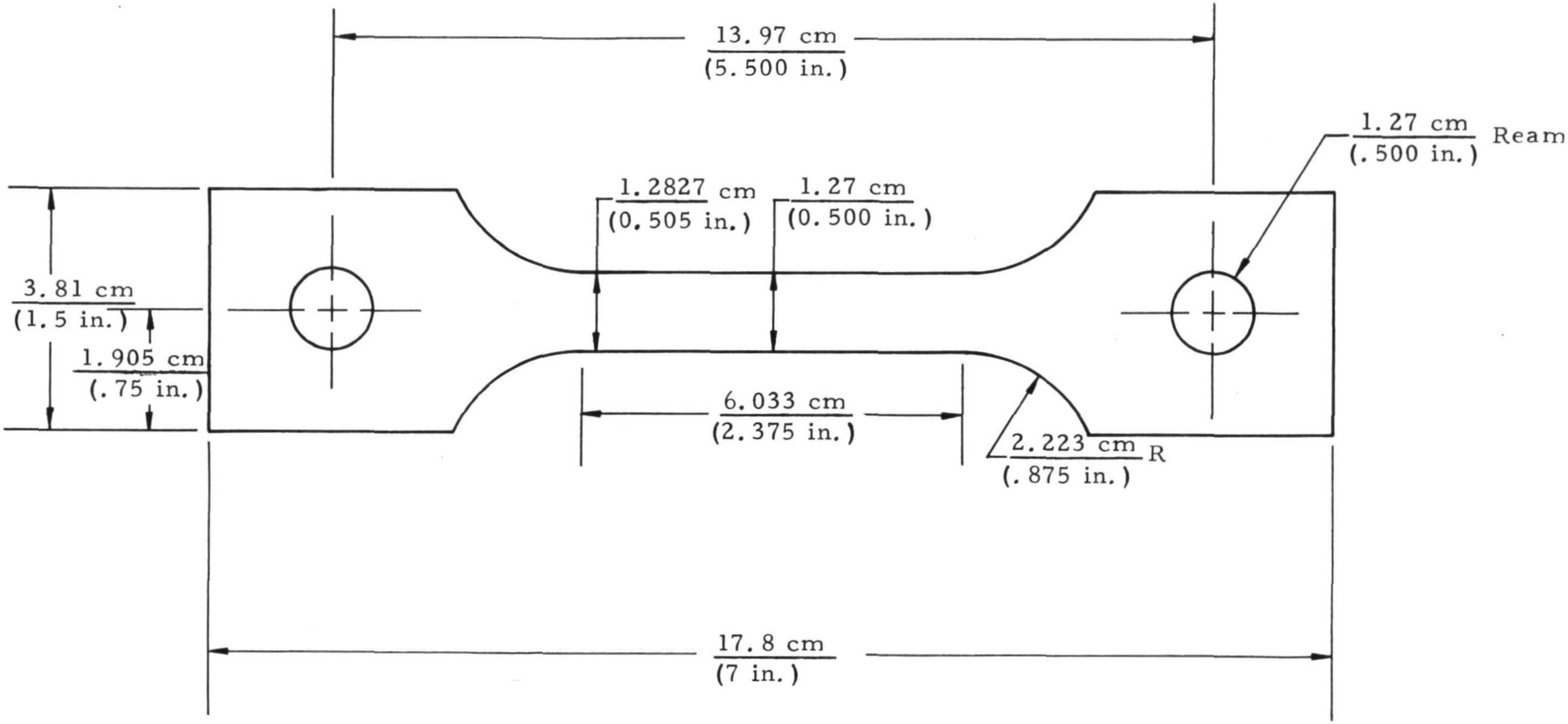


Figure 8 - TENSION SPECIMEN

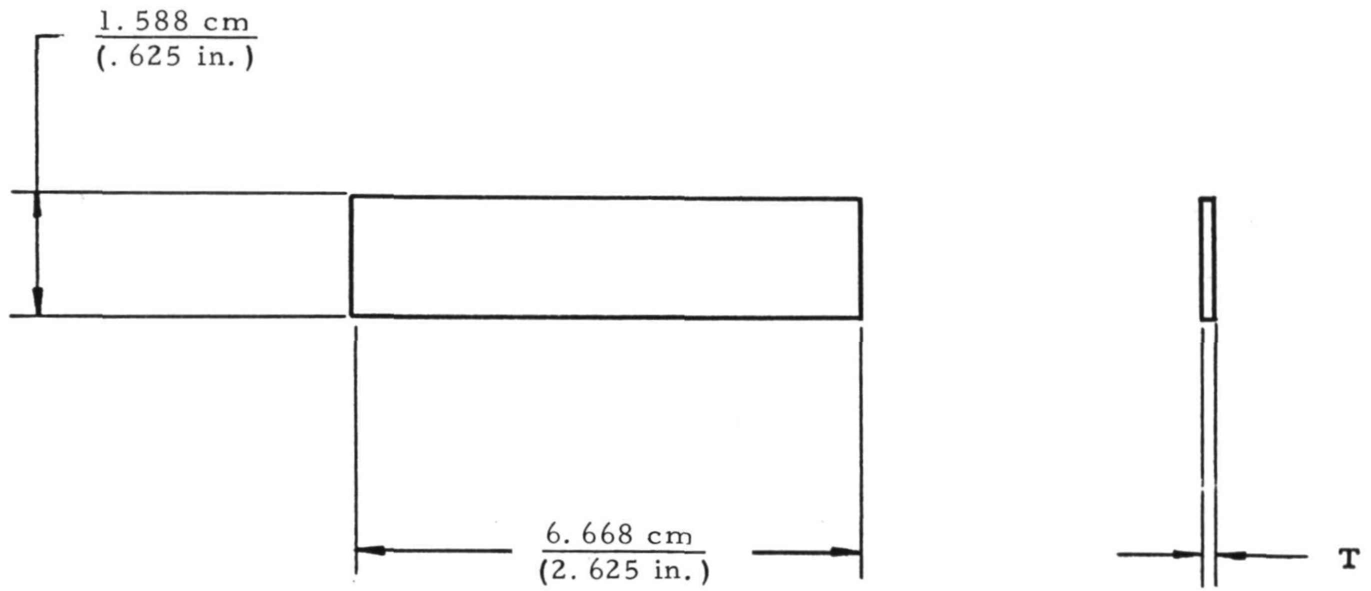


Figure 9 - COMPRESSION SPECIMEN

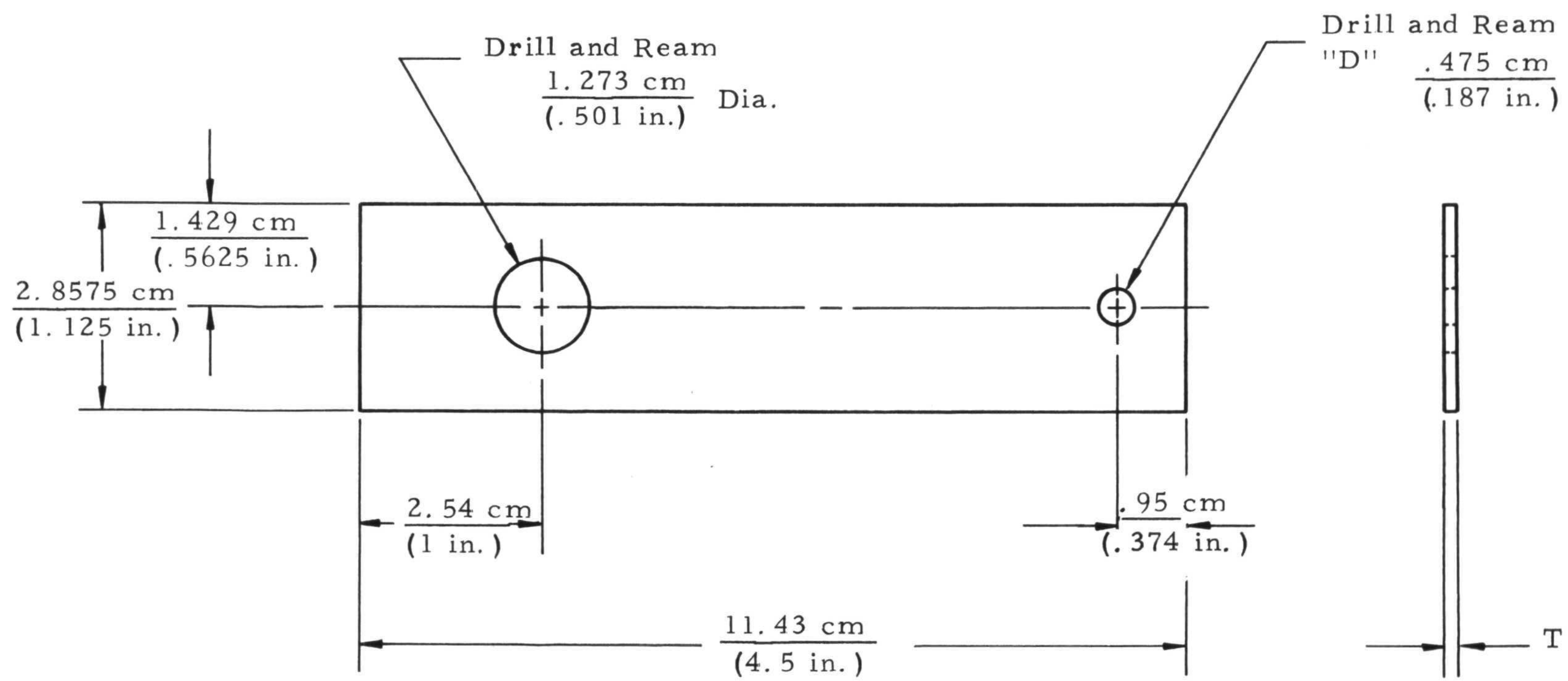


Figure 10 - BEARING SPECIMEN

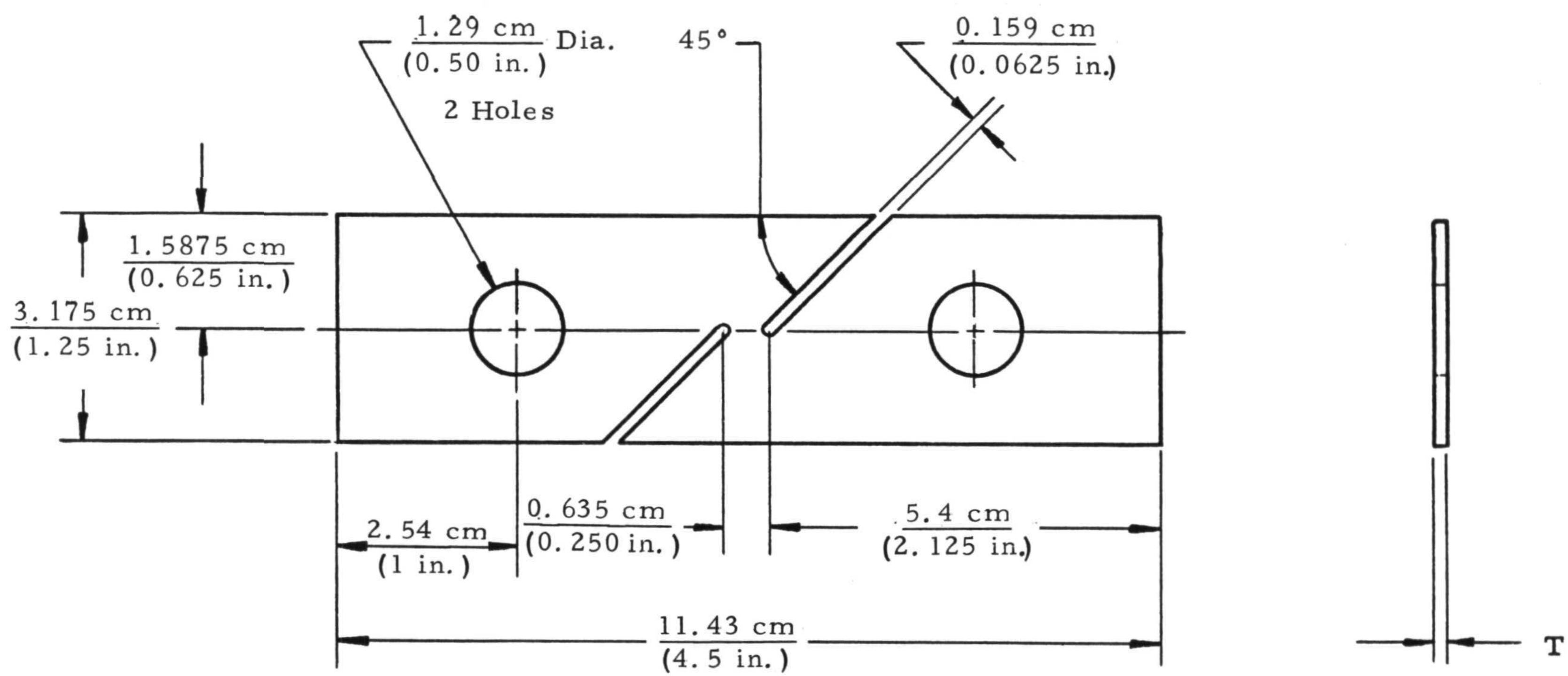


Figure 11 - SHEAR SPECIMEN

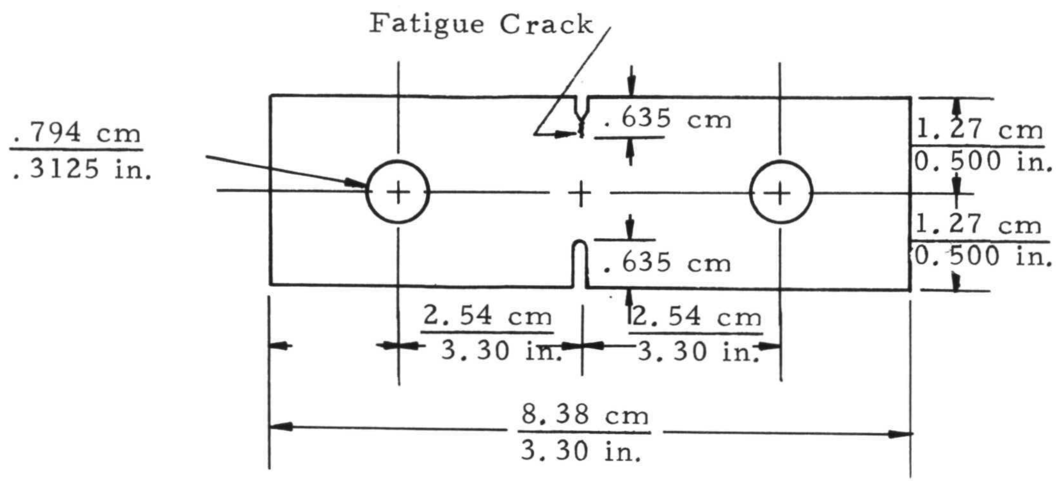


Figure 12 - Sharp Notch Specimen After Precracking and Final Machining

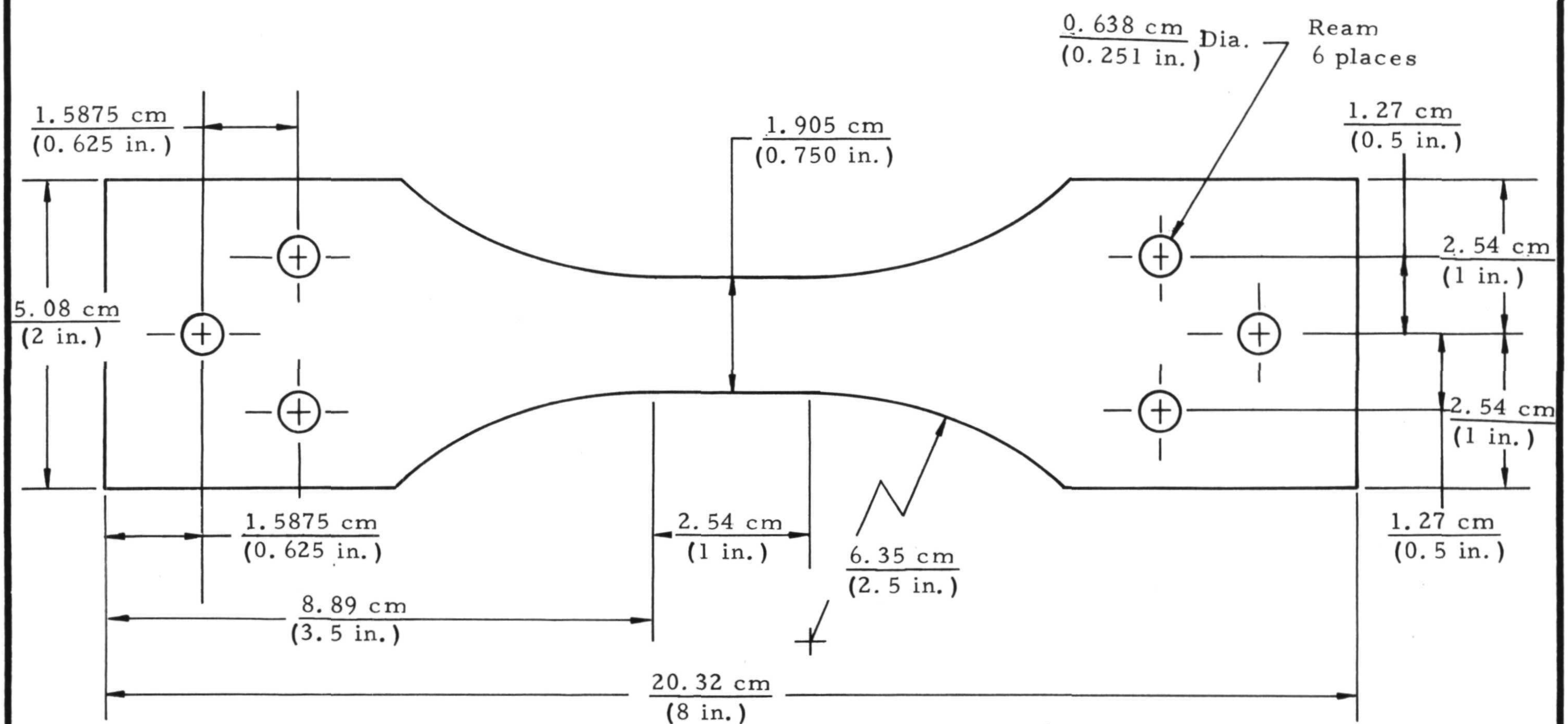


Figure 13 - FATIGUE SPECIMEN

MECHANICAL PROPERTIES

TASK I-1 TENSILE PROPERTIES

Measurements were made in accordance with ASTM Designation E21-69 to evaluate the ultimate tensile strength, 0.02% yield strength, 0.2% yield strength and the percent elongation for each heat of TD-NiCr sheet. Test temperatures were ambient, 922K, 1144K, 1255K, 1366K, 1477K, and 1589K with nine specimens being evaluated at each temperature. These nine tests involved three specimens taken parallel to the sheet rolling direction, three taken normal to the sheet rolling direction, and three taken 45° with respect to the sheet rolling direction. The tensile test specimen geometry is shown in Figure 8.

Conventional Microformer-type strain recording systems incorporating a clip-on extensometer were used for the ambient temperature tests. In Figure 14 the extensometer system used for the elevated temperature tests is shown.

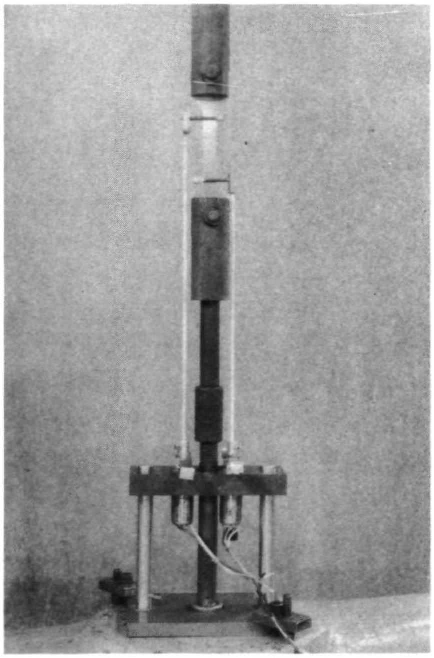


Figure 14 - High Temperature Tensile Extensometer System

The extensometer depicted used solid aluminum oxide rods to transmit the specimen motion to LVDT's, mounted to the stationary crosshead. The LVDT's converted this motion to an electronic signal which was magnified and supplied as the x input to drive an x-y recorder. The y axis input was supplied by electronic load cells connected in series with the specimen load-train system. The choice of aluminum oxide rods was dictated by the need for a lightweight extensometer which could be attached directly to the specimen and yet would withstand exposure to the high temperatures to be encountered in the test program.

The testing was performed in hydraulic tensile machines, using a strain rate of 0.005 cm/cm/min. through the 0.2% yield. A head rate of 0.127 cm/min. was then set and held until failure occurred.

Test temperature was maintained using chromel-alumel thermocouples through 1144K and platinum-13% rhodium thermocouples above 1144K.

Except for room temperature tensile tests, all specimens had reinforcing tabs attached to prevent failure at the pin hole loading area.

Typical stress-strain curves for Heat 3637 are given in Figure 15. These curves are for the parallel direction only but they illustrate what happens for specimens of all three directions and for both thicknesses of material. From these curves it can be seen that the 0.2% yield strength data was not available for all test temperatures. In the other test results the 0.02% yield strength data also was not available. In general 0.2% yield strength data could not be obtained for temperatures greater than 922K and 0.02% yield strength data could not be obtained for temperatures exceeding 1144K. Because yield data was not always available at elevated temperatures, only ultimate tensile strength data along with appropriate error limits is presented in the data summary plots, Figures 16 through 19. The error limit curves in these plots are drawn through the lower error limit for the minimum ultimate tensile strength value at each temperature and the upper error limit for the maximum ultimate tensile strength value at each temperature. In Figures 16 through 19 the 95% confidence limits are shown as continuous curves, the 90% confidence limits are shown as tick marks, and the average ultimate tensile strength values for each test direction are shown as data points. The procedures used for the statistical analysis of the tensile data are discussed in Appendix A. The summary of all tensile data is presented in Tables 1 through 28, Appendix B.

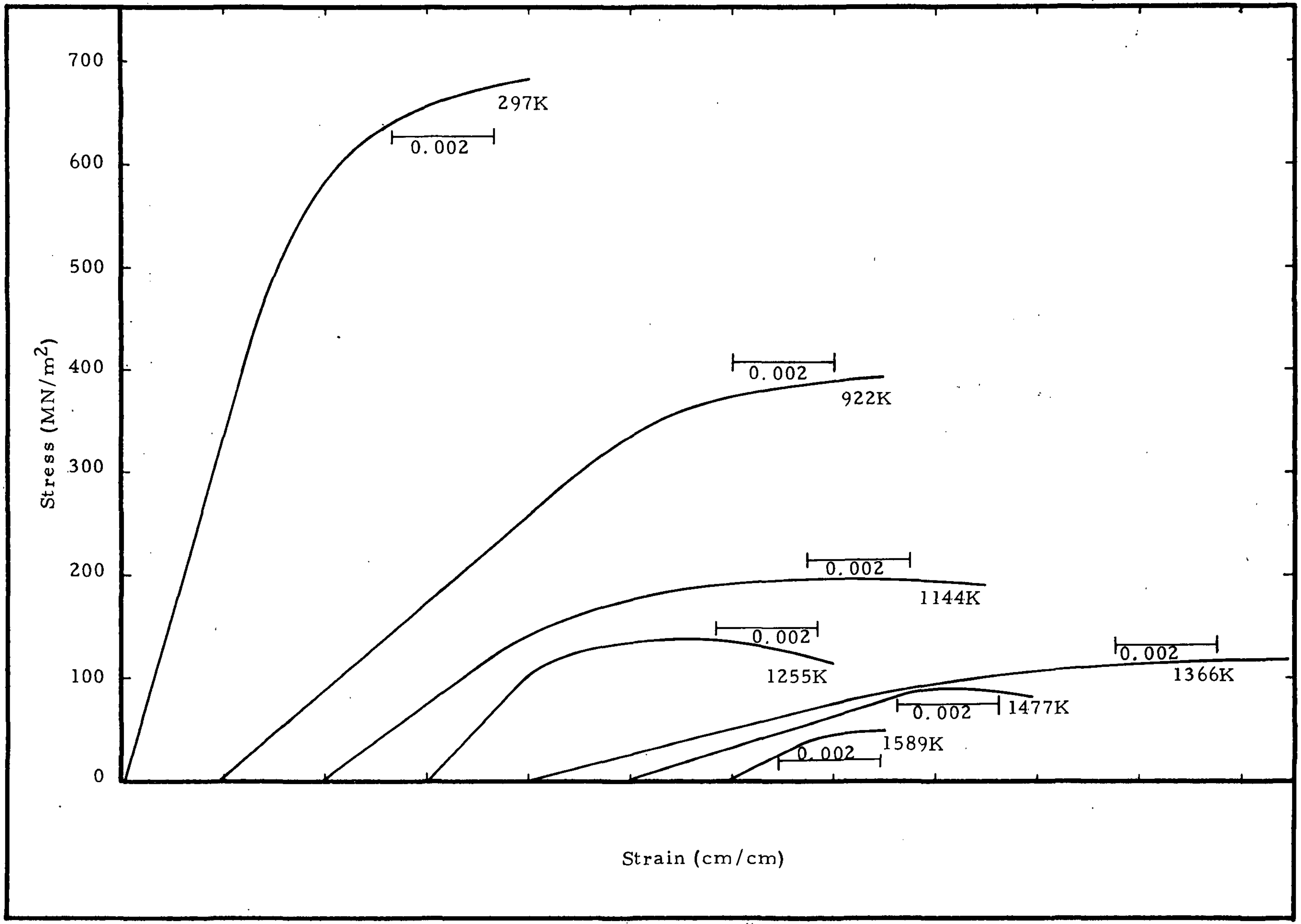


Figure 15 - TYPICAL STRESS STRAIN CURVES. HEAT 3637.
PARALLEL TO ROLLING DIRECTION.

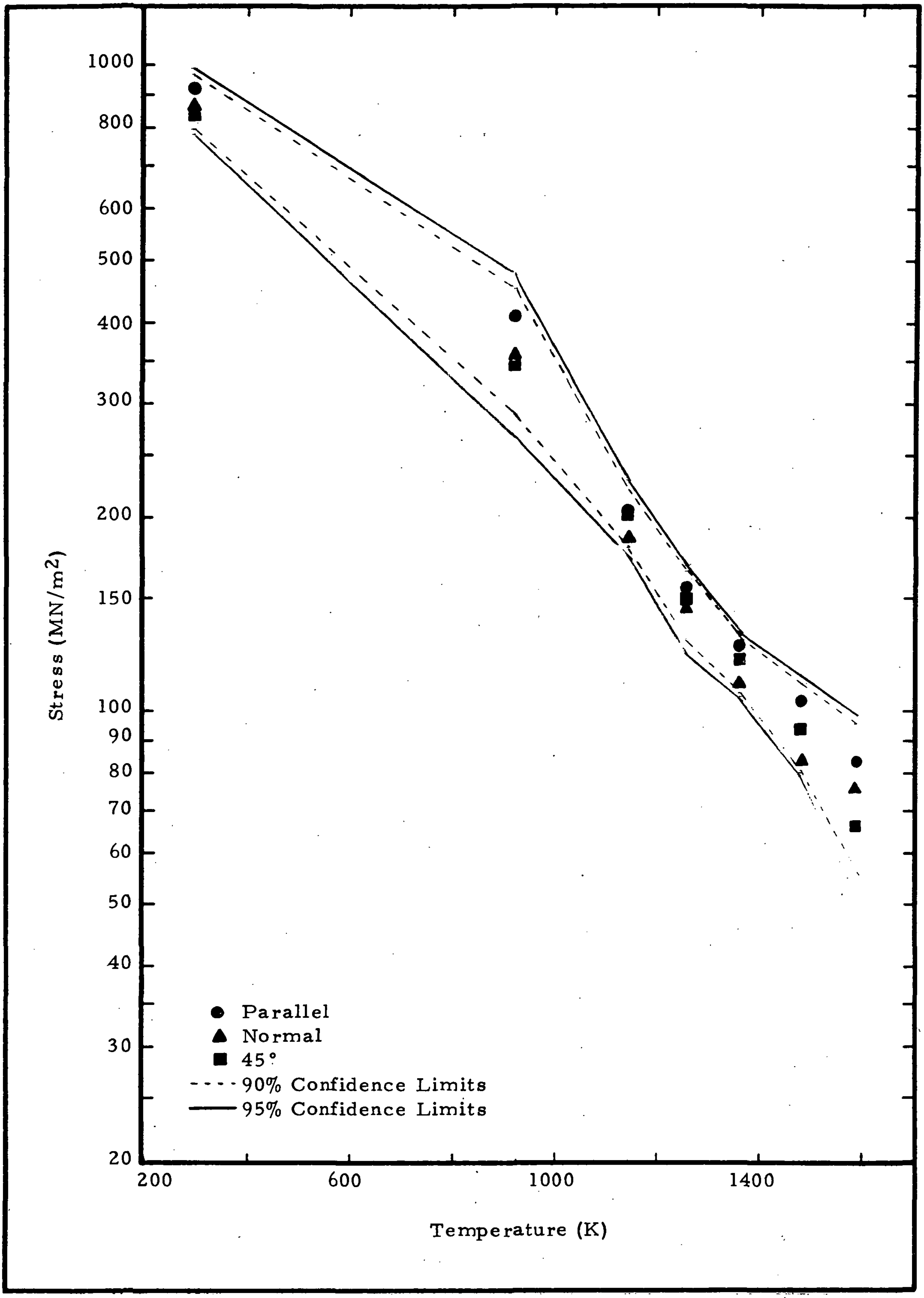


Figure 16 - ULTIMATE TENSILE STRENGTH AS A FUNCTION OF TEMPERATURE FOR HEAT 3636 (0.051 cm).

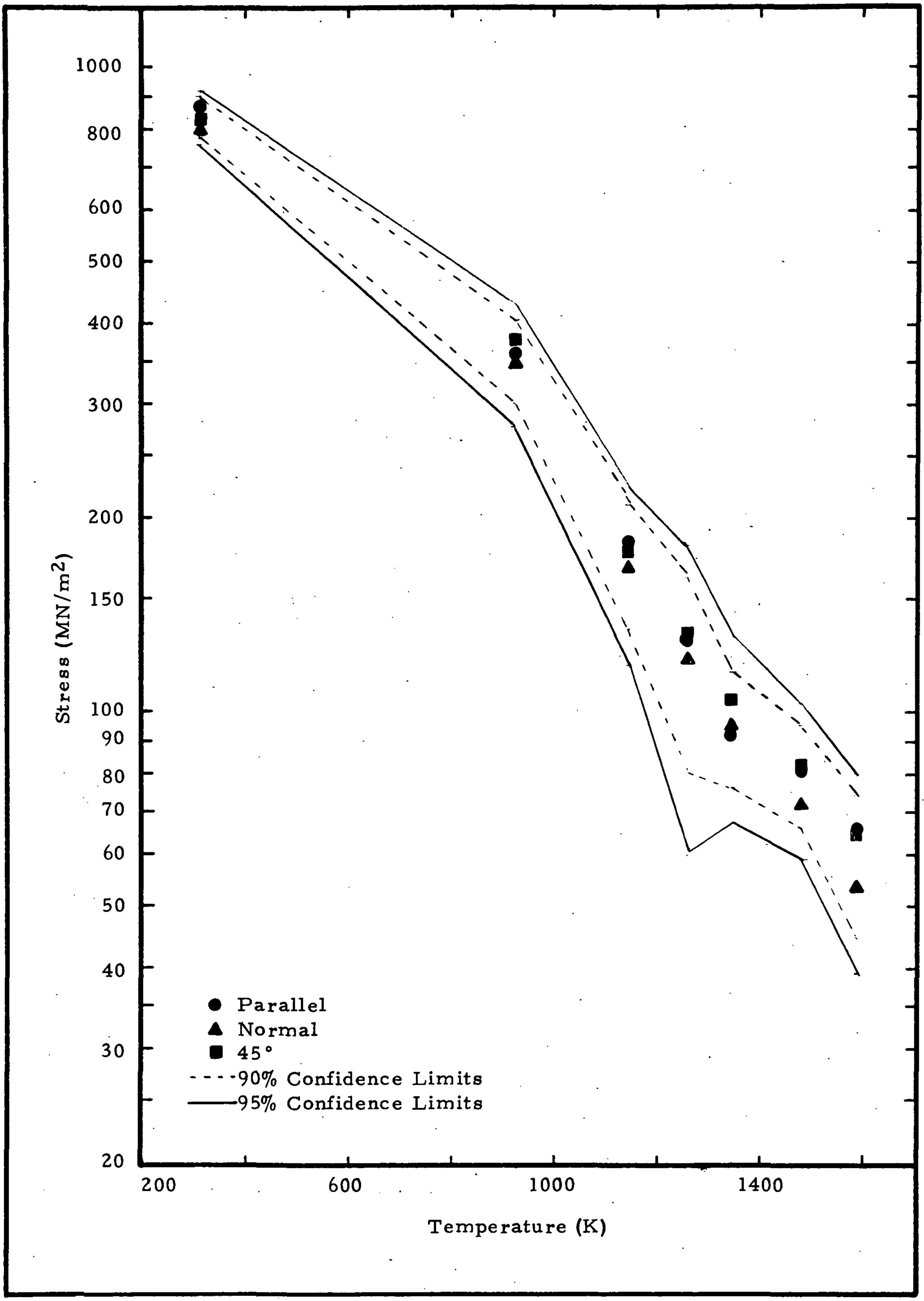


Figure 17 - ULTIMATE TENSILE STRENGTH AS A FUNCTION OF TEMPERATURE FOR HEAT 3637 (0.025 cm).

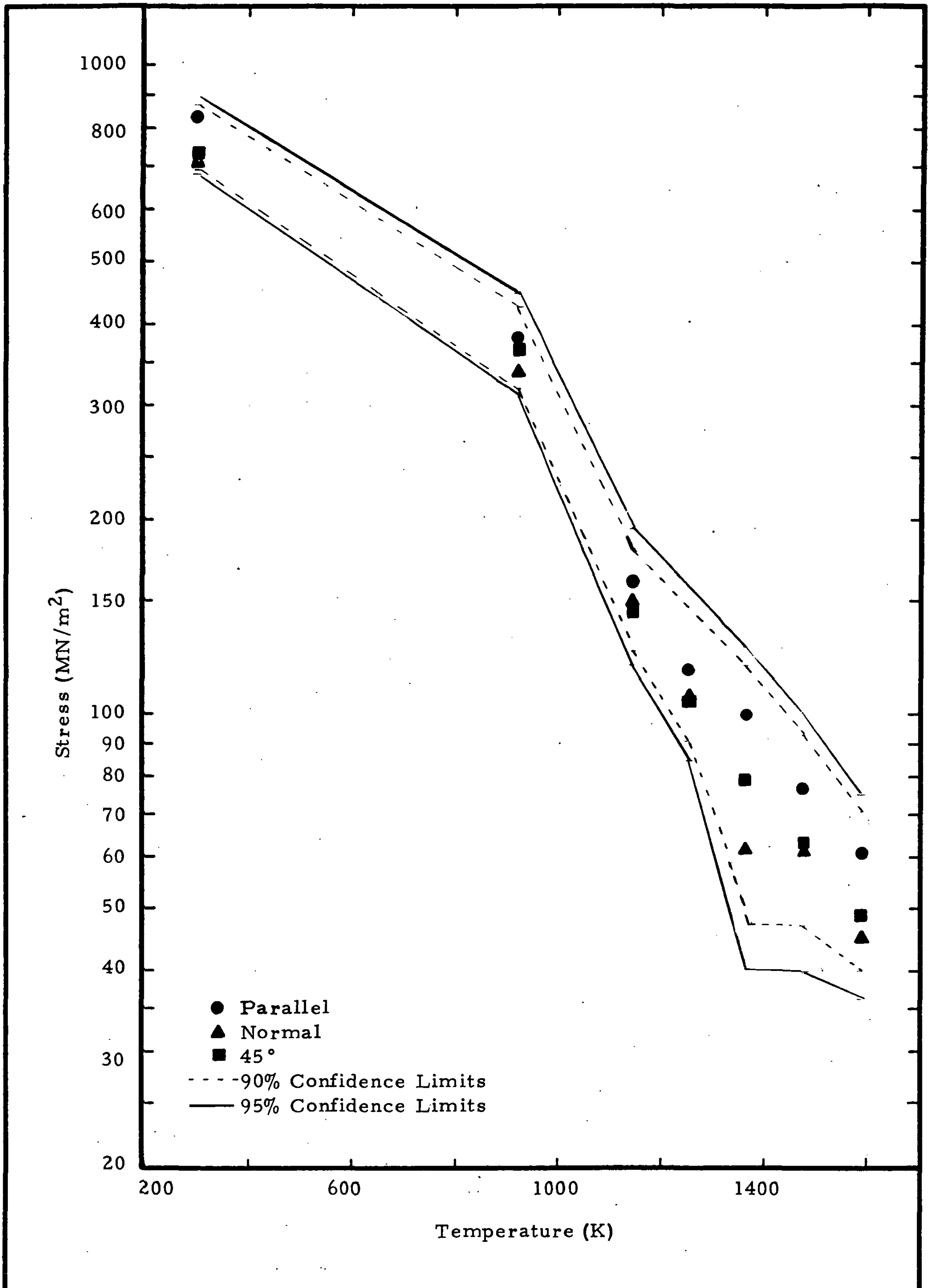


Figure 18 - ULTIMATE TENSILE STRENGTH AS A FUNCTION OF TEMPERATURE FOR HEAT 3697 (0.025 cm).

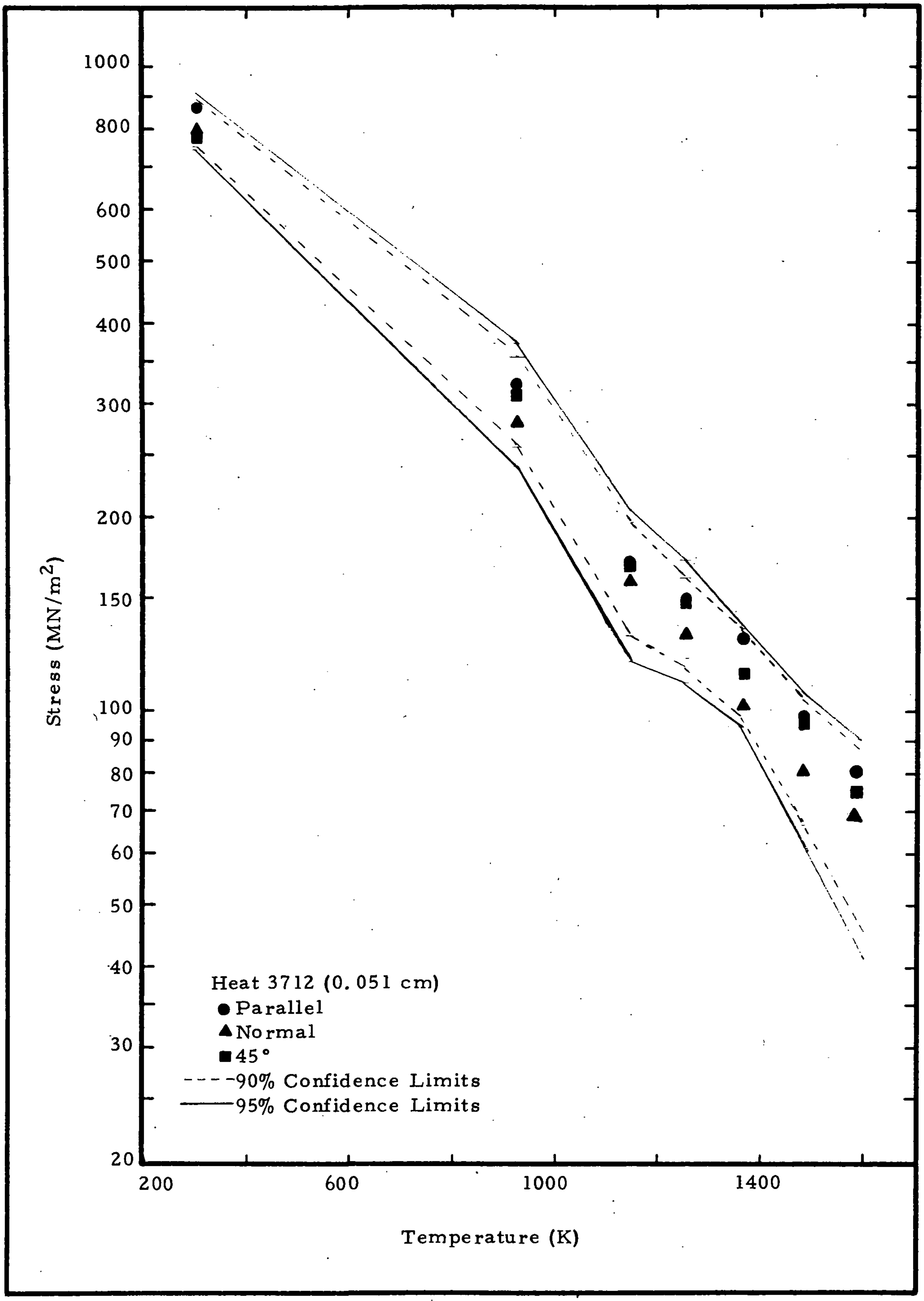


Figure 19 - ULTIMATE TENSILE STRENGTH AS A FUNCTION OF TEMPERATURE FOR HEAT 3712 (0.051 cm)

In Table E average tensile property values and confidence limits for thin TD-NiCr sheet are reported as a function of temperature. The averages were calculated from property data for all four heats and three test directions. For the cases (0.02% and 0.2% yield strength) where one or more test values were missing, no average was calculated. The average ultimate tensile strength data and confidence limits as a function of temperature are shown in Figure 20.

In reviewing the tensile data the following observations can be made:

a) With some exceptions the 0.051 cm material had higher ultimate strengths than the 0.025 cm material.

b) For all test temperatures the specimens taken parallel to the rolling direction generally had the highest ultimate strength with the 45° specimens usually also higher in strength than the specimens from the normal direction.

c) At test temperatures other than ambient the 0.025 cm material had elongations of less than 1% while the 0.051 cm material exhibited elongations of 1% or better through 1144K; however, for test temperatures exceeding 1144K, the 0.051 cm TD-NiCr sheet also exhibited tensile elongations less than 1%.

TABLE E

AVERAGE TENSILE PROPERTIES AND CONFIDENCE LIMITS FOR THIN TD-NiCr SHEET AS A FUNCTION OF TEMPERATURE

	Temperature, K						
	297	922	1144	1255	1366	1477	1589
Tensile Properties							
0.02% Y. S. (MN/m^2)	495.5	289.8	--	--	--	--	--
0.2% Y. S. (MN/m^2)	574.5	--	--	--	--	--	--
U. T. S. (MN/m^2)	820	348.8	172.1	132.1	102.1	82.3	65.4
Elong. (%)	14.3	2.4	1.1	0.7	0.7	0.7	0.5
90% Confidence Limits For:							
0.02% Y. S. (MN/m^2)	± 44.2	± 38.8	--	--	--	--	--
0.2% Y. S. (MN/m^2)	± 54.5	--	--	--	--	--	--
U. T. S. (MN/m^2)	± 88.7	± 57.2	± 31.3	± 27.3	± 31.8	±21.9	±20.3
Elong. (%)	± 7.7	± 4.3	± 1.1	± 0.5	± 0.4	± 0.5	± 0.35
95% Confidence Limits For:							
0.02% Y. S. (MN/m^2)	± 52.8	± 46.3	--	--	--	--	--
0.2% Y. S. (MN/m^2)	± 65.1	--	--	--	--	--	--
U. T. S. (MN/m^2)	±106.0	± 68.4	± 37.4	± 32.6	± 38.1	±26.1	±24.2
Elong. (%)	± 9.2	± 5.1	± 1.3	± 0.6	± 0.5	± 0.6	± 0.4

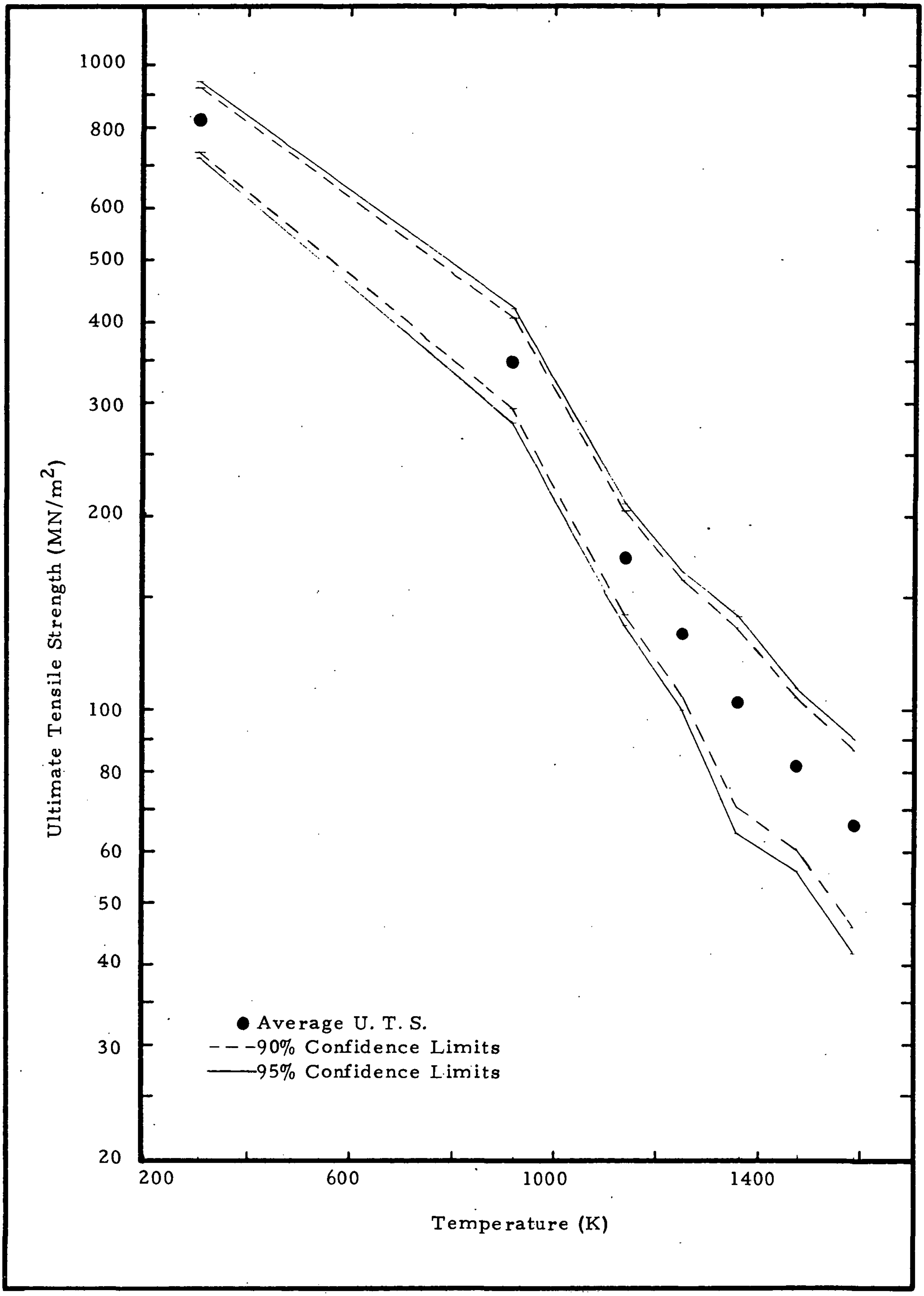


Figure 20 - AVERAGE ULTIMATE TENSILE STRENGTH AS A FUNCTION OF TEMPERATURE FOR ALL FOUR HEATS OF TD-NiCr SHEET.

TASK I-2 MODULUS OF ELASTICITY

The same extensometer system and specimen design used for the elevated temperature tensile tests was also used for the modulus of elasticity measurements. Specimens were loaded in a stress rupture frame or in the tensile machine and tested in accordance with ASTM Designation E231-69. Testing was conducted on duplicate specimens taken parallel, 45°, and normal to the sheet rolling directions from the two heats of 0.025 cm sheet (Heats 3637 and 3697). Measurements were made at room temperature, 922K, 1144K, and 1366K.

A summary of the modulus of elasticity values obtained is presented in Table F and plotted versus temperature in Figure 21.

TABLE F

MODULUS OF ELASTICITY AS A FUNCTION OF DIRECTION AND TEMPERATURE

Heat No.	Specimen Direction	Modulus of Elasticity (GN/m^2) 299K	922K	1144K	1366K
3637	Parallel	140.7	140.7	111.7	92.4
		131.0	135.1	104.8	77.2
	Normal	160.0	122.7	113.8	63.4
		166.2	119.3	110.3	82.0
	45°	198.6	149.6	123.4	88.3
		197.2	154.4	118.4	87.6
3697	Parallel	125.5	128.2	88.3	66.2
		125.2	133.1	84.1	77.9
	Normal	171.7	137.9	106.2	83.3
		188.2	115.1	104.5	87.6
	45°	236.5	178.6	126.2	95.8
		212.8	190.3	126.2	79.6

In general for both heats and all test temperatures, the modulus of elasticity for specimens taken 45° to the rolling direction is greater than that for specimens taken normal to the rolling direction which, in turn, is greater than the modulus of elasticity for specimens taken parallel to the rolling direction.

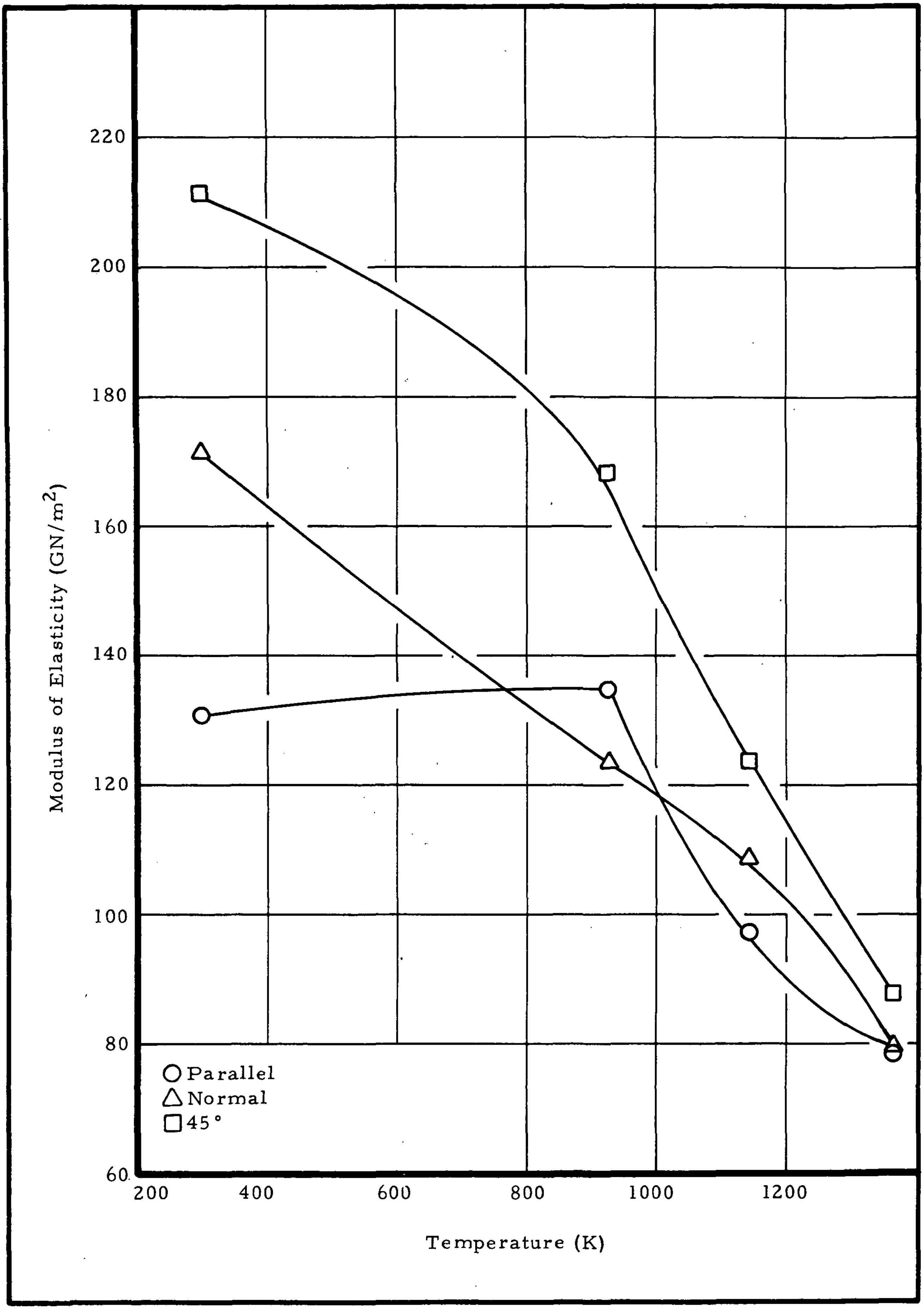


Figure 21 - MODULUS OF ELASTICITY AS A FUNCTION OF TEMPERATURE FOR 0.025 CM THICK TD-NiCr SHEET

TASK I-3 POISSON'S RATIO

A single heat of 0.025 cm material (Heat 3637) was used to determine Poisson's Ratio (ratio of transverse strain to the corresponding axial strain resulting from an axial stress) at room temperature (297K). The following test procedure which is in accordance with ASTM Designation E132-61 (reapproved 1965) was used to measure Poisson's Ratio. The values were obtained at ambient temperature using 90° rosette wire strain gages which had 0.635 cm square grids--electrically independent. The specimen was instrumented with gages on each face to compensate for bending during loading.

The axial stress was applied statically in a dead load creep frame. The load was applied in ten equal steps and the strain readings taken using an SR 4 strain indicator.

Strain measurements were also taken while unloading the specimen. This entire sequence was run a total of three times resulting in 42 values for Poisson's Ratio for each specimen. The data was introduced into a computer program and Poisson's Ratio and confidence limits evaluated. A summary of the test results is given in Table G. The average Poisson's Ratios for the parallel and normal directions are 0.33421 and 0.36795, respectively.

TABLE G

POISSON'S RATIO AS A FUNCTION OF DIRECTION AT ROOM TEMPERATURE

Heat No.	Specimen No.	Specimen Direction	Average Value Poisson's Ratio	Confidence Limits 90%	95%
3637	P-G-4-41	Parallel	0.33114	±.00069	±.00082
	P-G-7-35		0.33195	±.00169	±.00202
	P-G-8-8		0.33955	±.00092	±.00111
	P-G-5-24	Normal	0.37631	±.00089	±.00107
	P-G-6-35		0.35953	±.00104	±.00125
	P-G-7-38		0.36801	±.00096	±.00115

TASK I-4 COMPRESSION YIELD TESTING

Compression tests were run on specimens taken parallel and normal to the sheet rolling direction of both heats of 0.051 cm material at temperatures ranging from ambient to 1144K. The test specimen geometry is shown in Figure 9. Test procedures followed the recommended practices of ASTM E209-65 (reapproved 1969) for sheet specimens. The practices outlined are supposedly satisfactory for testing materials down to 0.051 cm thick, without producing "buckling". The procedures, however, assume that the thin sheet test material is not inherently brittle at the test temperature.

During the testing program an examination of the specimens after test and evaluation of the load-strain curve indicated that "buckling" had occurred prior to obtaining the 0.2% yield data. At 1144K some specimens (data not reported) showed "buckling" before the 0.02% yield strength. All testing above 1144K "buckled" before any yield data was obtained therefore no data is presented. The data is summarized in Table H and presented in total in Tables 29 and 30, Appendix C.

TABLE H

AVERAGE COMPRESSION DATA FOR 0.051 CM SHEET AS A FUNCTION OF DIRECTION AND TEMPERATURE

Temperature (K)	Specimen Direction	0.02% Y.S. (MN/m^2)	0.2% Y.S. (MN/m^2)
297	Parallel	515	640
	Normal	537	615
922	Parallel	323	(a)
	Normal	349	(a)
1144	Parallel	183	(a)
	Normal	209	212

Notes:

(a) Data not reported; examination of specimen indicated "buckling" of specimen which invalidates test results

TASK I-5 CREEP-RUPTURE PROPERTIES

Creep-rupture tests were performed on all four heats of the TD-NiCr sheet using procedures in accordance with ASTM Designation E139-69. Test temperatures were: 1144K, 1255K, 1366K, 1477K, and 1589K. Duplicate tests were performed at each temperature and stress level in an evaluation of samples taken normal and parallel to the sheet rolling direction. Stress levels were selected to allow the identification of the stress to produce rupture in 1, 10, 25, 50, 100, and 300 hours.

Graphical representations of the creep-rupture data for various heat-direction combinations are shown in Figures 22 through 29. In these figures manually faired curves to define approximate trend behavior are shown. All creep-rupture data is presented in tabular form in Tables 31 through 34, Appendix D. In addition, isothermal plots of all the stress-rupture data from the four heats of TD-NiCr are plotted in Figures 30 through 34 for each testing direction. The curves in these figures are also manually faired.

Originally, statistical analysis of the creep-rupture data was planned, however, post-test examination of a series of creep-rupture tested specimens (Heat 3636 - specimens taken normal and parallel to the sheet rolling direction tested at various stress levels between 1144K and 1589K) revealed that microstructural damage occurred during testing.[Ref. 2] Because of the changes in microstructure it was felt that the creep-rupture data obtained may not be completely reliable for design purposes; hence, statistical analysis was not considered to be warranted. On the other hand, the TD-NiCr creep-rupture data is useful as it defines the maximum strength of the material for long time-high temperature-high stress conditions.

A study of isothermal plots (Figures 30 through 34) leads to the following general observations:

a) Over the entire temperature range where testing was conducted, the 0.051 cm material yields rupture lives which are more consistent than the 0.025 cm material.

b) Specimens whose gage section is parallel to the rolling direction yield higher rupture strengths than those taken from the normal direction.

c) At all temperatures and for both thicknesses of material, the normal specimens showed better data correlation than specimens from the parallel direction.

d) At lower temperatures the 0.025 cm material has an unpredictable rupture behavior. This is especially true of specimens from Heat 3697 where duplicate stress levels can produce instantaneous rupture or might run 300+ hours without failure.

e) As the test temperature increases, the 0.025 cm material and 0.051 cm material approach each other in consistency and rupture strength.

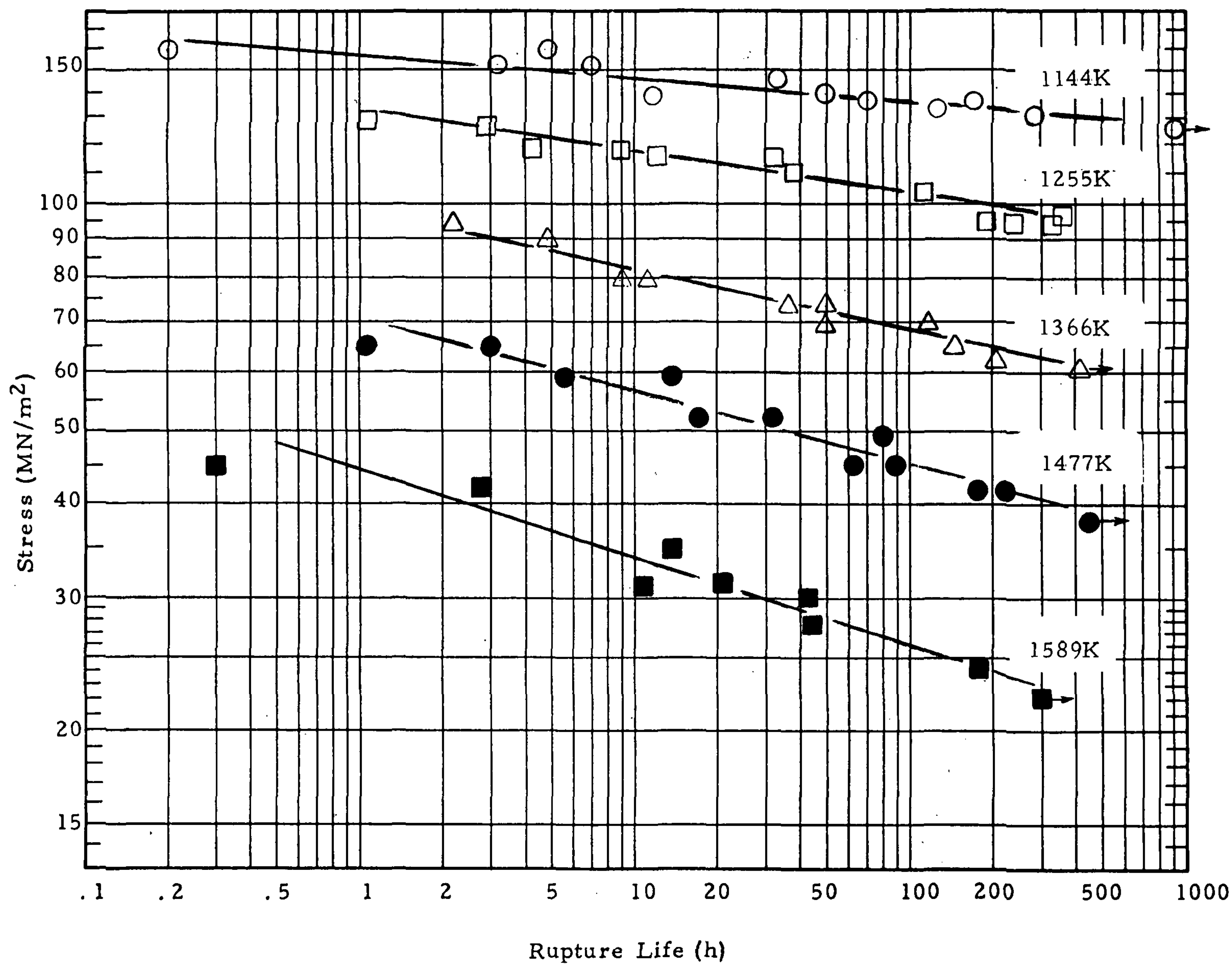


Figure 22 - CREEP RUPTURE STRENGTH OF TD-NiCr SHEET. HEAT 3636 (0.051 cm). PARALLEL TO ROLLING DIRECTION.

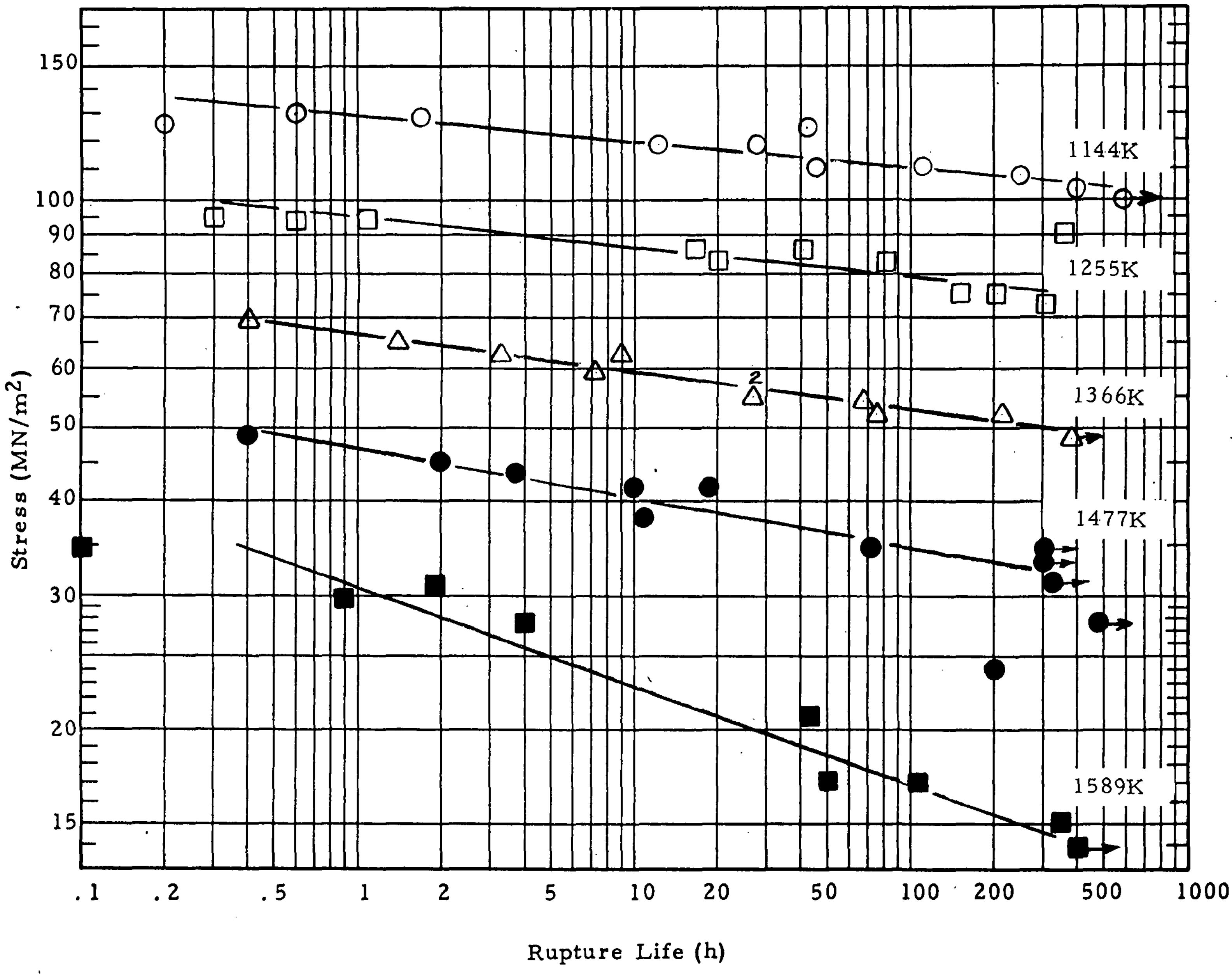


Figure 23 - CREEP RUPTURE STRENGTH OF TD-NiCr SHEET. HEAT 3636 (0.051 cm). NORMAL TO ROLLING DIRECTION.

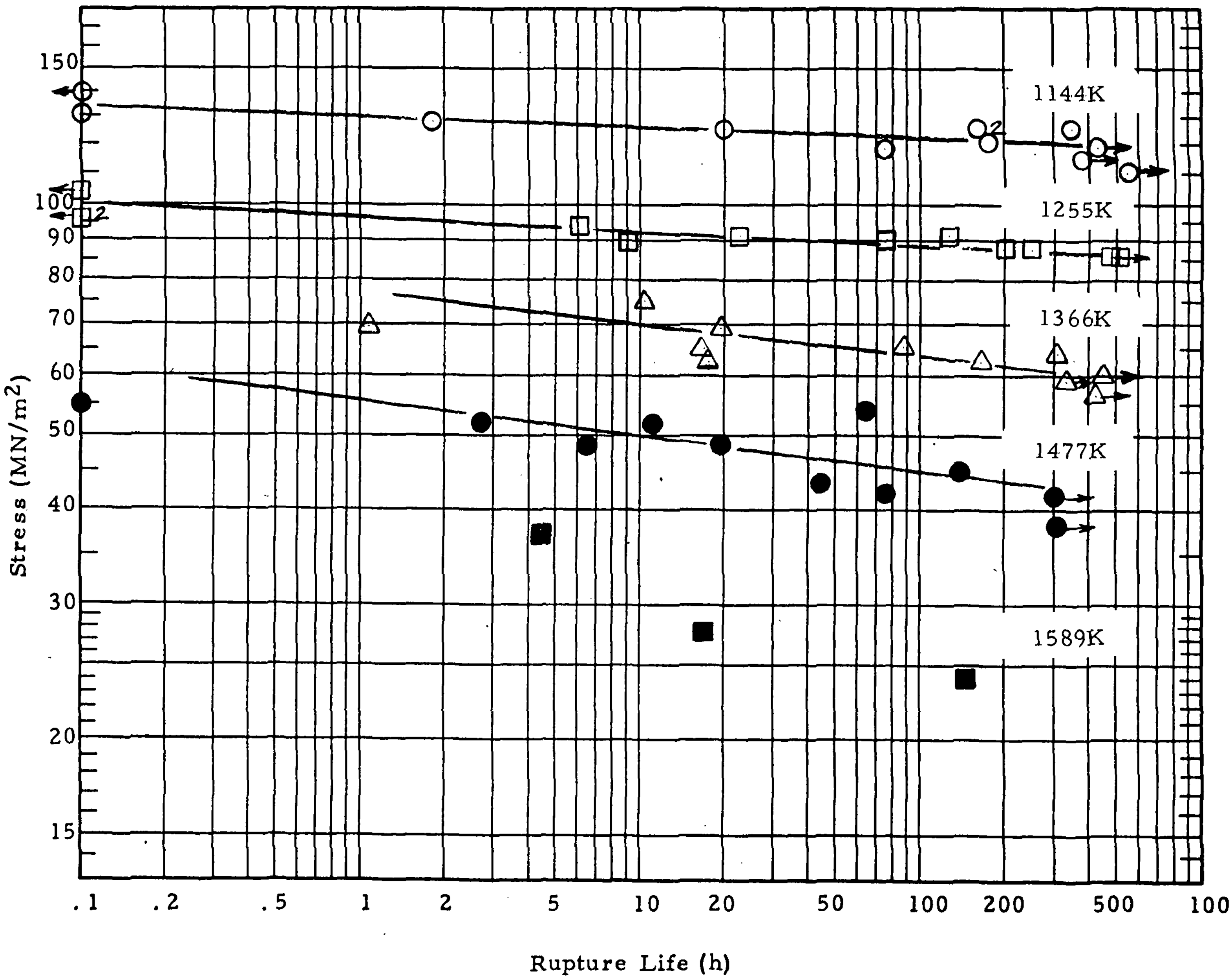


Figure 24 - CREEP RUPTURE STRENGTH OF TD-NiCr SHEET. HEAT 3637 (0.025 cm). PARALLEL TO ROLLING DIRECTION.

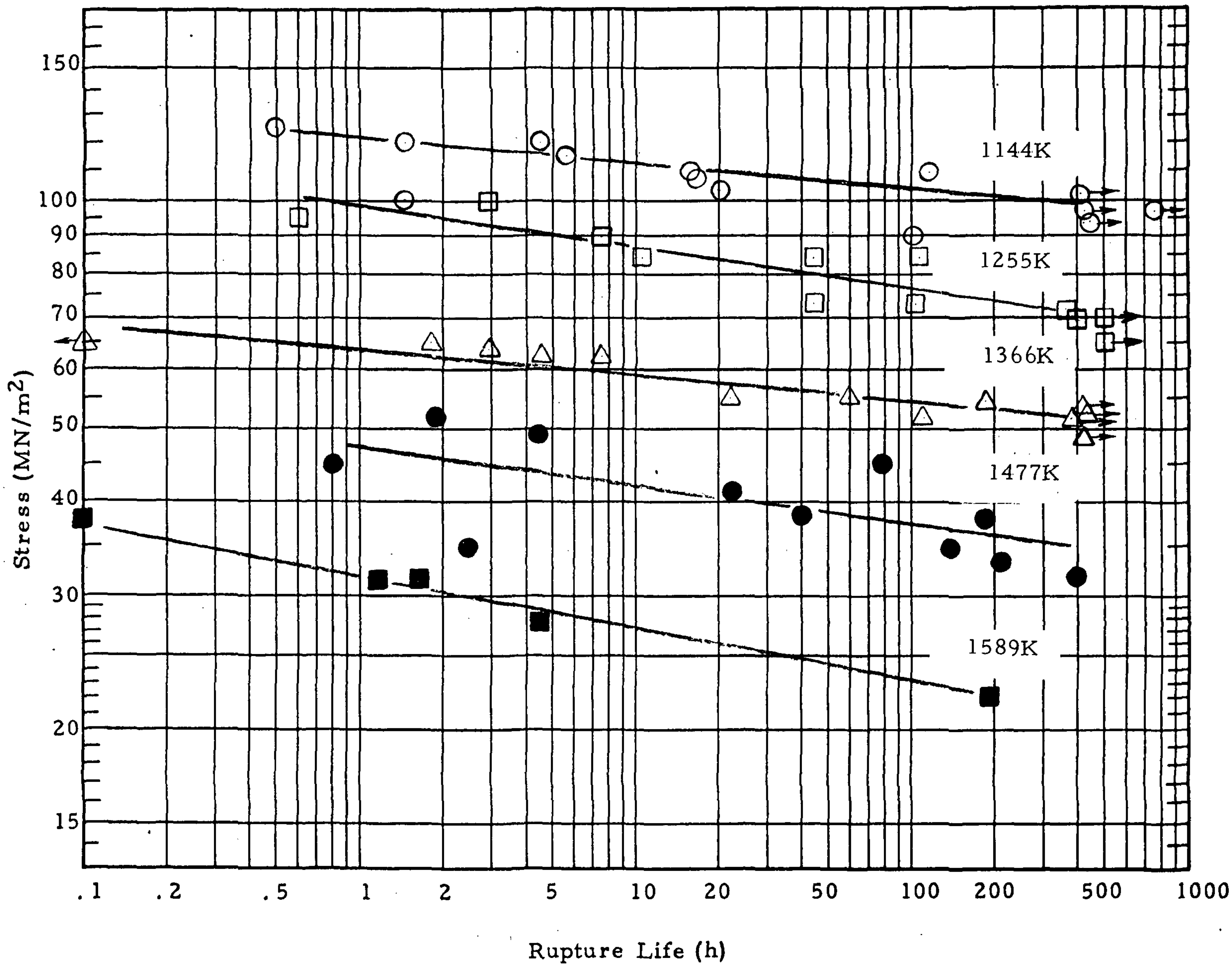


Figure 25 - CREEP RUPTURE STRENGTH OF TD-NiCr SHEET. HEAT 3637 (0.025 cm). NORMAL TO ROLLING DIRECTION.

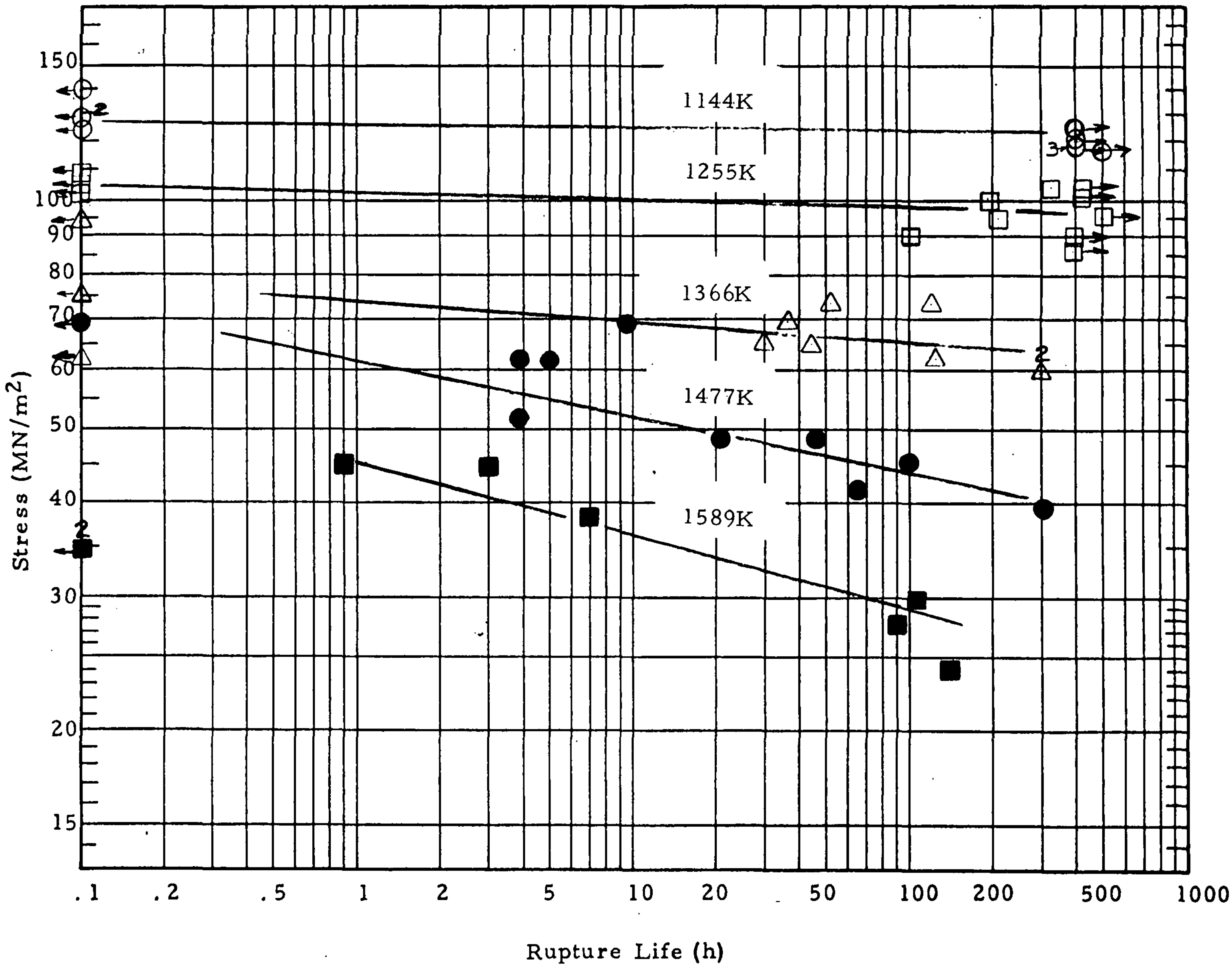


Figure 26 - CREEP RUPTURE STRENGTH OF TD-NiCr SHEET. HEAT 3697 (0.025 cm). PARALLEL TO ROLLING DIRECTION.

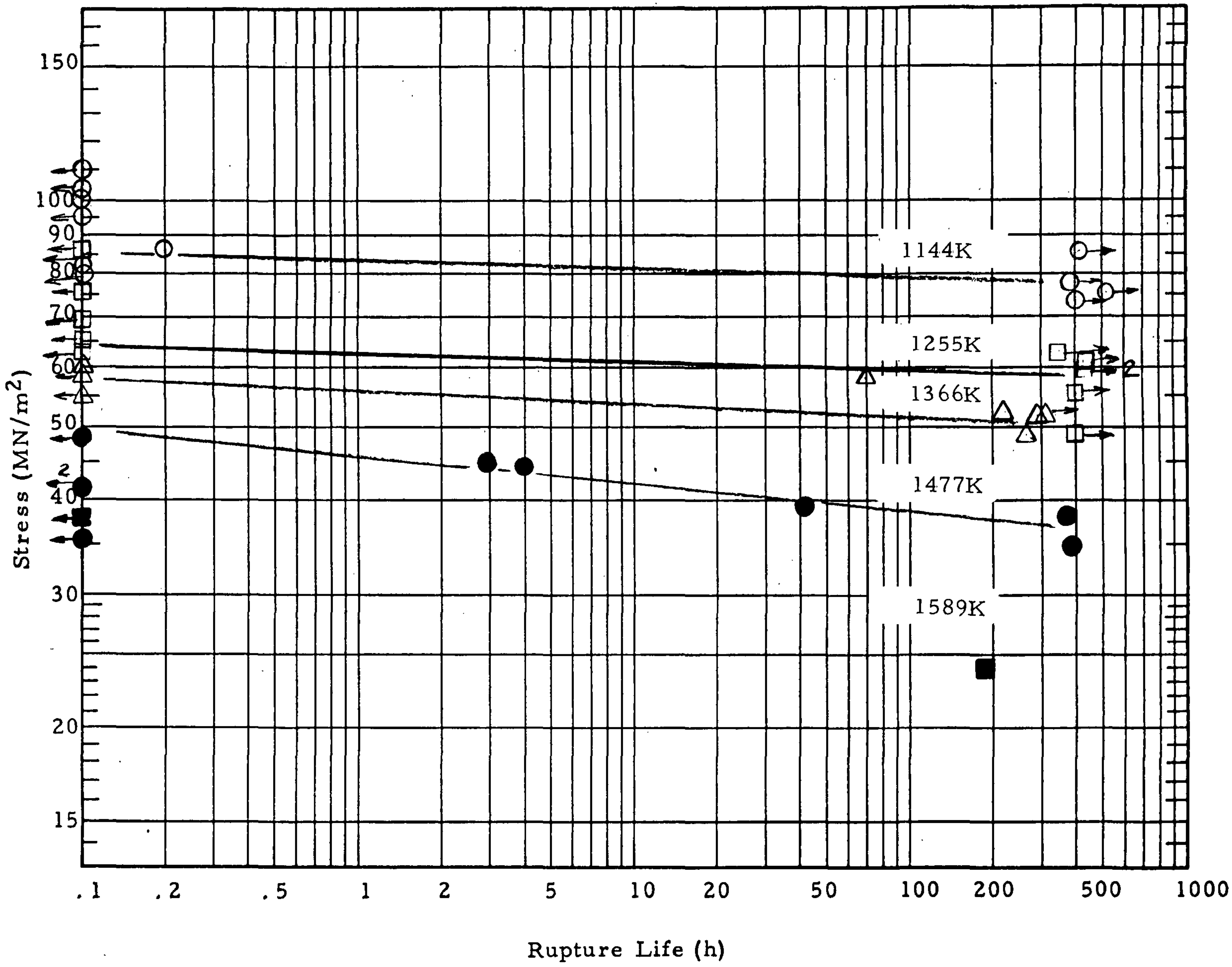


Figure 27 - CREEP RUPTURE STRENGTH OF TD-NiCr SHEET. HEAT 3697 (0.025 cm). NORMAL TO ROLLING DIRECTION.

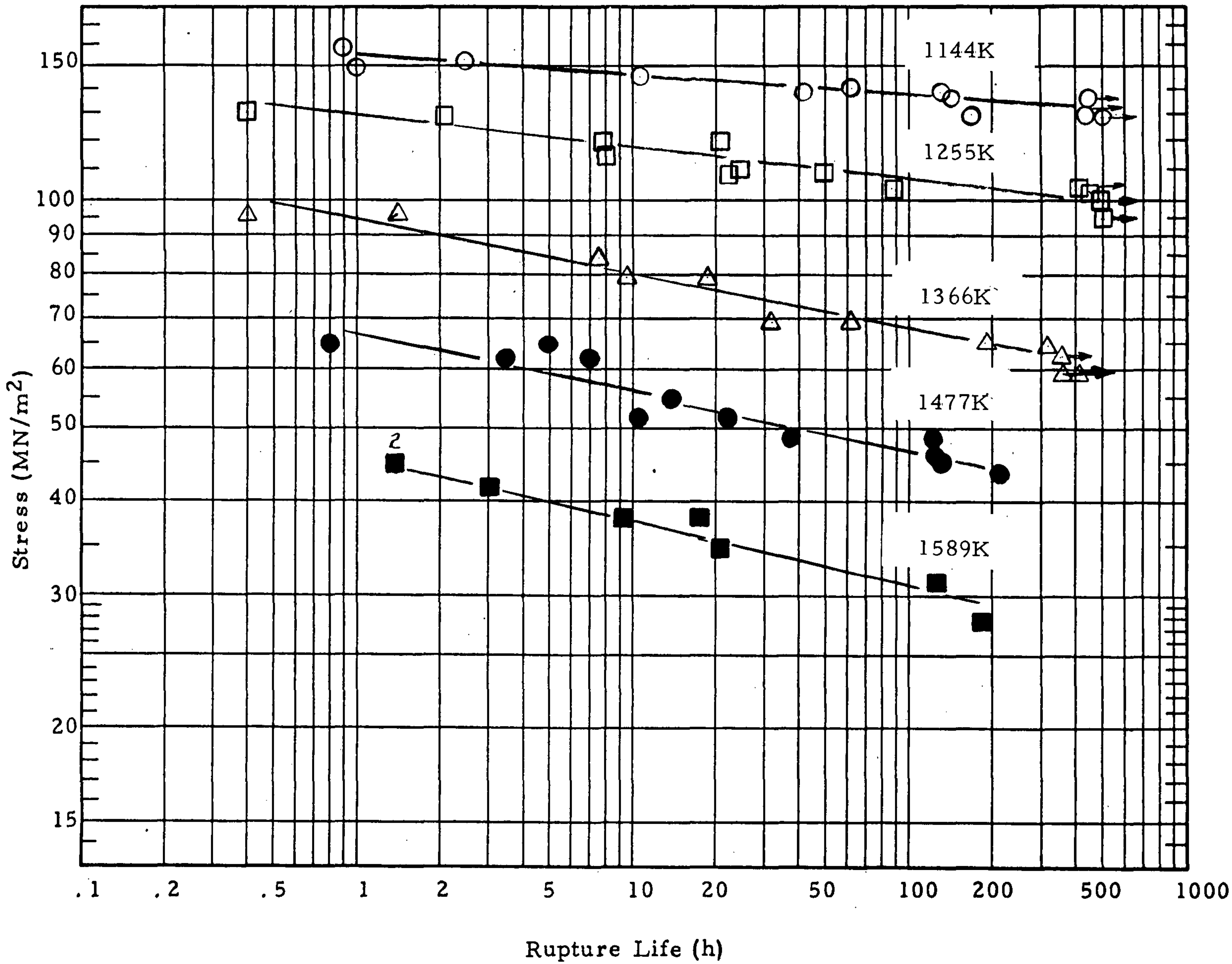


Figure 28 - CREEP RUPTURE STRENGTH OF TD-NiCr SHEET. HEAT 3712 (0.051 cm). PARALLEL TO ROLLING DIRECTION.

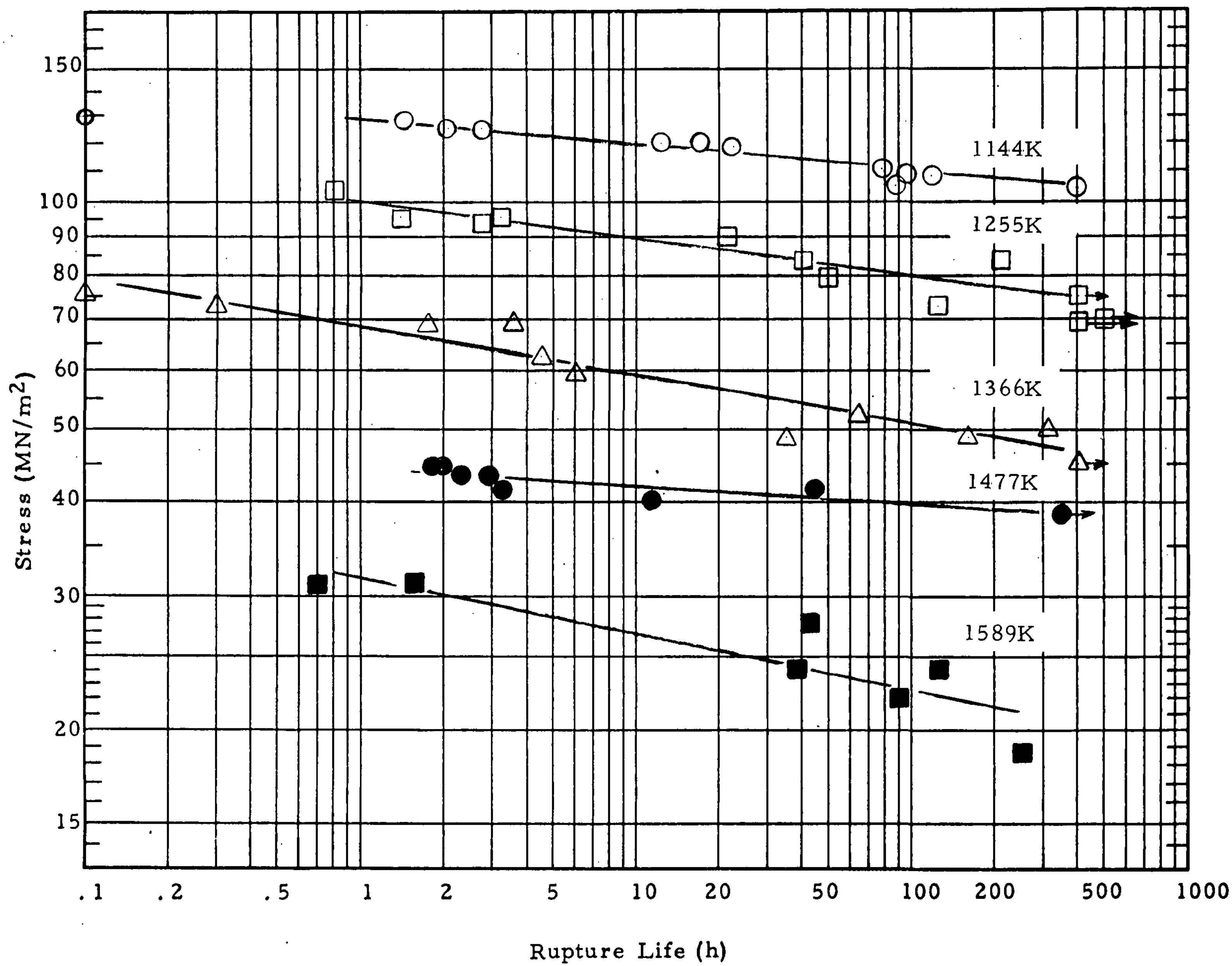


Figure 29 - CREEP RUPTURE STRENGTH OF TD-NiCr SHEET. HEAT 3712 (0.051 cm). NORMAL TO ROLLING DIRECTION.

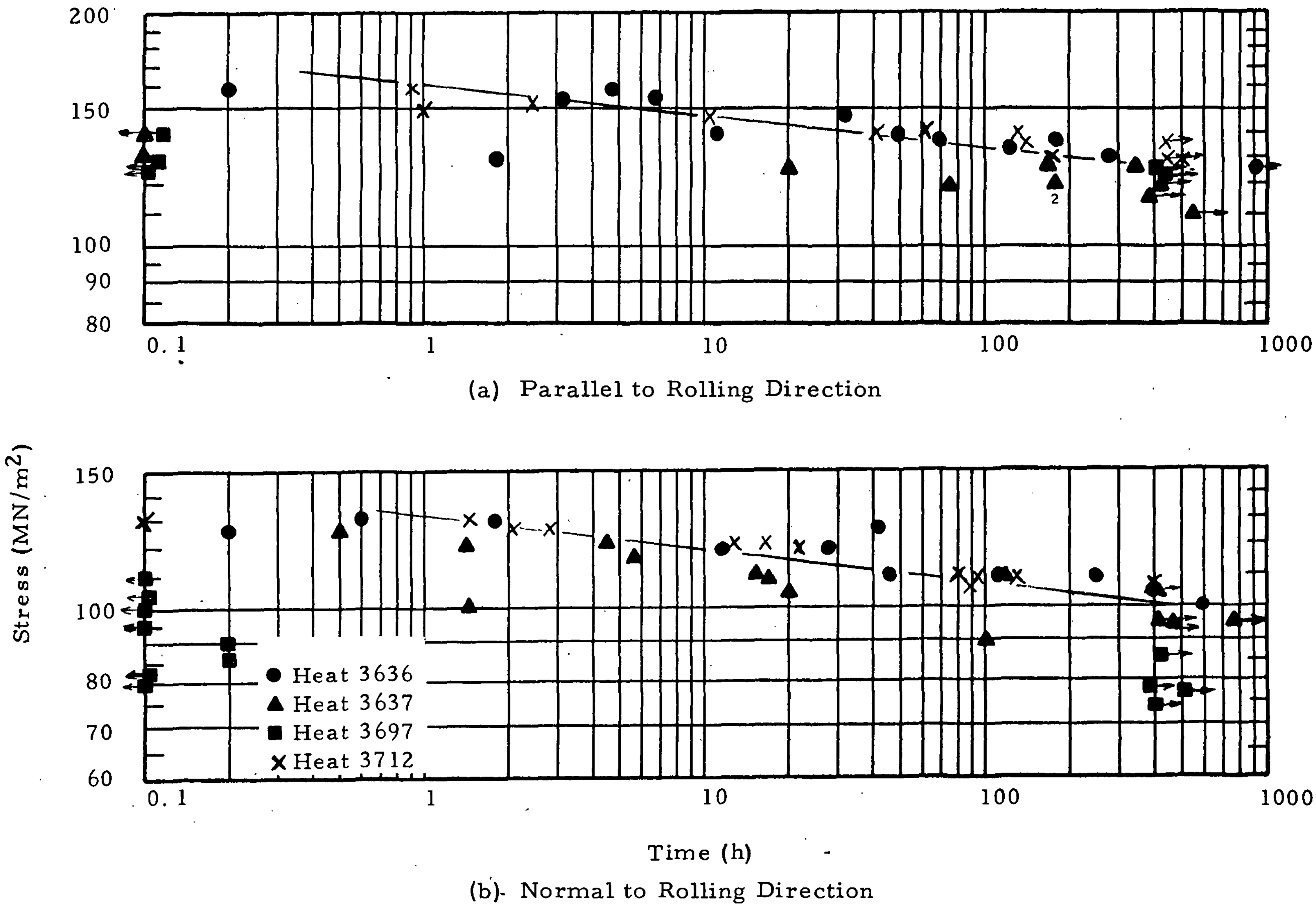


Figure 30 - CREEP RUPTURE STRENGTH OF ALL FOUR HEATS OF TD-NiCr SHEET AT 1144K.

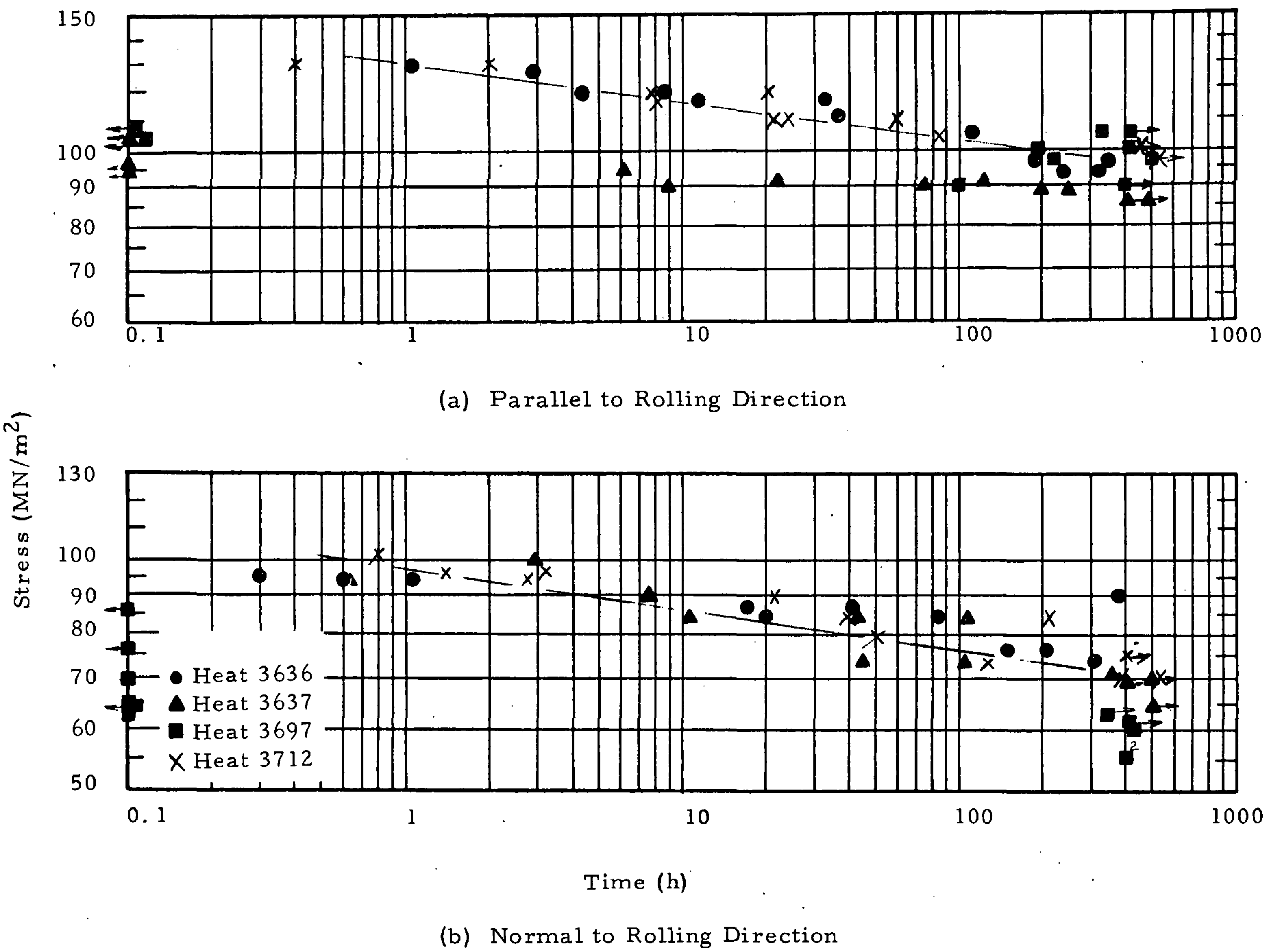
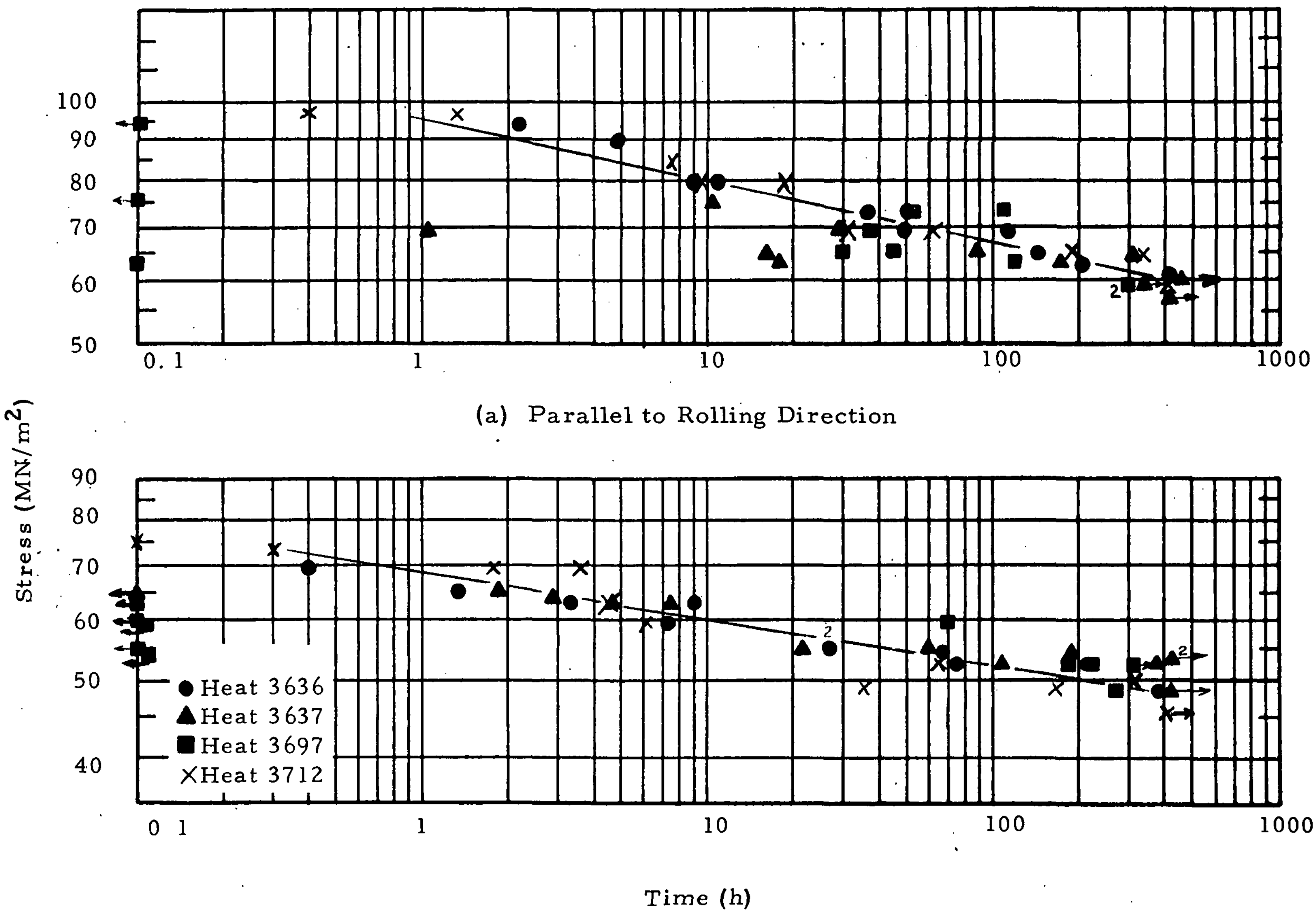


Figure 31 - CREEP RUPTURE STRENGTH OF ALL FOUR HEATS OF TD-NiCr SHEET AT 1255K.



(a) Parallel to Rolling Direction

(b) Normal to Rolling Direction

Figure 32 - CREEP RUPTURE STRENGTH OF ALL FOUR HEATS OF TD-NiCr SHEET AT 1366K.

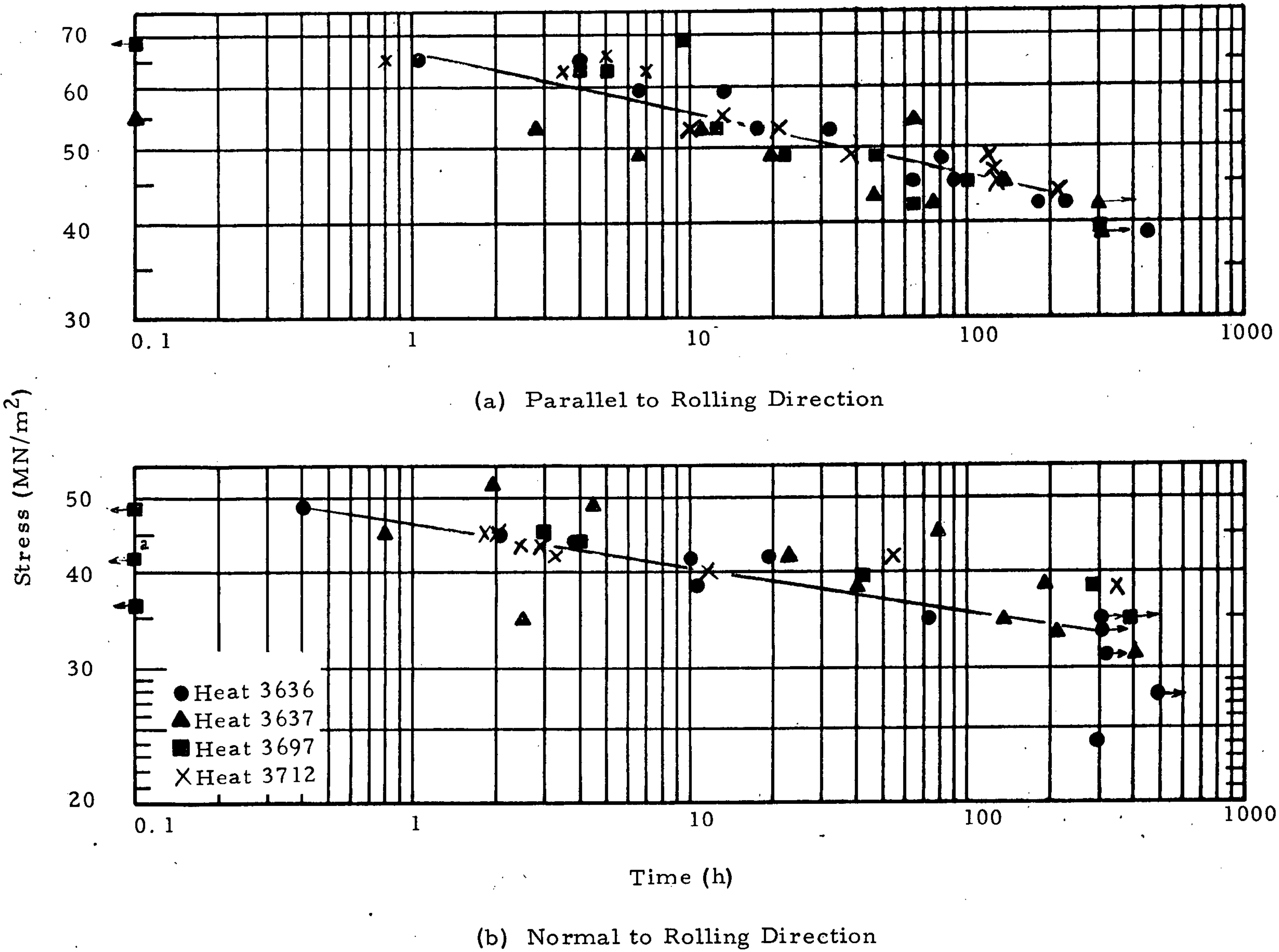
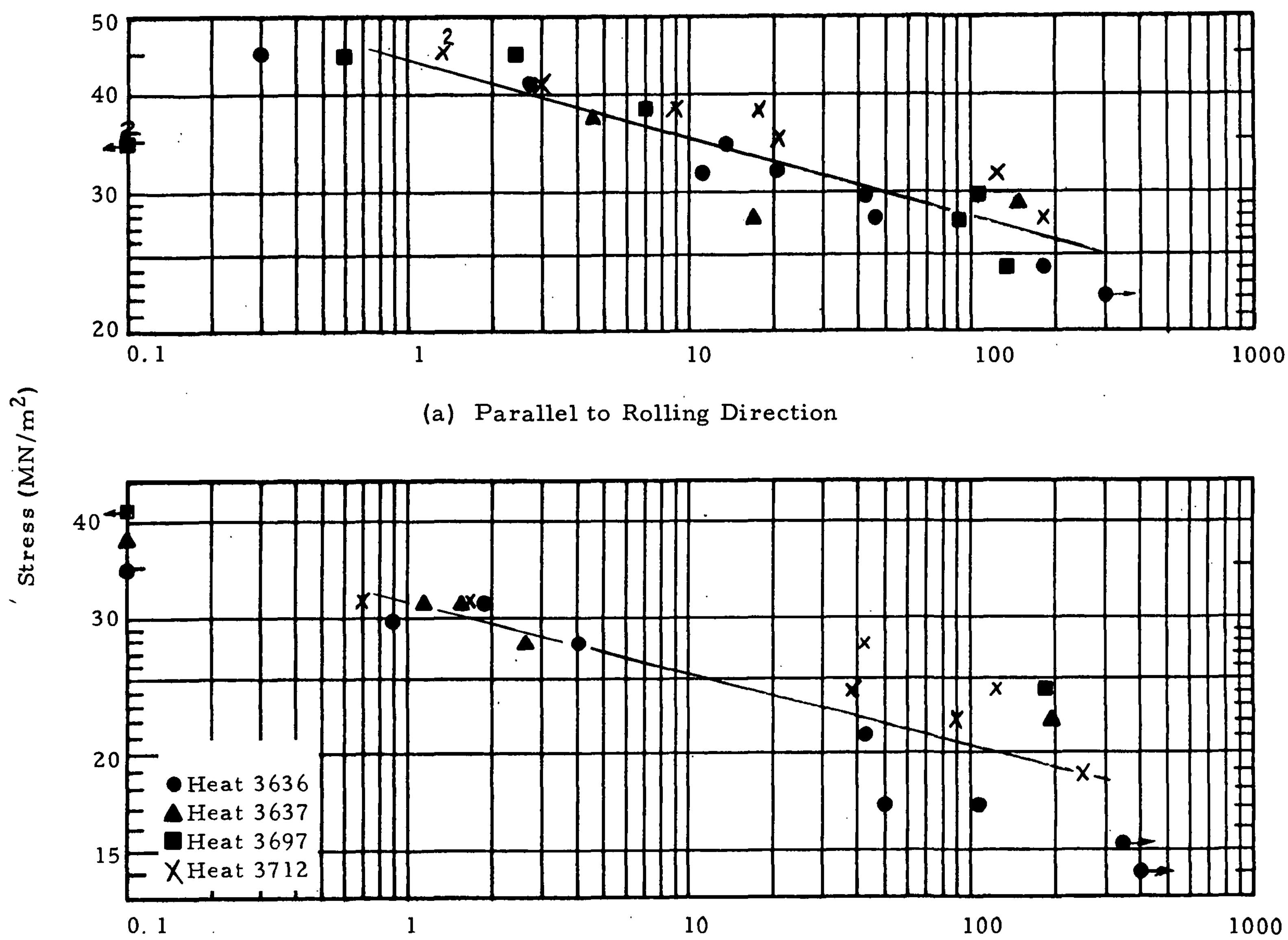


Figure 33 - CREEP RUPTURE STRENGTH OF ALL FOUR HEATS
OF TD-NiCr SHEET AT 1477K.



(a) Parallel to Rolling Direction

(b) Normal to Rolling Direction

Figure 34 - CREEP RUPTURE STRENGTH OF ALL FOUR HEATS OF TD-NiCr SHEET AT 1589K.

TASK I-6 CREEP STRENGTH

Constant load creep tests were performed in accordance with ASTM Designation E139-69 on all four heats of the TD-NiCr sheet. Creep extension was measured using optical creep techniques. Scribed, interlocking platinum strip extensometers were attached directly to the gage sections. Using the scribe markings for sighting, a 20X creep microscope was used to measure creep extension as the extensometer separated. These tests were performed at 1144K, 1255K, 1366K, and 1477K on specimens taken parallel and normal to the sheet rolling direction. The creep tests were designed to generate the data necessary to define the stress levels corresponding to 0.1 and 0.2% creep in 100 hours. Originally the stress level to produce 0.5% creep in 100 hours was to be determined; however, metallography of creep-tested TD-NiCr sheet revealed that major changes in the microstructure occurred during creep. For example, ThO_2-free regions and voids within these regions were seen after a few tenths of a percent creep deformation. (Ref. 2) Also, Fansteel (Ref. 3), in a post-test analysis of thin TD-NiCr sheet (0.025 to 0.076 cm) which had been creep tested at 1366K to various strain levels, observed that the room temperature tensile properties were greatly reduced by the effects of small creep strains (strains $>0.2\%$). Because of these observations it was decided that it would not be meaningful to analyze the data to determine the 0.5% creep strength. An additional reason for not supplying the creep strength to produce 0.5% strain in 100 hours was the fact that in several temperature-heat combinations it was impossible to obtain 0.5% creep strain without causing the specimen to rupture.

For this study, total plastic creep strain was measured. By definition, total plastic creep strain is equal to the plastic creep strain on loading plus the time dependent strain. These quantities are schematically shown in Figure 35 as well as several typical creep curves obtained during this study. In Tables 35 through 66, Appendix F, all creep data is tabulated in the form of measured creep strain as a function of time for the various heat-direction-temperature combinations. In the analysis of the creep data, reference was made to each individual creep curve to obtain the creep strain obtained in 100 hours at the imposed stress level. Approximately six creep curves were available for each heat, direction, and test temperature to provide creep strain information over the range from about 0.05% to a few percent. This information led to a 100-hour isochronous stress-strain plot from which the desired material characteristics could be obtained.

A statistical analysis of the 100-hour isochronous stress-strain information was performed based on an approach developed in a previous Metcut study. (Ref. 4) An evaluation of creep data for 2-1/4Cr-1Mo steel at 811K and 304 stainless steel at 922K indicated that an effective representation of isochronous stress-strain behavior over the range of interest (0.5 to 5%) was obtainable by employing the form:

$$\epsilon = A\sigma^{B} \tag{1}$$

where σ is the stress corresponding to a creep strain, ϵ, in a certain time period (100 hours for the present program), and A and B are constants. A computer program was developed to furnish such an analysis and to provide for 90 and 95% confidence limits. In this way, data obtained at various stress levels provided 100-hour creep strain values over the range of interest and the computer analysis led to the desired creep strength values corresponding to 0.1 and 0.2% creep strain. The procedure used to analyze the creep data is outlined in Appendix E. The creep data used in the statistical analysis as well as the creep strength values and confidence limits is listed in Tables 35 through 66, Appendix F. In Tables I and J the stresses calculated to produce 0.1 and 0.2% creep strain in 100 hours of testing are presented as a function of heat, direction, and temperature. An analysis of the $\sigma_{0.1}$, stress to produce 0.1% strain in 100 hours, data in Table I indicated some interesting effects of temperature, direction, and sheet thickness. A plot on rectangular coordinates of $\sigma_{0.1}$ as a function of temperature yielded the results shown in Figures 36 and 37. For the parallel orientation, Heats 3636 and 3712 (both 0.051 cm thick) seemed to exhibit the same behavior and a straight line has been drawn to represent these results. Slightly lower strength is indicated for Heats 3637 and 3697 (both 0.025 cm thick); and within about 20% (except for Heat 3637 at 1144K and 1255K), the behavior of these heats can be represented by the lower line shown in Figure 36. It is interesting that the lines drawn for the two sheet thicknesses are essentially parallel indicating identical temperature dependencies. Taking temperature and sheet thickness effects into consideration, the data in Figure 36 yields:

$$\sigma_{0.1} = 444\,\ell^{0.0562} - 0.2275T \tag{2}$$

where $\sigma_{0.1}$ is the creep strength in the parallel direction in MN/m^2, ℓ is the sheet thickness in cm, and T is the temperature in degrees K.

Data for the normal orientation (see Figure 37) exhibits a behavior pattern which is slightly different from that noted in Figure 36. Heat 3637 (0.025 cm) appears to be definitely weaker than all the other heats over the entire temperature range but the creep strength seems to gradually approach that exhibited by the other heats at the highest temperature. Heat 3697 (0.025 cm) seems to have a creep strength which is essentially identical to that noted in the tests of the two 0.051 cm heats. A solid line has been drawn in Figure 37 to represent the $\sigma_{0.1}$ versus temperature behavior for Heats 3636, 3712, and 3697. The equation for this behavior pattern is as follows:

$$\sigma_{0.1} = 238.7 - 0.147T \tag{3}$$

where stress, σ, is in MN/m^2 and T is the temperature in degrees K. It will be noted that both the creep strength and the temperature dependence of creep strength for the normal orientation are decidedly less than that observed for the parallel orientation. This difference persists over the entire temperature range studied.

Rectangular plots of the 100-hour stress-strain behavior indicate a very rapid leveling off in the region beyond a strain value of 0.1%. For this reason the 100-hour, 0.2% creep strength for this material is not a great deal larger than the 0.1% value. A detailed comparison of these two strength characteristics revealed that except for a few instances the 0.2% value was never more than 10% greater than the 0.1% value.

TABLE I

STRESS, $\sigma_{0.1}$, CALCULATED TO PRODUCE 0.1 PERCENT CREEP STRAIN IN 100 HOURS AS A FUNCTION OF HEAT, DIRECTION, AND TEMPERATURE

Heat No.	Specimen Direction	$\sigma_{0.1}$, MN/m^2 Temperature, K: 1144	1255	1366	1477
3636	Parallel	112.4	84.0	58 (est.)	38.0
	Normal	72.1	51.8	33.8	21.5
3637	Parallel	83.7	52.8	44.4	24 (est.)
	Normal	57.0	43.4	30.4	16.2
3697	Parallel	97.7	72.5	46.7	30.1
	Normal	80 (est.)	55.3	33.1	18.8
3712	Parallel	116.0	85.1	64.9	36.9
	Normal	70.7	53.5	37.7	25.0

TABLE J

STRESS, $\sigma_{0.2}$, CALCULATED TO PRODUCE 0.2 PERCENT CREEP STRAIN IN 100 HOURS AS A FUNCTION OF HEAT, DIRECTION, AND TEMPERATURE

Heat No.	Specimen Direction	$\sigma_{0.2}$, MN/m^2 Temperature, K: 1144	1255	1366	1477
3636	Parallel	119.7	87.2	61 (est.)	39.8
	Normal	76.8	53.8	35.4	22.6
3637	Parallel	87.8	55.6	47.7	25 (est.)
	Normal	65.6	45.6	33.1	17.4
3697	Parallel	114.1	82.8	55.0	31.3
	Normal	98 (est.)	65.2	40.5	21.0
3712	Parallel	122.0	90.8	68.5	40.1
	Normal	79.4	58.1	40.7	26.3

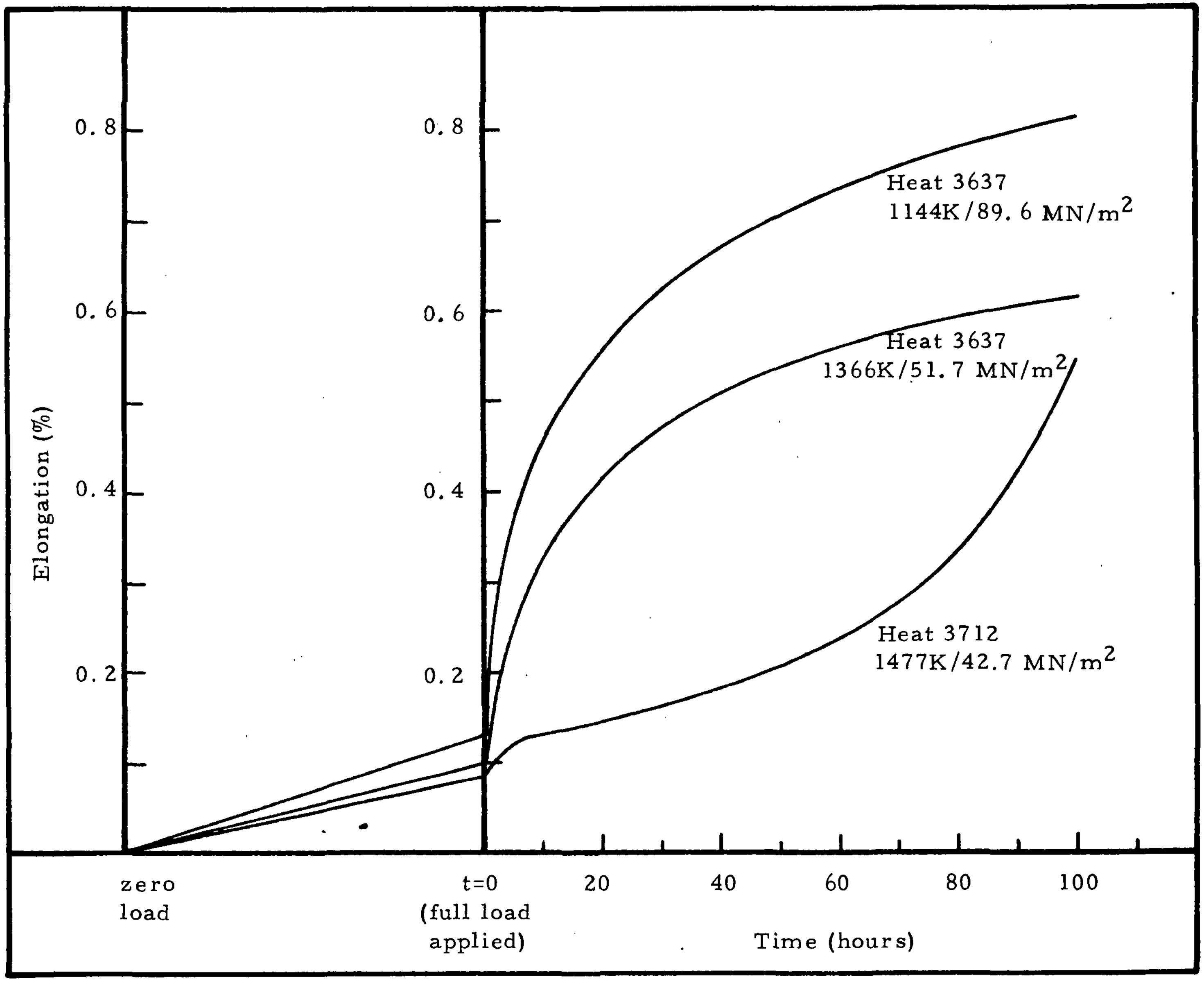


Figure 35 - SCHEMATIC DRAWING TO ILLUSTRATE THE CONCEPT OF TOTAL PLASTIC STRAIN AND SEVERAL TYPICAL CREEP CURVES

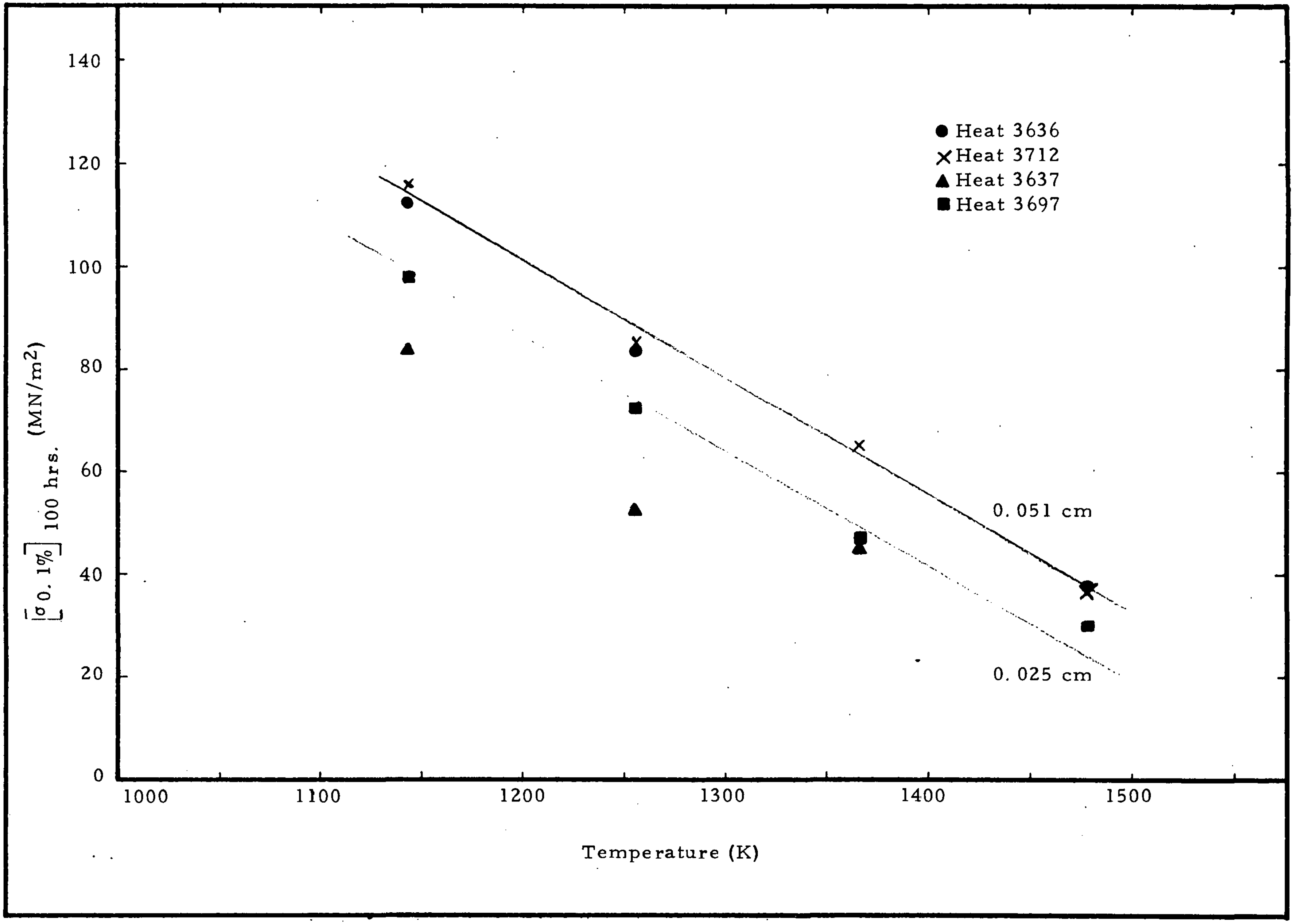


Figure 36 - STRESS TO PRODUCE 0.1% CREEP IN 100 HOURS, $\sigma_{0.1\%\ -\ 100\ hrs.}$ AS A FUNCTION OF TEST TEMPERATURE AND HEAT FOR SPECIMENS TAKEN PARALLEL TO THE ROLLING DIRECTION.

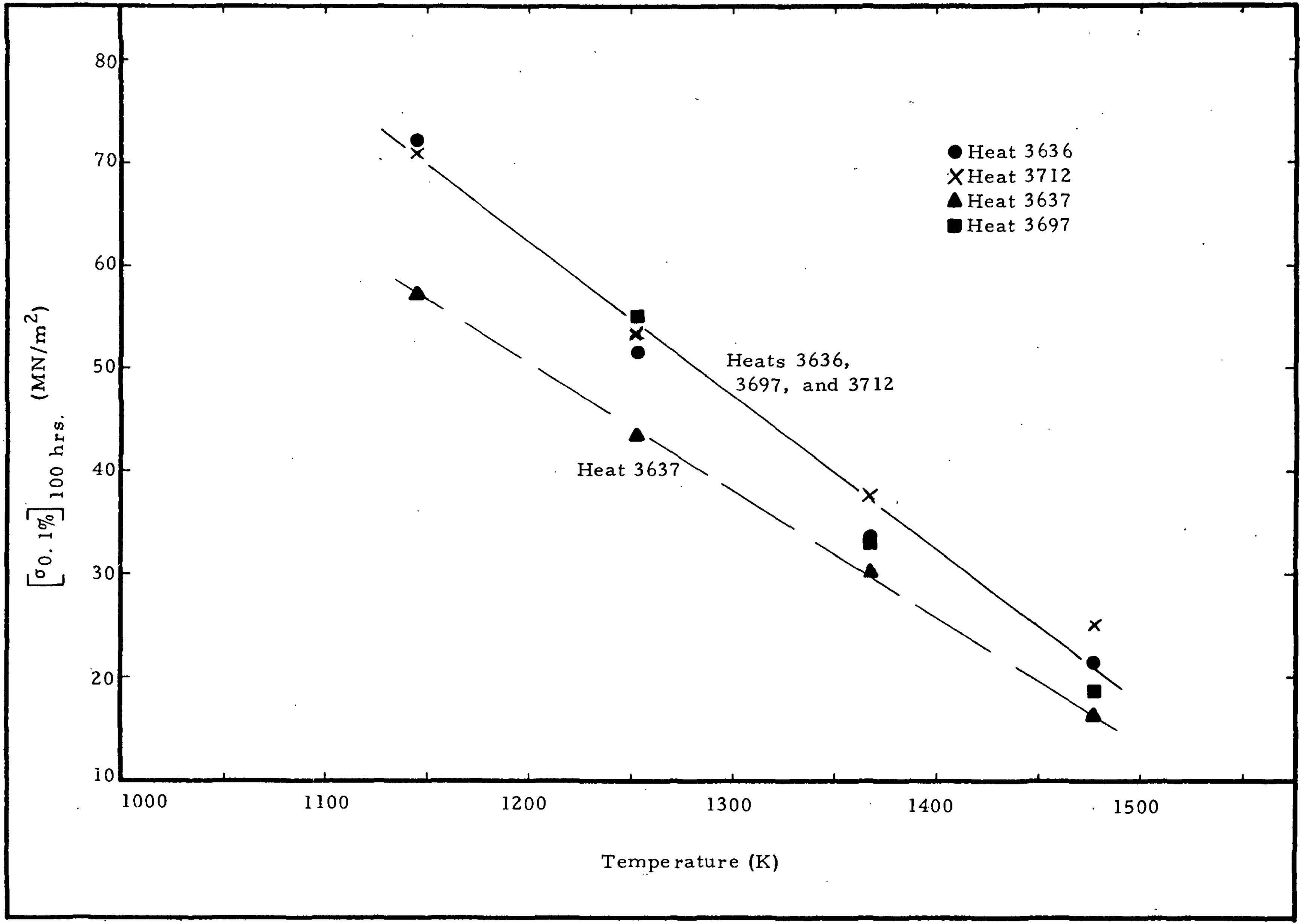


Figure 37 - STRESS TO PRODUCE 0.1% CREEP IN 100 HOURS, $\sigma_{0.1\%\ 100\ hrs.}$ AS A FUNCTION OF TEST TEMPERATURE AND HEAT FOR SPECIMENS TAKEN NORMAL TO THE ROLLING DIRECTION.

TASK I-7 BEARING STRENGTH

The bearing strength tests generally followed the testing procedures as described in ASTM E238-68 for pin type bearing tests of metallic materials.

Ideally, a ratio of pin diameter to specimen thickness of from 2 to 4 is used to prevent either breaking the pin or buckling the specimen. Because a pin of this ratio would be extremely small for the TD-NiCr material in this study, it was decided to use the other criterion, that is, the hole should have approximately the same size as that required in the intended use. A hole 0.48 cm in diameter with an edge distance ratio of 2 was chosen.

Pin bearing tests were conducted on all four heats of TD-NiCr sheet on specimens taken parallel and normal to the sheet rolling direction. Tests were performed at room temperature, 922K, 1144K, 1366K, and 1477K. Figure 38 shows the test setup for all specimens through 1366K. At 1477K deflection was measured using a crosshead extensometer. The bearing strength test specimen geometry is shown in Figure 10.

Due to the unconventional test procedures and the observation that the bearing strength tests, especially at lower temperatures, yielded data which exhibited large variations in strength even for duplicate specimens, the bearing strength data was not statistically analyzed.

Test data is presented therefore as average values of each heat in Table K and plotted in Figures 39 and 40. Figure 39 shows the data for the 0.051 cm material and Figure 40 presents the 0.025 cm data.

In comparing the test data, no consistent trends could be established to show any heat as stronger than another of the same thickness or one direction as stronger than the other. The only consistency noticed was that yield and ultimate strength were one and the same for the 0.025 cm material at all temperatures above ambient temperature.

The data for all specimens is presented in Tables 67 through 70, Appendix G.

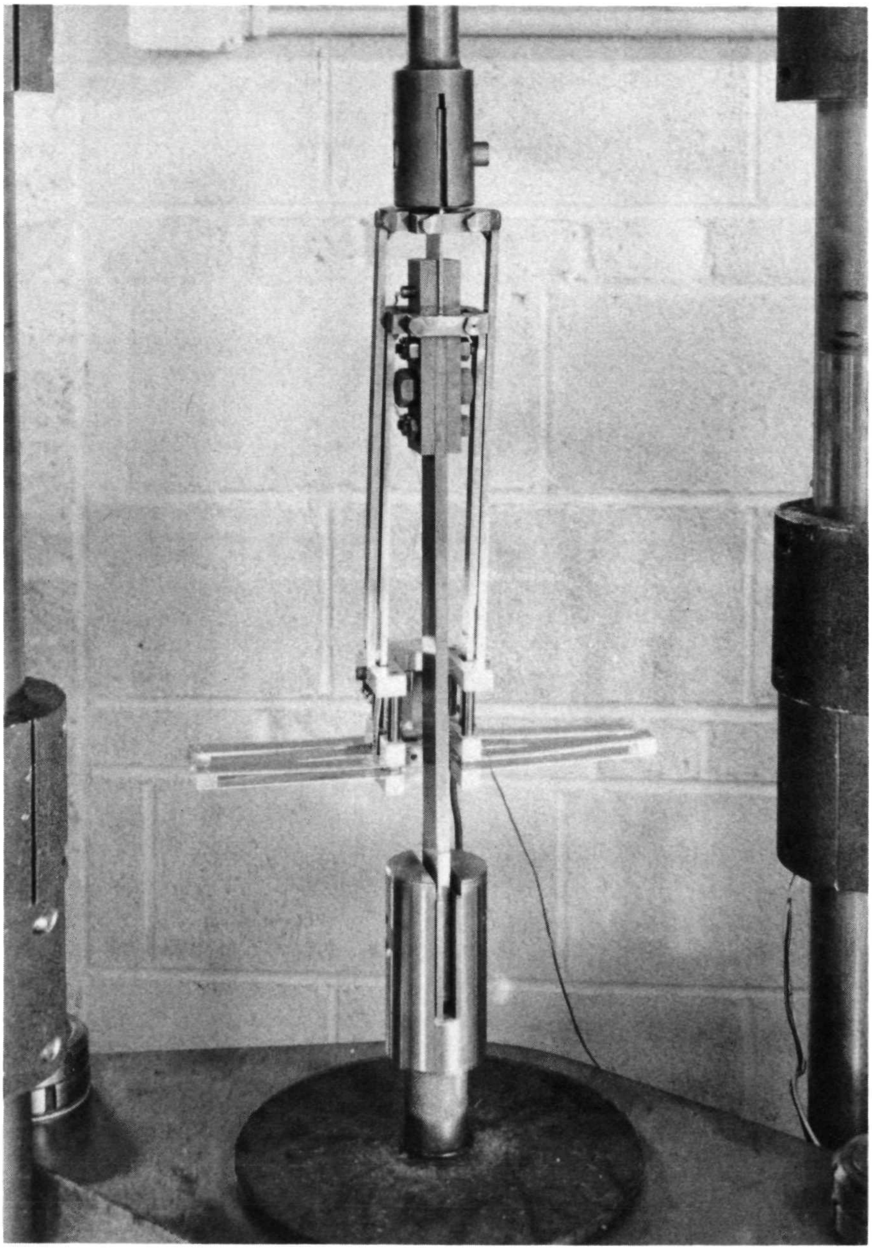


Figure 38 - Bearing Strength Test Setup

TABLE K

AVERAGE BEARING STRENGTH PROPERTIES

Temp. (K)	Specimen Direction	Heat 3636 Ultimate (MN/m^2)	Heat 3636 Y. S. (MN/m^2)	Heat 3637 Ultimate (MN/m^2)	Heat 3637 Y. S. (MN/m^2)	Heat 3697 Ultimate (MN/m^2)	Heat 3697 Y. S. (MN/m^2)	Heat 3712 Ultimate (MN/m^2)	Heat 3712 Y. S. (MN/m^2)
297	Parallel	1215	1120	681	657	715	715	1234	1186
	Normal	1305	1230 (a)	698	698	830	830	1149	900 (a)
922	Parallel	828	768	523	523	603	603	682	656
	Normal	848	826	533	618 (a)	580	704 (a)	720	677
1144	Parallel	393	352	234	234	276	276	403	375
	Normal	406	395	270	270	265	265	419	398
1366	Parallel	256	224	179	179	184	184	236	211
	Normal	254	232	204	204	216	216	245	228
1477	Parallel	202	202	141	141	189	189	193	190
	Normal	221	221	166	166	208	208	211	211

(a) Single Value

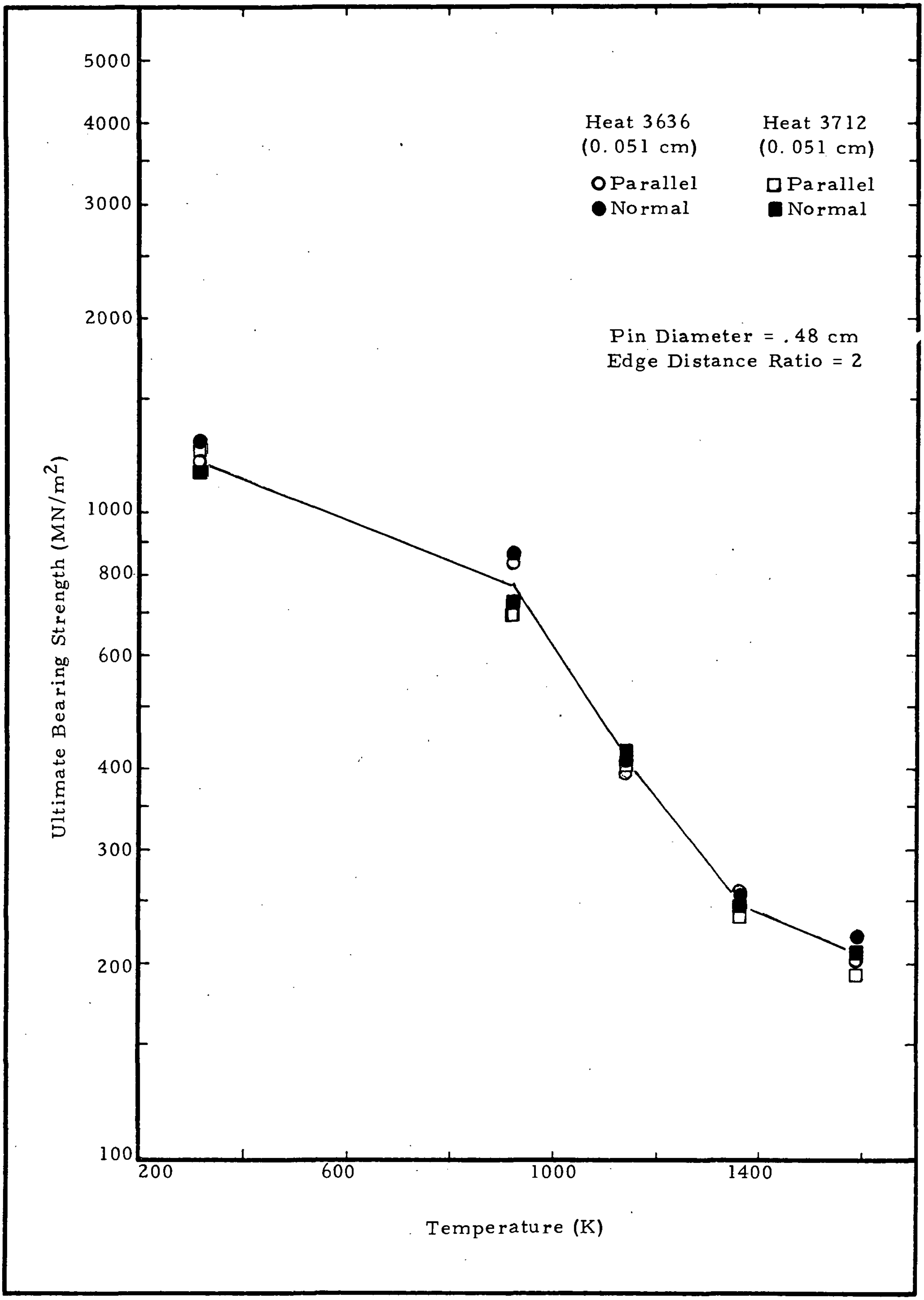


Figure 39 - AVERAGE ULTIMATE BEARING STRENGTH AS A FUNCTION OF TEMPERATURE FOR 0.051 CM THICK TD-NiCr SHEET

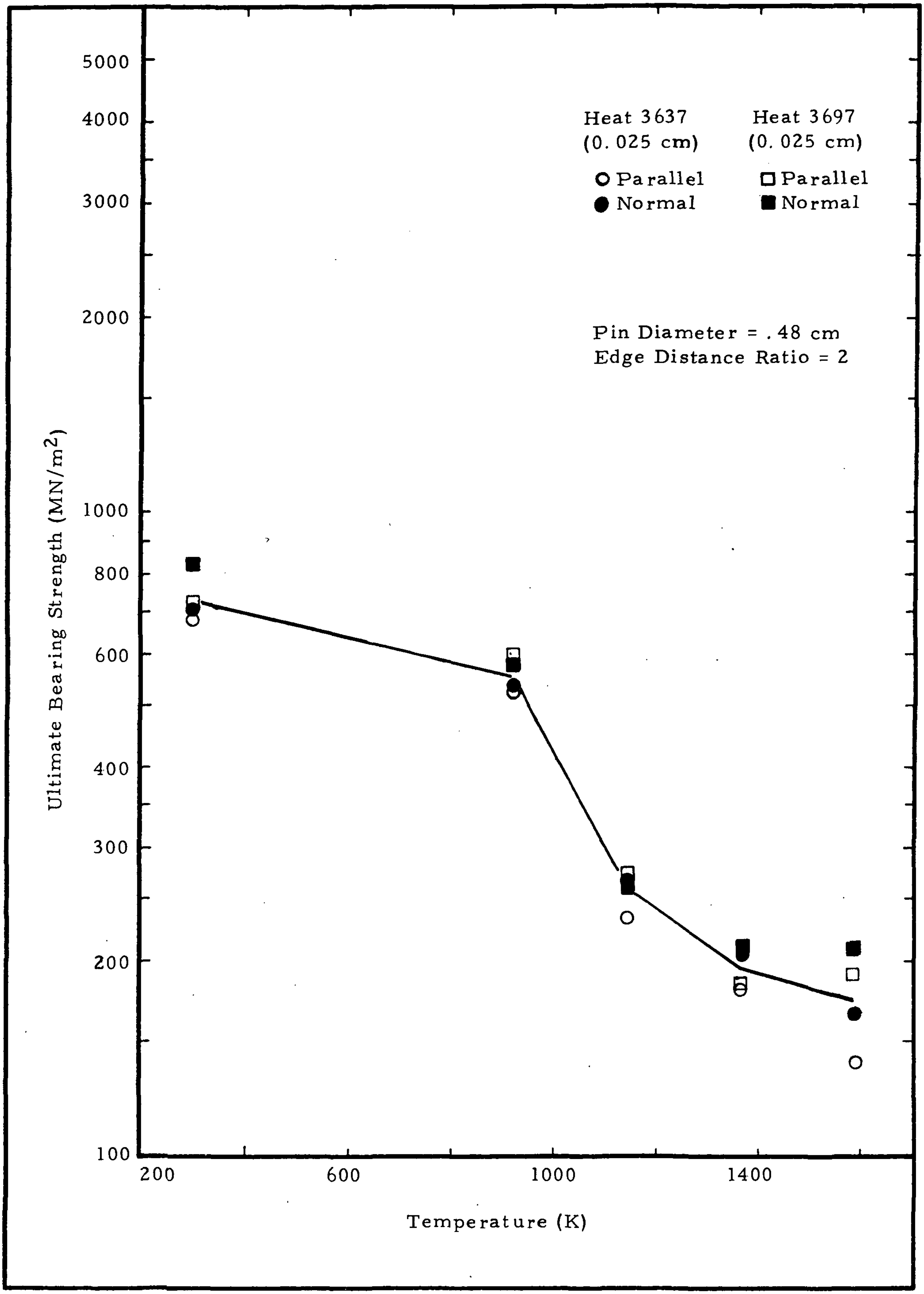


Figure 40 - AVERAGE ULTIMATE BEARING STRENGTH AS A FUNCTION OF TEMPERATURE FOR 0.025 CM THICK TD-NiCr SHEET

TASK I-8 SHEAR STRENGTH

Shear strength data was obtained on one heat of 0.051 cm thick material (Heat 3712) at room temperature and 1366K. Two specimens were tested at each temperature, both parallel and normal to the rolling direction. The shear strength test specimen geometry is shown in Figure 11.

The specimens were tested at a head rate of 0.127 cm/min. To prevent twisting of the thin specimens during the tests, guide plates were used which supplied restrictions to twisting without influencing strength.

In this study shear strength is defined as the maximum load divided by the original cross sectional area of the shearing surface.

The test results are presented in Table L.

TABLE L

SHEAR STRENGTH DATA FOR HEAT 3712 AS A FUNCTION OF DIRECTION AND TEMPERATURE

Specimen No.	Specimen Direction	Temp. (K)	Shear Strength (MN/m^2)
S-J-2-34	Parallel	297	554
S-J-6-27	Parallel	297	582
S-J-1-46	Normal	297	553
S-J-5-15	Normal	297	561
S-J-1-49	Parallel	1366	92.4
S-J-6-36	Parallel	1366	88.9
S-J-4-27	Normal	1366	83.4
S-J-7-24	Normal	1366	86.2

The average shear strength at room temperature is 562 MN/m^2 and the average shear strength at 1366K is 87.7 MN/m^2.

TASK I-9 SHARP NOTCH STRENGTH

Sharp notch tension tests were performed on two heats of TD-NiCr at 297K and 1366K. The testing procedures were in general accord with ASTM E338-68, however, the specimen design was modified per suggestions by W. F. Brown, Jr. (Ref. 5) The modified specimen as shown in Figure 12 contains two symmetrically opposed edge notches, one of which was fatigue cracked and the other machined with a blunt tip. The blunt notch was machined to the same length as the notch plus fatigue crack on the opposite side to produce a balanced stress field. By way of procedure, the specimen was manufactured originally as a single edge notch specimen which was subsequently precracked in fatigue. The blunt machine notch was produced after fatigue precracking.

The sharp notch strength tests were performed in a universal testing machine at a head rate of 0.127 cm/min. The elevated temperature (1366K) was produced by an electrical resistance heated furnace surrounding the specimen.

All sharp notch strength results are presented in Table M. Sharp notch strength was determined for two heats of material (3637 and 3712) which had nominal sheet thicknesses of 0.025 and 0.051 cm, respectively. The results in the table are also presented in terms of the ratio of sharp notch strength to the yield strength. In most cases the yield strength used for calculation was the 0.2% offset yield strength. In other cases where the 0.2% yield strength could not be obtained, the 0.02% yield strength was used. In general, all sharp notch strength ratios were in the neighborhood of or greater than unity. It was noted further that the sharp notch strength ratio was greater for specimens of normal orientation than for specimens of parallel orientation at 297K. The opposite was true with respect to orientation at 1366K. Overall the results appear to indicate that TD-NiCr is not notch sensitive.

TABLE M

SHARP NOTCH TENSILE STRENGTH FOR TWO HEATS OF TD-NiCr SHEET AS A FUNCTION OF DIRECTION AND TEMPERATURE

Heat No.	Specimen Direction	Temp. (K)	Sharp Notch Strength (MN/m^2)	Sharp Notch Strength: 0.2% Yield Strength
3637	Parallel	297	661.9	0.99
		297	727.4	1.09
		297	660.5	0.99
	Normal	297	719.1*	1.15*
		297	750.2*	1.20*
		297	812.9	1.30
		297	728.8	1.16
	Parallel	1366	75.2*	0.94*+
		1366	103.4	1.30+
		1366	108.9	1.36+
	Normal	1366	88.9	1.04+
		1366	88.3	1.04+
3712	Parallel	297	600.6	1.07
		297	599.9	1.07
	Normal	297	795.0	1.53
		297	765.3	1.47
	Parallel	1366	117.9	1.18
		1366	110.3	1.10
	Normal	1366	104.1	1.15+
		1366	96.5	1.07+

*Specimen failed at pin hole; value given is based on max. load obtained in each test.

+Reported in terms of 0.02% Y.S. since 0.2% Y.S. could not be obtained

TASK I-10 FATIGUE PROPERTIES

Axial fatigue tests (tension-tension) were performed to characterize the fatigue properties of TD-NiCr sheet at ambient temperature. One heat (3637) of 0.025 cm thick sheet was evaluated along with one heat (3712) of 0.051 cm thick sheet. Both normal and parallel rolling directions were investigated in tests involving an R-value (minimum tensile stress/maximum tensile stress) of 0.1 at a frequency of 1800 cps. These tests were performed in duplicate and were designed to establish the S/N curve for each heat over the range from 10^4 to 10^6 cycles. The test specimen geometry is shown in Figure 13.

A summary of the test results obtained in this study is presented in Table 71, Appendix I. This data is also shown graphically in Figures 41 through 45 to indicate the following:

a) In the regime up to about 300,000 cycles, all heats exhibit about the same fatigue characteristics. No appreciable difference was noted between the normal and parallel orientations or between the 0.025 cm and 0.051 cm sheet thickness.

b) Beyond 300,000 cycles, all heats continue to exhibit the same fatigue behavior except for Heat 3712 normal (0.051 cm thick) which displayed a very decided leveling off to identify an endurance limit slightly above 414 MN/m^2.

c) The best reproducibility for the duplicate tests was noted in the tests of 3712 normal while the poorest reproducibility was observed in the tests of 3637 parallel.

An analysis was made of each data set in order to establish 90 and 95% confidence limits on the stress range. The details of this analysis are given in Appendix H. The equation form chosen for this analysis is given in Equation (4) and was used in previous Metcut analyses with satisfactory results. This form has also been used by White and Lewszuk(Ref. 6) in an analysis of fatigue data over the range from 10^5 to 10^7 cycles.

$$\sigma - \sigma_0 = A N_f^m \qquad (4)$$

where σ is the applied (maximum) stress in MN/m^2, σ_0 is a constant in MN/m^2, A and m are constants, and N_f is the number of cycles at failure.

A summary of the values for A, m and σ_0 obtained in this analysis is as follows:

		A	m	σ_0
Heat 3712	Parallel	445.8	-0.166	21.02
Heat 3712	Normal	162.9	-0.376	62.02
Heat 3637	Parallel	359.7	-0.0928	-36.22
Heat 3637	Normal	850.2	-0.246	34.27

These constants substituted into Equation (4) led to the curves plotted in Figures 41 through 45 and provide a fairly effective representation of the experimental results within the range of the data. The 90 and 95% confidence limits are also plotted as smooth curves in these figures.

An analysis of all the test data taken as a group (i. e. - all heats and directions) and fitted to Equation (4) resulted in the following constants:

$$A = 612.0$$
$$m = -0.224$$
$$\sigma_0 = 39.02$$

Figure 46 illustrates the predicted S/N curve and appropriate confidence limits for the pooled data.

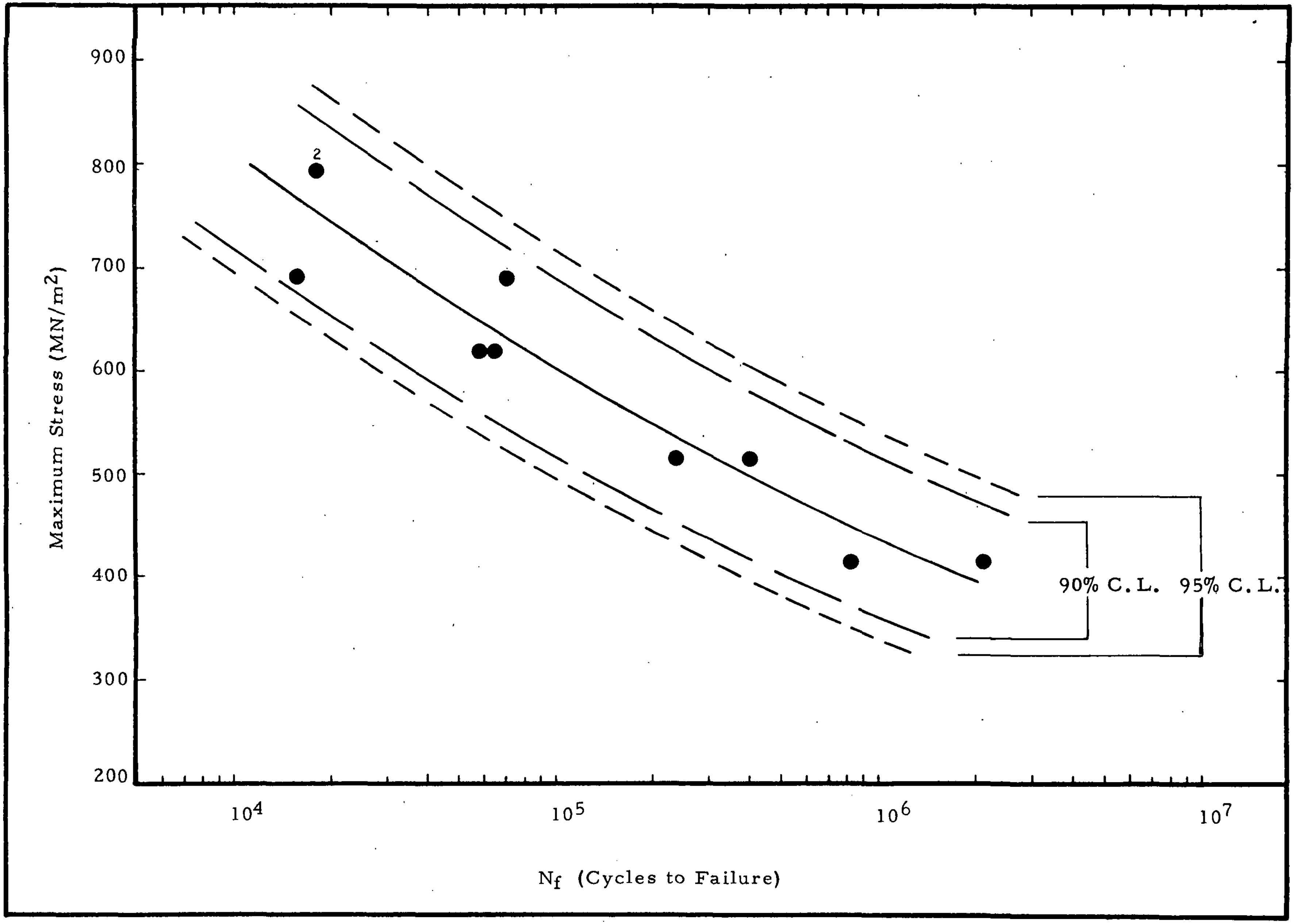


Figure 41 - FATIGUE S/N CURVE FOR HEAT 3637 (PARALLEL) AT ROOM TEMPERATURE

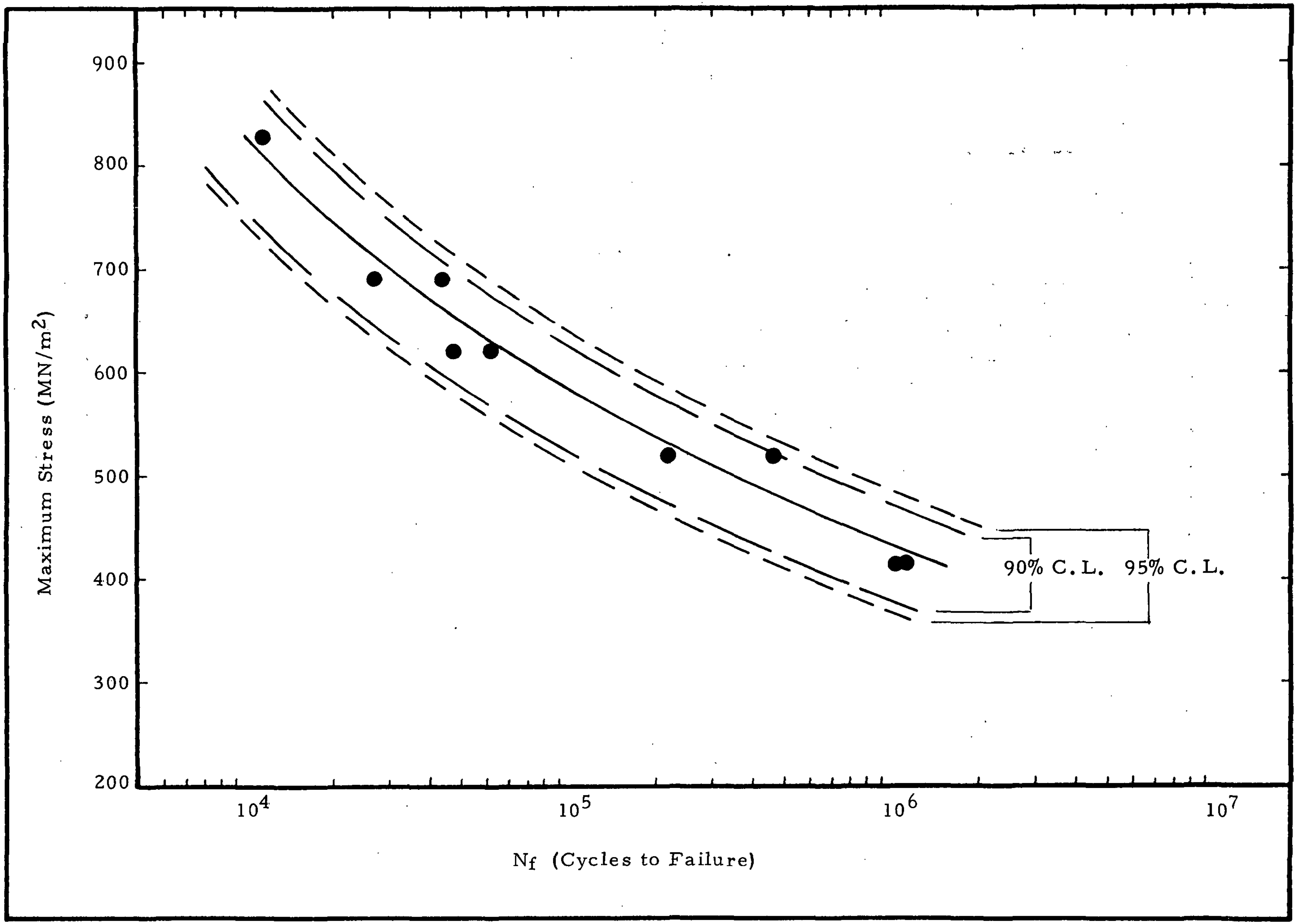


Figure 42 - FATIGUE S/N CURVE FOR HEAT 3637 (NORMAL) AT ROOM TEMPERATURE

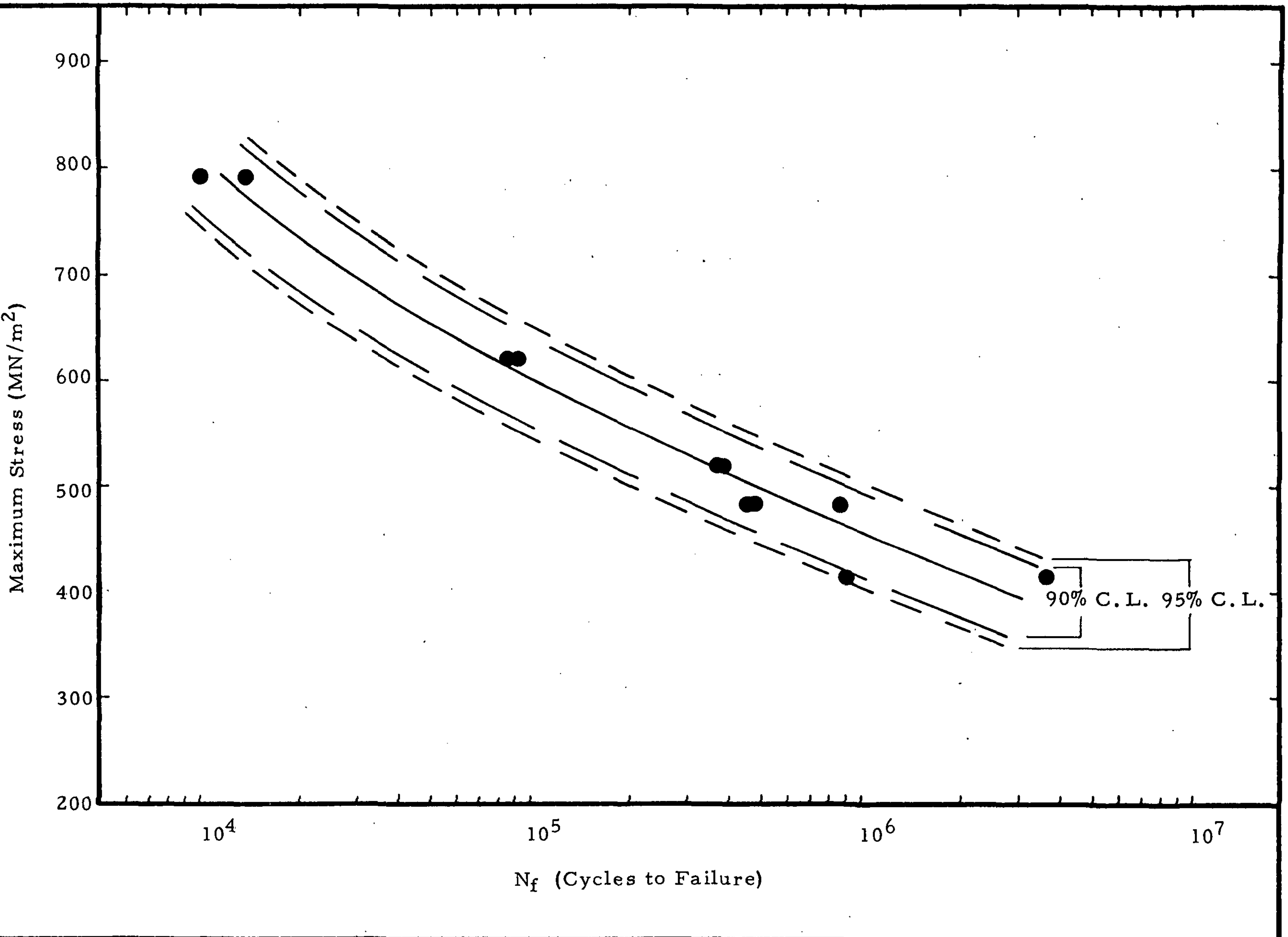


Figure 43 - FATIGUE S/N CURVE FOR HEAT 3712 (PARALLEL) AT ROOM TEMPERATURE

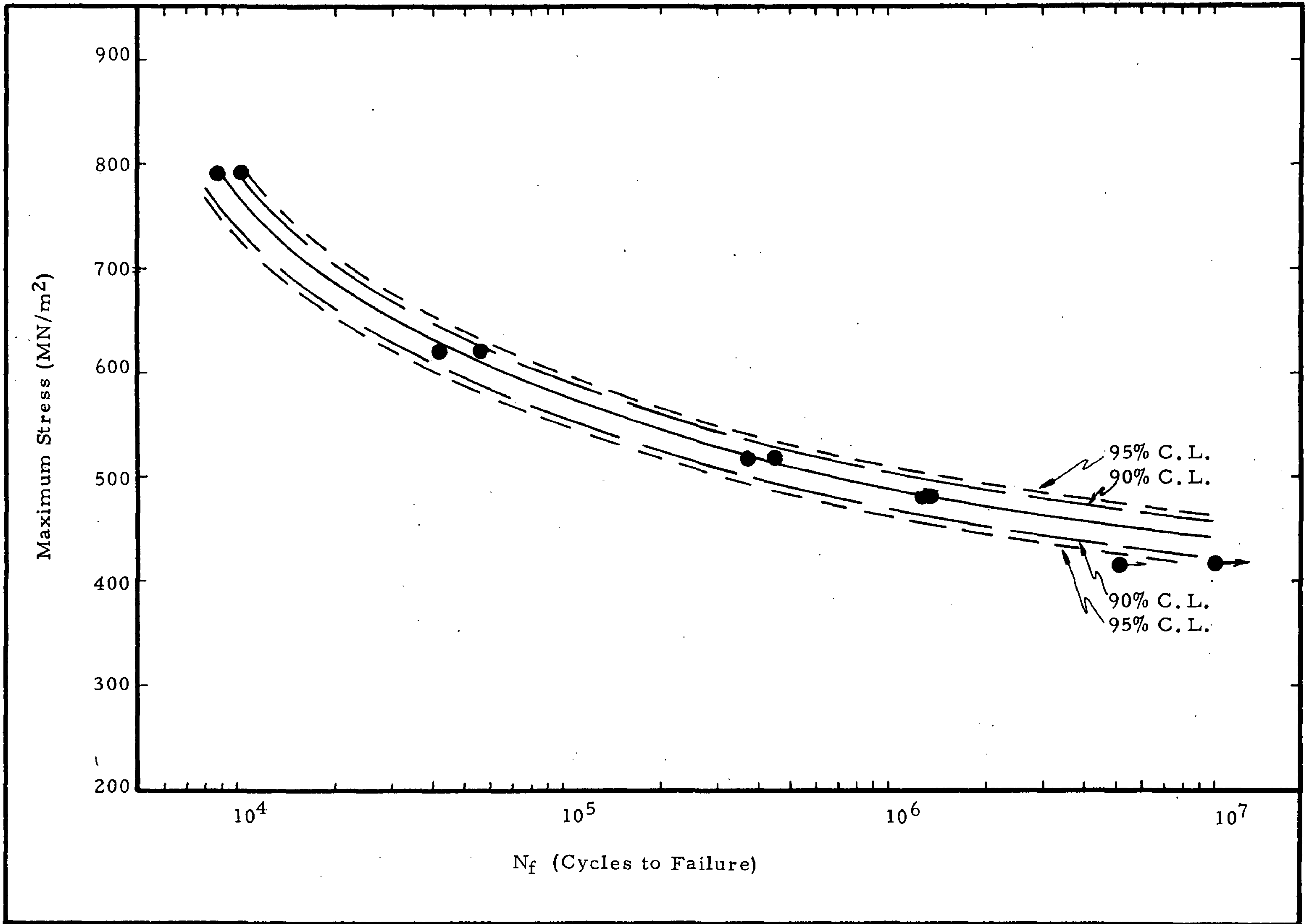


Figure 44 - FATIGUE S/N CURVE FOR HEAT 3712 (NORMAL) AT ROOM TEMPERATURE

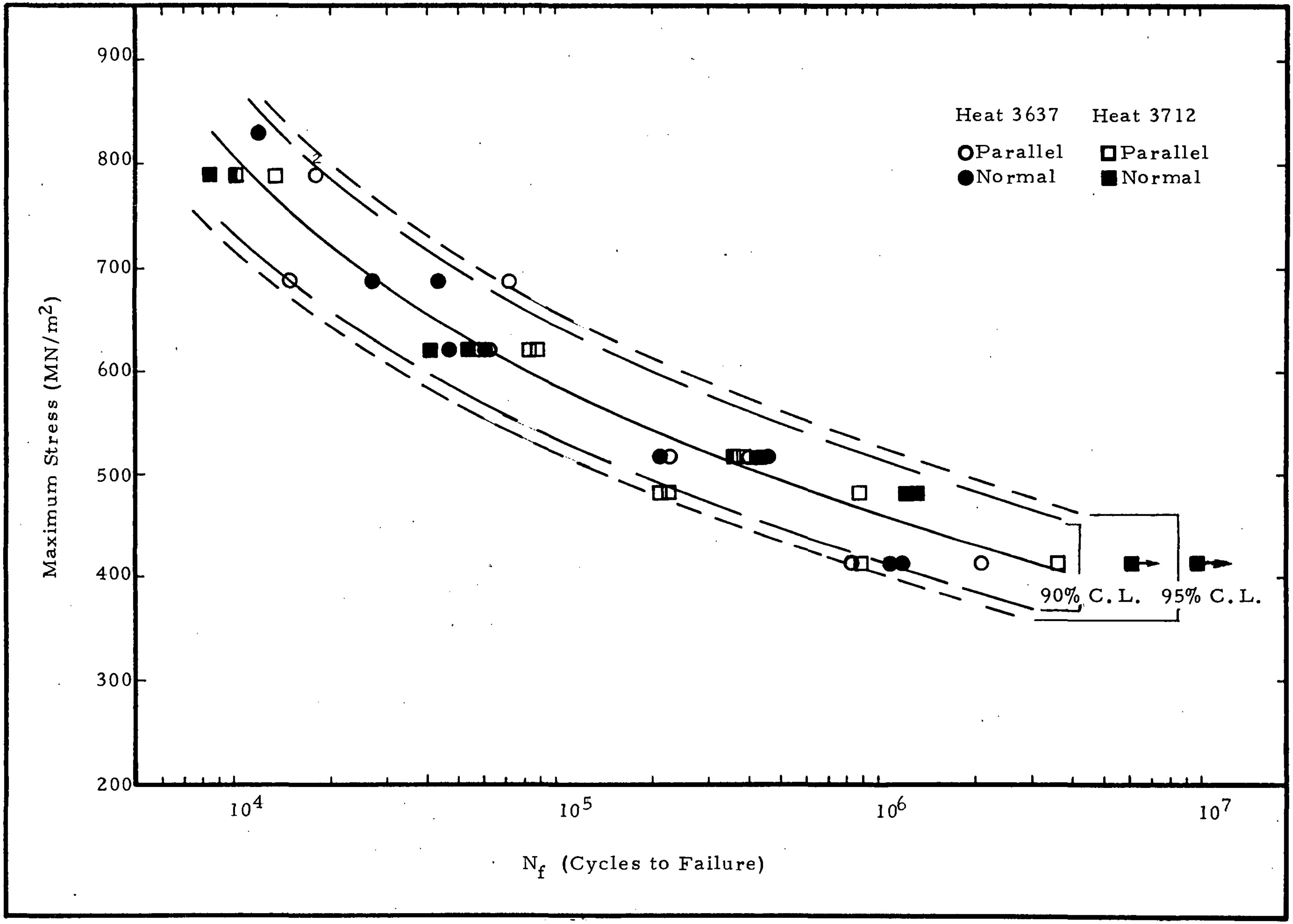


Figure 45 - FATIGUE S/N CURVE FOR TWO HEATS OF TD-NiCr SHEET AT ROOM TEMPERATURE

PHYSICAL PROPERTIES

The Thermophysical Properties Research Center, West Lafayette, Indiana, was chosen as the subcontractor to obtain the physical property data required for fulfillment of this contract.

The testing at TPRC was performed under the supervision of Dr. R. E. Taylor.

Metcut supplied TPRC with test specimens as described in the sections of this report covering test procedures used in evaluating the various physical properties.

TASK II-1 LINEAR THERMAL EXPANSION

Linear thermal expansions are measured in the multiproperty apparatus, which is described in detail in the literature. (Ref. 7, 8, 9) Each sample of 0.103 cm thick TD-NiCr (Heat 3715) 35.56 cm long by 0.312 cm wide, was suspended in a vertical position by clamping onto one end. The sample's expansion was obtained by measuring the relative displacement of two flags attached to the sample. The flags consisted of 0.0025 cm tantalum sheet about 0.635 cm long (in the direction of the sample) and 0.312 cm wide. Several sharp notches were cut into one edge of each flag and the two flags were spot-welded about 10.16 cm apart on the sample so that the notches were parallel to the sample axis and each other. A tantalum tube heater was placed around the sample. Slots were cut in the heater to provide viewing of the flags.

The samples were heated by radiation from the surrounding tube heater, which was heated electrically within a vacuum enclosure. The displacements of the flags were measured with twin telemicroscopes viewing through an optical window in the bell jar. The arrangement of the experimental apparatus is pictured in Figure 46, which shows the vacuum system, twin telemicroscopes and the spot lights used to illuminate the notches when the sample does not provide sufficient self-illumination. Both telemicroscopes are securely mounted on one Invar bar and can be moved as a unit. This permits compensating for the change in length of the sample from the upper clamp to the top flag by adjusting both telemicroscopes simultaneously so that the upper telemicroscope cross-hair is positioned on a fiducial notch in the upper flag. Then the relative displacement of the fiducial marks on the lower flag in relation to the fiducial mark on the upper flag is measured directly using the filar eyepiece of the lower telemicroscope. The smallest division on the drum of the filar eyepiece corresponds to a cross-hair movement of 0.0005 mm. In general the movement of six of the smallest divisions is detectable yielding a sensitivity of 0.003 mm for each telemicroscope. For a 10.16 cm long sample, this corresponds to a change in length of about 0.006%. Since a 1% expansion of a 10.16 cm sample corresponds to a change in length of about 1 mm, this expansion should be measurable with an accuracy of about 0.6%. The filar eyepiece was checked using a Gaertner glass scale calibrated by the manufacturer against an NBS standard (NBS Standard Test 2.4/170598). The displacement of several fiducial marks is observed at each sample temperature and the average change in length is used when presenting the data. Typically the expansions calculated using different fiducial marks at each temperature were within 0.3% of each other.

Temperatures along the sample are measured using platinum-10% rhodium thermocouples attached to the sample near each flag and at the midpoint between flags. The effective sample temperature for each measurement is computed by volume averaging the temperatures at these locations. Typical differences between the temperatures measured at the flags and the sample midpoint were 0° at room temperature increasing to 20° at 1550K. The thermocouples were calibrated prior to use in the Leeds and Northrup calibration facility shown in Figure 47. The output of the platinum-10% rhodium thermocouples at each equilibrium temperature was compared to that obtained on a platinum-10% rhodium thermocouple calibrated by the National Bureau of Standards (NBS Test G37561A) while the thermocouples were in intimate contact with a large thermal mass inside the calibration furnace. All thermocouple outputs were measured using a Leeds and Northrup guarded six-dial potentiometer which was calibrated using temperature-controlled standard cells (Eppley Laboratory, Box Serial No. 3650, NBS Test 211-0216-29145).

The expansion of a standard sample of copper (SRM-736) obtained from the Office of Standard Reference Materials, National Bureau of Standards, was measured over the range for which values were given prior to the initiation of the measurements on the TD-NiCr samples. The results are plotted on Figure 48. It can be seen that the present results are well within 1% of the NBS values.

The thermal expansion data for specimens machined normal to the rolling direction and machined parallel to the rolling direction is shown in Figures 49 and 50. The measured values for the percent expansion at various temperatures are given in Table 72, Appendix J.

From Figures 49 and 50 it is seen that the agreement between the values for Specimens P-1 and P-2 and for Specimens N-1 and N-2 are within a few tenths of a percent of each other. Furthermore, the agreement between the expansion of the normal and parallel samples are also of this same magnitude. The data for the parallel and normal cut samples may be expressed (within 0.3%) by the following equations:

$$\begin{aligned}\%\ \text{expansion (Normal)} = {} & -0.31595 + 9.4675 \times 10^{-4}\ T \\ & + 5.2043 \times 10^{-7}\ T^2\ (T \text{ in K})\end{aligned} \tag{5}$$

$$\begin{aligned}\%\ \text{expansion (Parallel)} = {} & -0.31833 + 9.6431 \times 10^{-4}\ T \\ & + 5.0875 \times 10^{-7}\ T^2\ (T \text{ in K})\end{aligned} \tag{6}$$

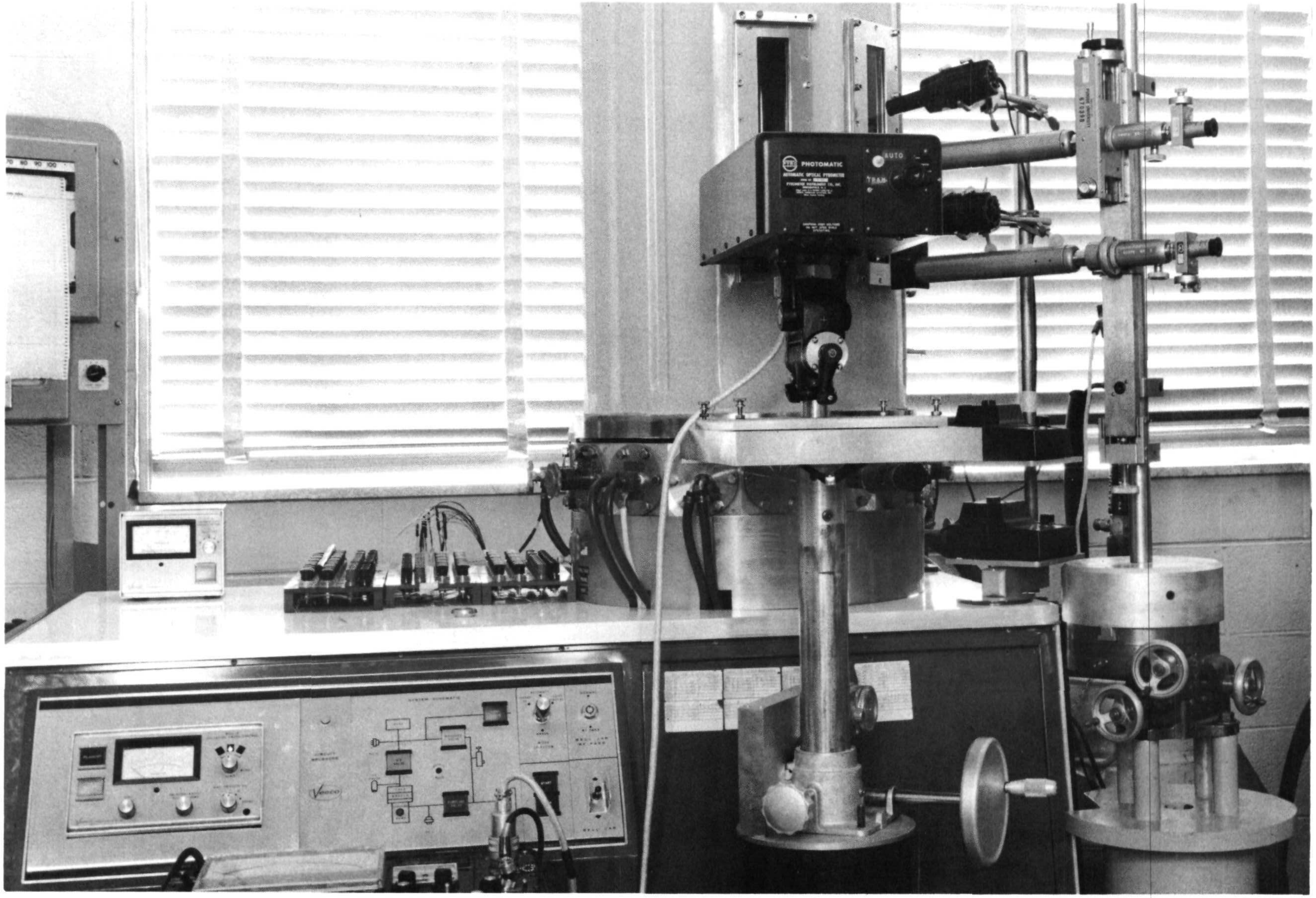


Figure 46 - MULTI-PROPERTY APPARATUS USED FOR VARIOUS THERMOPHYSICAL PROPERTY MEASUREMENTS

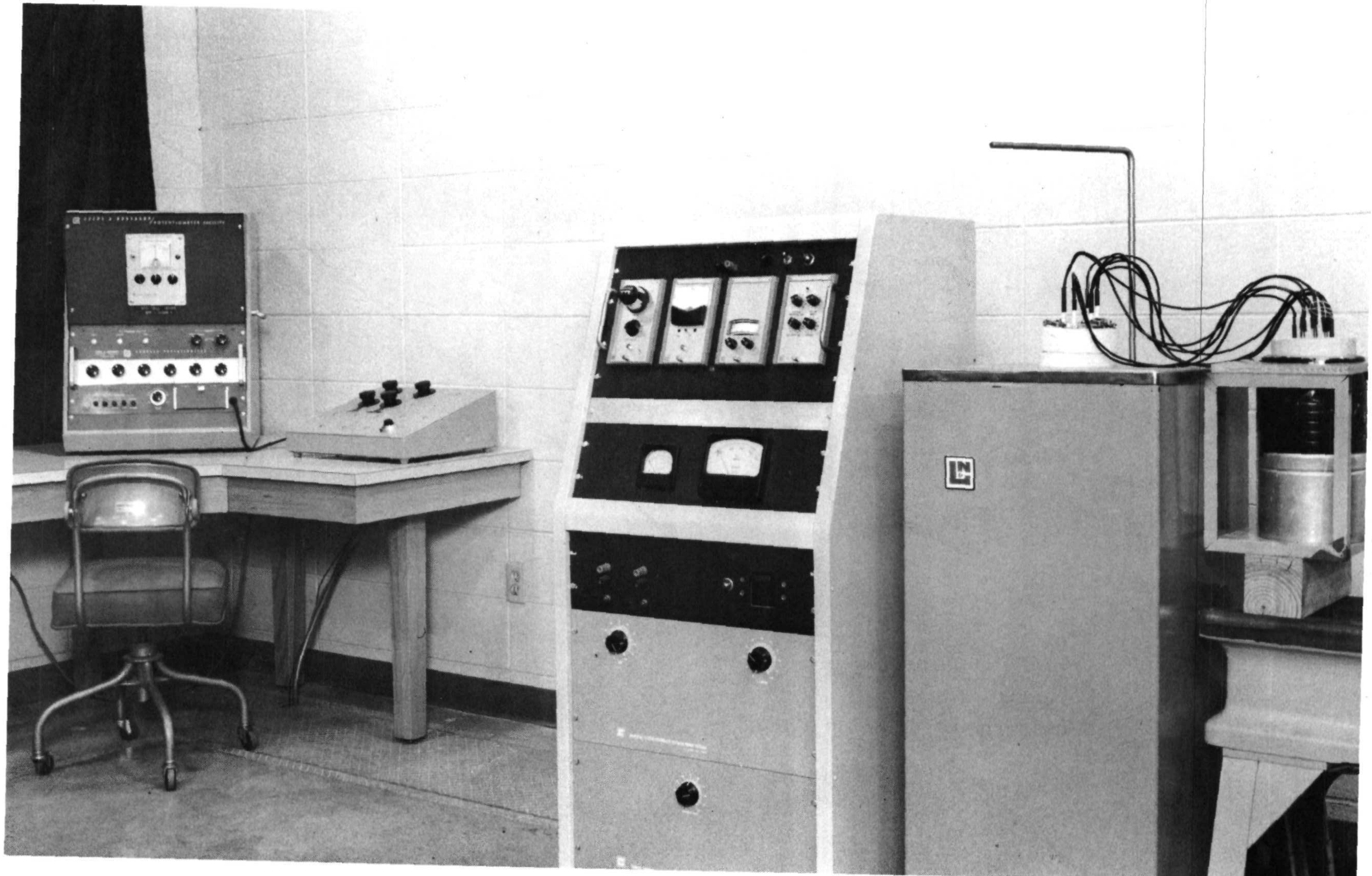


Figure 47 - THERMOCOUPLE CALIBRATION FACILITY

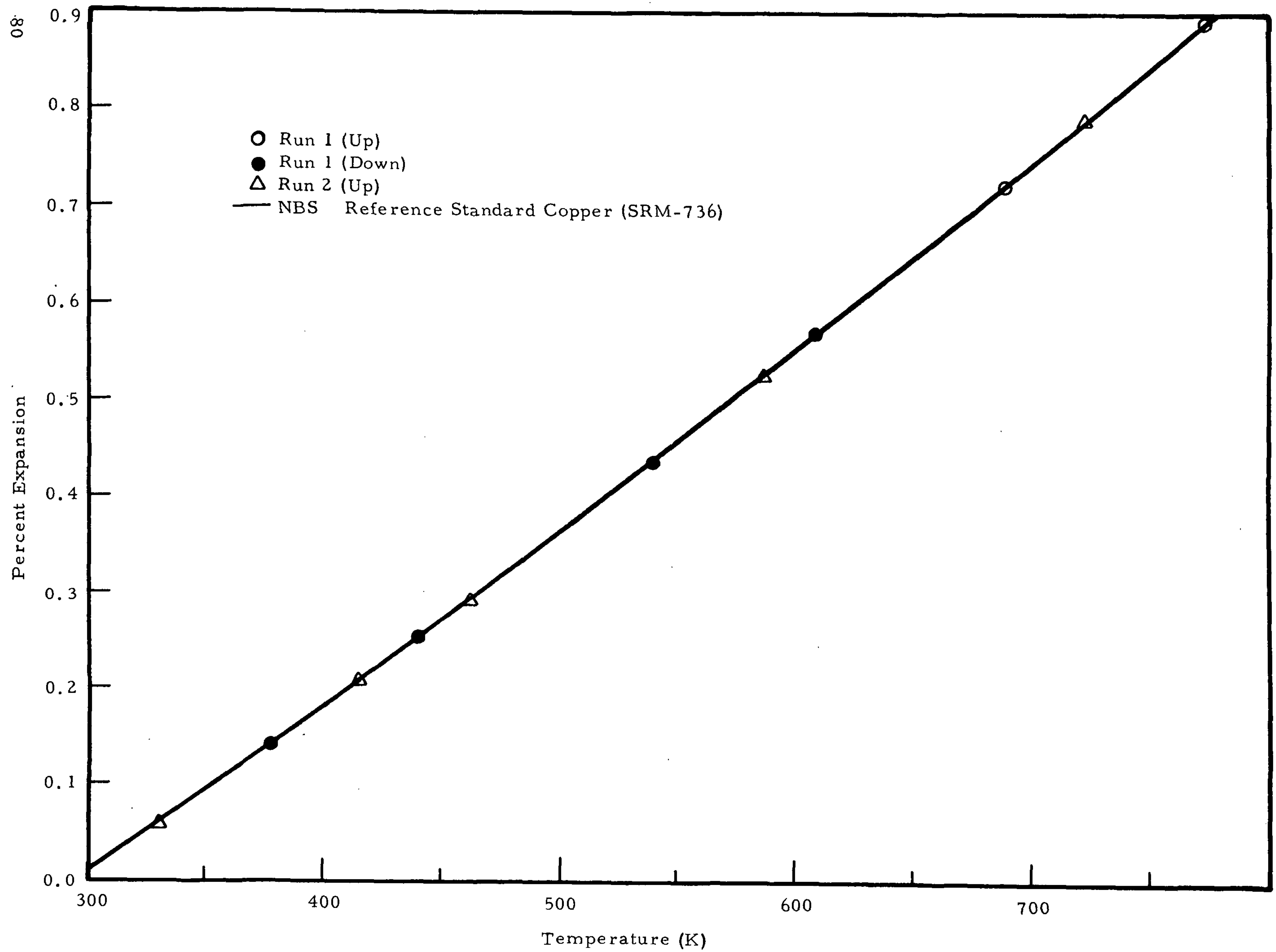


Figure 48 - THERMAL EXPANSION OF SRM COPPER

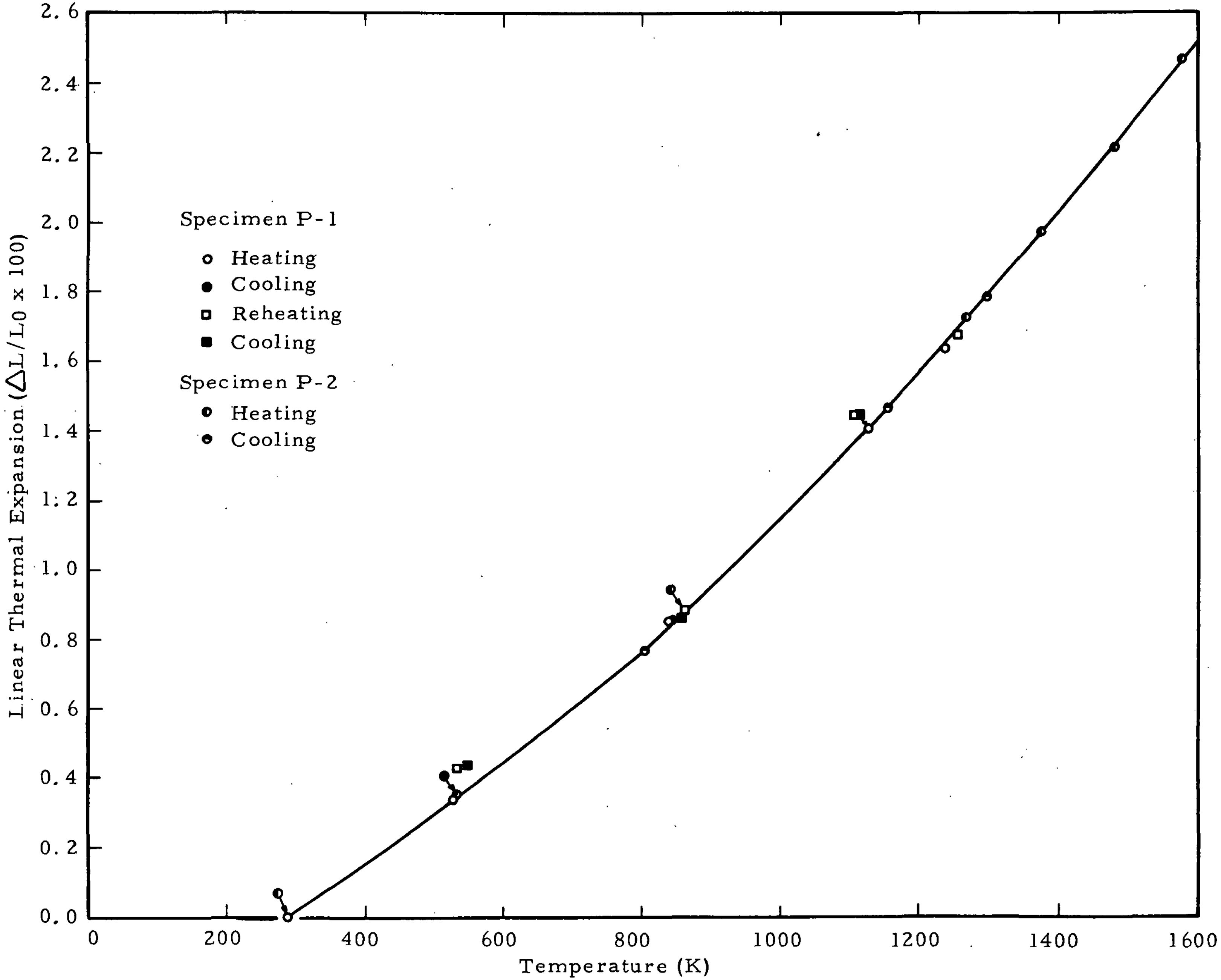


Figure 49 - THERMAL EXPANSION OF TD-NiCr PARALLEL TO THE SHEET ROLLING DIRECTION

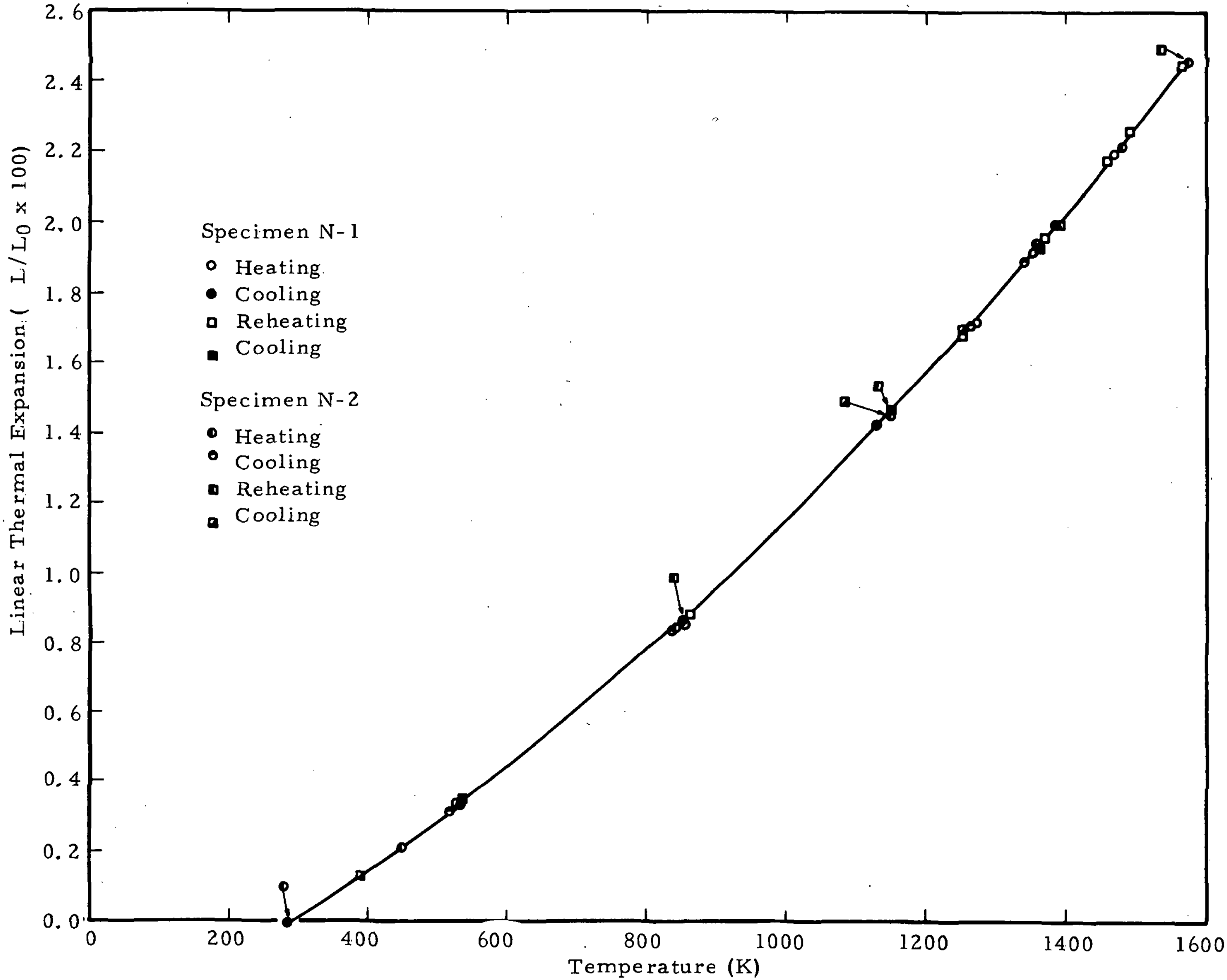


Figure 50 - THERMAL EXPANSION OF TD-NiCr NORMAL TO THE SHEET ROLLING DIRECTION

TASK II-2 TOTAL HEMISPHERICAL EMITTANCE AND ELECTRICAL RESISTIVITY

The multiproperty apparatus described in Task II-1 (Linear Thermal Expansion) and shown in Figure 46 was modified for emittance measurements. The twin telemicroscopes and spotlights mounted external to the bell jar (Figure 46) were not used. Likewise, the thermal heater was not used, but the sample was heated by passing regulated DC current through it while the samples were mounted between electrodes. One of the electrodes was movable to permit sample expansion and contraction during temperature cycling.

Samples of 0.103 cm TD-NiCr (Heat 3715), 60.96 cm long and 0.9525 cm wide were used for emittance measurements. Five calibrated chromel-alumel thermocouples were attached along the center section of the sample and two chromel voltage probes were spot-welded one inch apart in the central section. The distance (L) between voltage probes, the perimeter (P) of the sample and the cross-sectional area (A) were determined. Because the thickness of the samples was not uniform along the test section, average thickness and average temperatures were employed in the calculations.

Measurements of the current (I) voltage drop across the voltage probes (E) and temperature (T) along the test section were recorded at steady-state at a number of preselected temperatures from 700 to 1589K. The measured values consisted of the average obtained when the current was flowing first in one direction and then reversed in order to eliminate thermal emf effects.

The electrical resistivity(ρ) was calculated from the relation:

$$\rho = \frac{A}{L}\frac{E}{I} \tag{7}$$

and the total hemispherical emittance (ϵ_H) was calculated from the relation:

$$\epsilon_H = \frac{EI - Q}{PL\,\sigma(T^4 - T_0{}^4)} \tag{8}$$

where σ is the Stefan-Boltzmann constant and T_0 is the temperature of the water-cooled bell jar and Q is the heat loss due to the atmosphere surrounding the sample. For the measurements made at less than

$213.3\ \mu N/m^2$, Q equals zero. A series of experimental conditions was employed consisting of as-received surface (belt sanded, 120 grit), surface polished to a finish better than 16 rms, both polished and as-received oxidized in air at 1311K for one-half hour, and both polished and as-received oxidized in air for one-half hour at 1311K and further oxidized at $213.3\ N/m^2$ for 25 hours at 1422K. Samples were measured under high vacuum ($213.3\ \mu N/m^2$) and at $213.3\ N/m^2$ for each of the conditions listed. The experimental conditions are listed in Table 73, Appendix K.

The total hemispherical emittance data is given in Table 74, Appendix L, and resistivity data taken during some of the runs is given in Table 75, Appendix M. All the emittance and resistivity data are plotted in Figures 51 through 62. The data for a given specimen condition measured at $213.3\ N/m^2$ and at less than $213.3\ \mu N/m^2$ is presented on each figure.

The total hemispherical results for Specimens 6 and 5 (as-received) are shown in Figure 51. Consider first the data for Specimen 6 which was measured at less than $213.3\ \mu N/m^2$. The total emittance increased from 0.1792 at 516K to 0.2704 at 1365K. Above 1300K considerable chromium evolution occurred and an extensive coating formed on the observation windows and the interior of the bell jar. Upon rerunning the sample, it was found that the emissivity was 0.5002 at 690K increasing to 0.6718 at 1262K when additional chromium evolution was noticed and the run was terminated. Following the run, the sample's surface was metallic, spotted and pitted. The emittance of Specimen 5 was measured at $213.3\ N/m^2$. The emittance at 699K (0.2096) was close to that of Specimen 6 (0.2025 at 698K) but, in contrast to the data of Specimen 6, the emittance of Specimen 5 significantly increased with time at temperatures above 800K. The results of measurements taken at 5-minute intervals at various temperatures are shown in Figure 51. These measurements were taken during constant power input conditions. Thus as the emittance increased, the sample temperature decreased. For example, the sample temperature decreased from 1590 to 1546K as the emittance increased from 0.4552 to 0.4990 over a 5-minute interval (Table 74, Appendix L). The measurement at 1361K was made after the rate of change of emittance had slowed considerably and the emittance at 1479 and 1585K did not change appreciably with time. Measurement made during the third run agreed substantially with the extrapolation of the latter measurements made during the second run indicating that a reasonably stable emittance condition had been established for $213.3\ N/m^2$ conditions.

Now consider the resistivity measurements made simultaneously with the emittance measurements for Specimens 6 and 5 (Figure 52). The electrical resistivity of all TD-NiCr samples exhibits maximum near 800K and the resistivity below and near the maximum apparently is unstable. Therefore, we will only consider the data above 900K. Note that electrical resistivity of Specimen 6 permanently increased after heating above 1360K, whereas the resistivity for Specimen 5 agreed very well (above 900K) upon temperature cycling to 1585K. This shows that although the total emittance of both samples increased to about 0.6 at 1300K, the mechanisms associated with the increase were entirely different.

The data for polished Specimens 7 and 8 under vacuum of less than 213.3 uN/m^2 and at 213.3 N/m^2, respectively, is given in Figures 53 and 54. The data for Specimen 7 shows the emittance increases from 0.1887 at 697K to 0.2367 at 1354K. The sample was then cooled and reheated and the emittance and resistivity data were found to have increased slightly above their initial values. Upon heating at constant power input at 1500K, the emittance increased and the temperature decreased as chromium was evolved. The resistivity also decreased, but along a different curve from the heating curve. Emittance and resistivity data taken during cooling were substantially above the initial data. It should be noted that the initial emittance data for the polished Specimen 7 (Figure 53) was about 10% lower than for the as-received Specimen 6 (Figure 51). The emittance data for the polished Specimen 8 (Figure 53), measured at 213.3 N/m^2, exhibited a behavior similar to that observed for Specimen 5 (Figure 51). The emittance increased with time at temperatures above 800K and finally attained a value of about 0.7 at 1600K. Subsequent measurements indicated a reasonably stable emittance behavior increasing from 0.628 at 922K to about 0.7 at 1600K (the same value attained by the as-received sample measured at 213.3 N/m^2). The resistivity of the sample measured at 213.3 N/m^2 was reproducible upon temperature cycling.

As-received Specimens 4 and 1 were oxidized in air for one-half hour at 1311K prior to the emissivity measurements. During the first and second runs the emissivity of Specimen 4, measured at less than 213.3 $\mu N/m^2$, increased from 0.4797 at 697K to 0.7515 at 1564K (Figure 55). The specimen was heated to about 1600K before being returned to room temperature. Upon subsequent heating, it was found that the emissivity increased from 0.5146 at 697K to 0.7774 at 1568K. The resistivity (above 900K) was found to be reproducible upon temperature cycling (Figure 56). The emissivity of Specimen 1 increased from 0.4963 at 695K to 0.7465 at 1543K when measured at 213.3 N/m^2 (Figure 55). However, the emissivity decreased to 0.7299 and the temperature increased to 1552K upon heating at constant power for 5 minutes. The emissivity measured during the cooling cycle was less than the emissivity measured during the heating cycle above 1250K but was less than that measured during the heating cycle below 1250K. The resistivity measured during the cooling cycle was less than that measured during the heating cycle (Figure 56).

The behavior of the polished Specimens 11 and 9 which were oxidized in air for one-half hour at 1311K prior to measurement was similar to that of Specimens 4 and 1. The emittance of Specimen 11 (after first cycling to 1100K) increased from 0.4892 at 698K to 0.775 at 1573K under high vacuum and the emissivity measured on cooling was greater than that measured during the heating cycle (Figure 57). The emissivity of Specimen 9 decreased during 5 minutes of constant power at 213.3 N/m^2 at 1600K (Figure 57), as did the electrical resistivity (Figure 58).

As-received Specimens 2 and 20 were oxidized in air for one-half hour at 1311K similar to the treatment given Specimens 4, 1, 11, and 9. However, Specimens 2 and 20 were further oxidized for 25 hours at 1422K at 213.3 N/m^2 prior to the emissivity measurements which were made under vacuum of less than 213.3 $\mu N/m^2$. The emissivity of Specimen 2 (Figure 59) was appreciably greater than that of Specimen 4 (Figure 55), indicating that the additional oxidation at 213.3 N/m^2 at 1422K increased the emissivity. However, upon heating above 1589K, the emissivity of Specimen 2 decreased under high vacuum while that of Specimen 4 increased so that the two emittances of Specimens 2 and 4 approached each other after being subjected to 1589K heating under high vacuum.

Similarly, the emittance of Specimen 20, which was subjected to the same oxidation treatment as Specimen 2 but which was measured at 213.3 N/m^2 pressure (Figure 59), was appreciably greater than that of Specimen 1. Since Specimen 1 was not subjected to the additional 25 hour oxidation at 1422K, the comparison of the results for Specimen 20 and Specimen 1 again shows that the additional oxidation markedly increased the emissivity. The emissivity at high temperature of Specimen 20 decreased upon heating above 1589K and the cooling curve crossed the heating curve data (Figure 59). This behavior is similar to that observed for Specimen 1 (Figure 55). The resistivity behavior of Specimens 2 and 20 (Figure 60) was quite similar to that described for Specimens 4 and 1 (Figure 55).

The polished Specimens 12 and 10 were subjected to the half-hour oxidation in air at 1311K and at 213.3 N/m^2 for 25 hours at 1422K. The emittances of these two specimens were greater than those of Specimens 11 and 9 which were not subjected to the additional oxidation, again demonstrating that the oxidation for 25 hours at 213.3 N/m^2 at 1422K increased the emissivity of samples first subjected to heating in air at 1311K for one-half hour. The emittance of both Specimen 12 (measured at 213.3 $\mu N/m^2$, Figure 61) and Specimen 10 (measured at 213.3 N/m^2, Figure 61) decreased upon heating to 1589K, but the resistivity values were not significantly affected.

By intercomparing the results of the various experiments, several conclusions can be drawn. Heating TD-NiCr above 1400K at less than 213.3 $\mu N/m^2$ causes rapid chromium evolution and increases the emissivity. Polishing the samples to 16 rms finish decreases the emissivity about 10% (below the temperature of marked chromium evolution). TD-NiCr oxidizes noticeably at 800K at 213.3 N/m^2 and the emittance approaches 0.7 at 1550K for both polished and as-received material. The emittance of samples oxidized in air at 1311K for one-half hour and then measured above 1366K at 213.3 N/m^2 tends to decrease to the values measured on samples at 213.3 N/m^2 which had not been subjected to prior oxidation. Emittance of samples oxidized in air at 1311K for one-half hour is not very reproducible upon the initial heating in high vacuum at 1144K. Oxidizing samples for 25 hours at 1422K at 213.3 N/m^2 increases the emittances of samples previously oxidized in air for one-half hour at 1311K. Heating samples that have been oxidized at 213.3 N/m^2 at 1422K to temperatures above 1477K at 213.3 N/m^2 causes the emittance to decrease. The rate and magnitude of this decrease depends upon the maximum temperature reached. The emittances of oxidized samples that were polished prior to oxidation tend to be somewhat higher than those of samples which were not polished prior to oxidation. The maximum emittance noted during the tests was 0.835 at 1575K for a polished specimen oxidized in air for one-half hour at 1311K and at 213.3 N/m^2 at 1422K for 25 hours, but this emittance value decreased to 0.805 within five minutes while the sample temperature was maintained above 1575K. All the data for oxidized samples can be represented by a band increasing from $0.54 \pm .07$ at 700K to $0.75 \pm .07$ at 1550K.

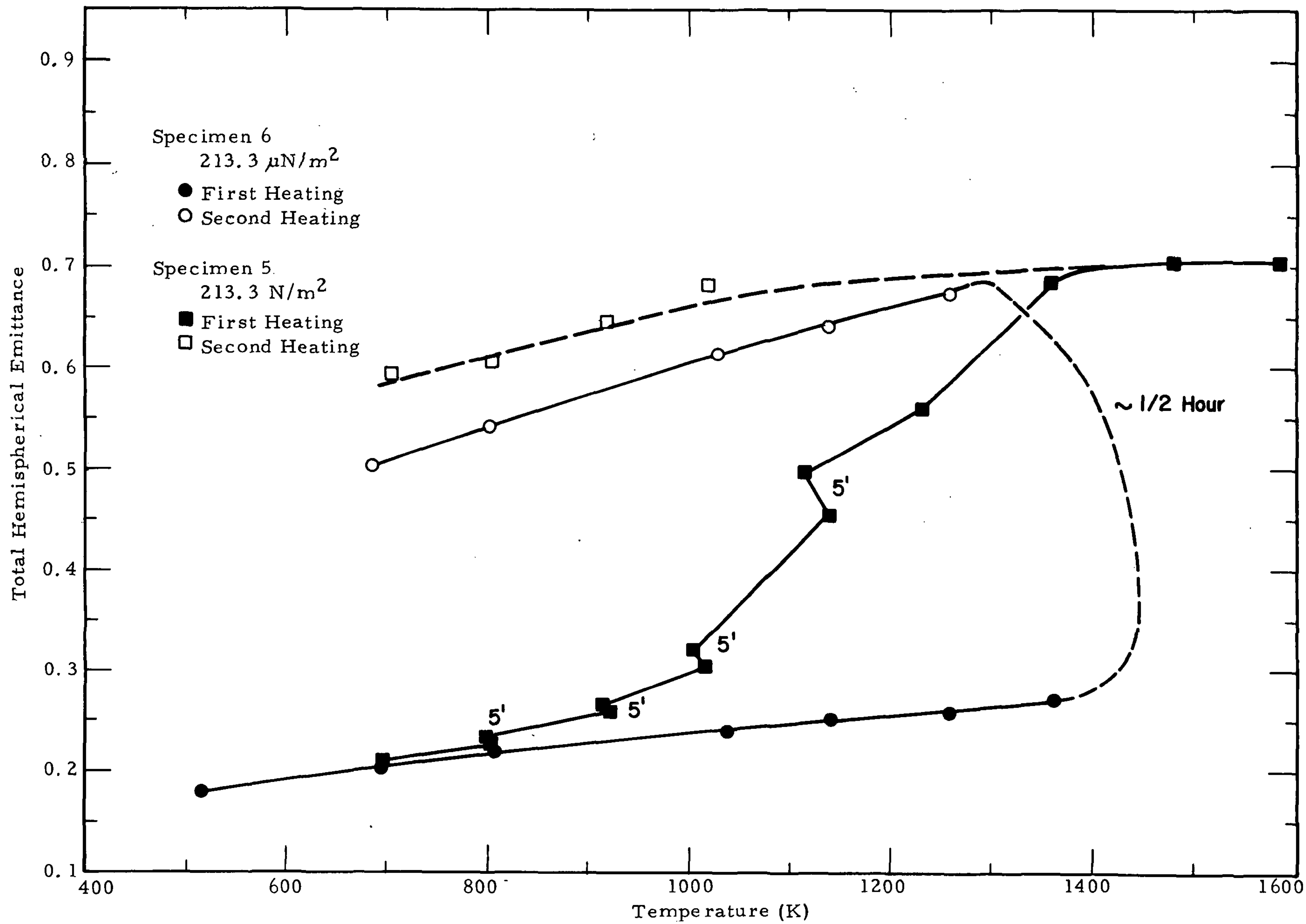


Figure 51 - TOTAL HEMISPHERICAL EMITTANCE OF TD-NiCr FOR AS-RECEIVED SURFACE FINISH AS A FUNCTION OF TEMPERATURE AND PRESSURE

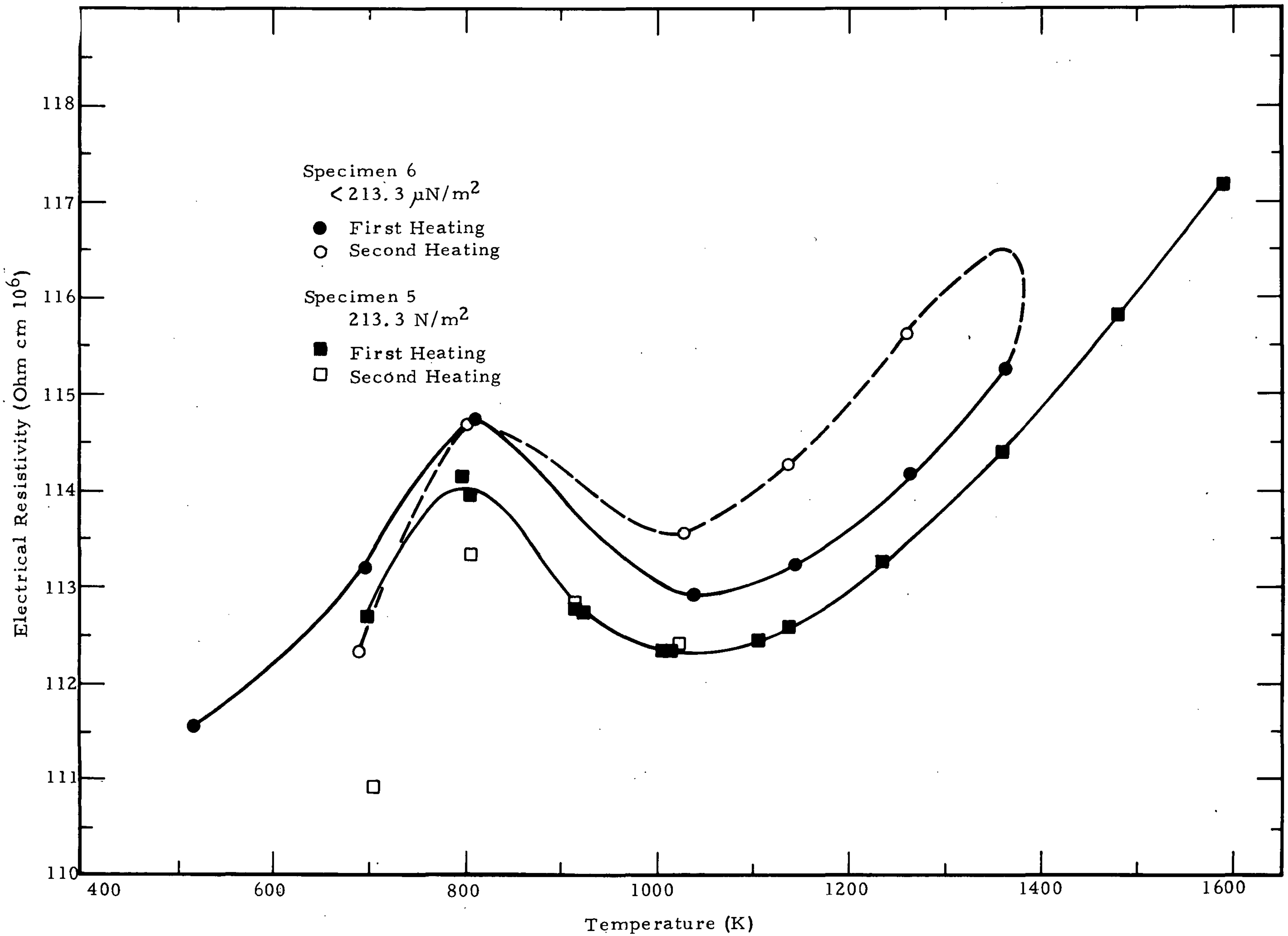


Figure 52 - ELECTRICAL RESISTIVITY OF TD-NiCr FOR AS-RECEIVED SURFACE FINISH AS A FUNCTION OF TEMPERATURE AND PRESSURE

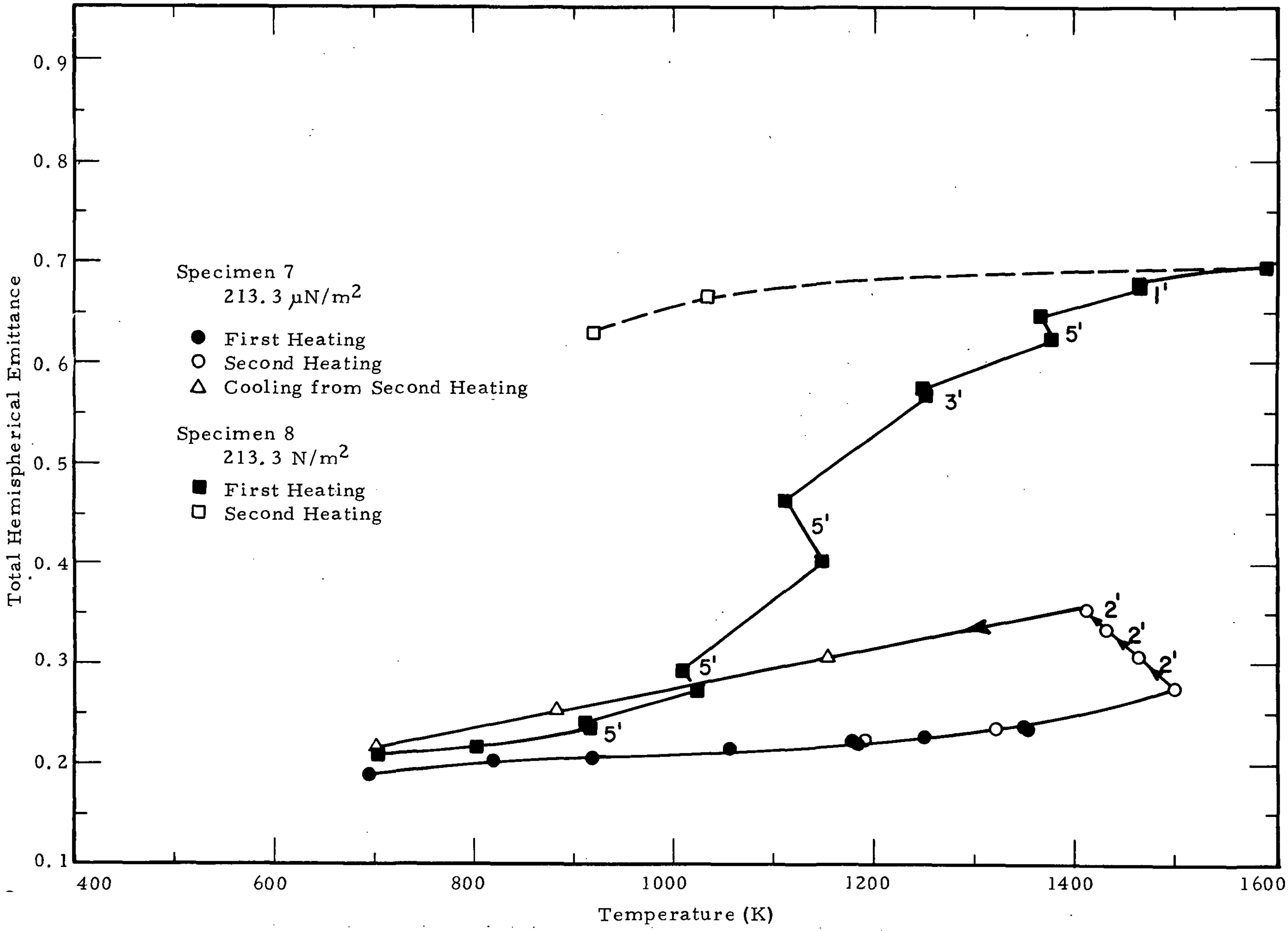


Figure 53 - TOTAL HEMISPHERICAL EMITTANCE OF TD-NiCr FOR POLISHED SURFACE FINISH AS A FUNCTION OF TEMPERATURE AND PRESSURE

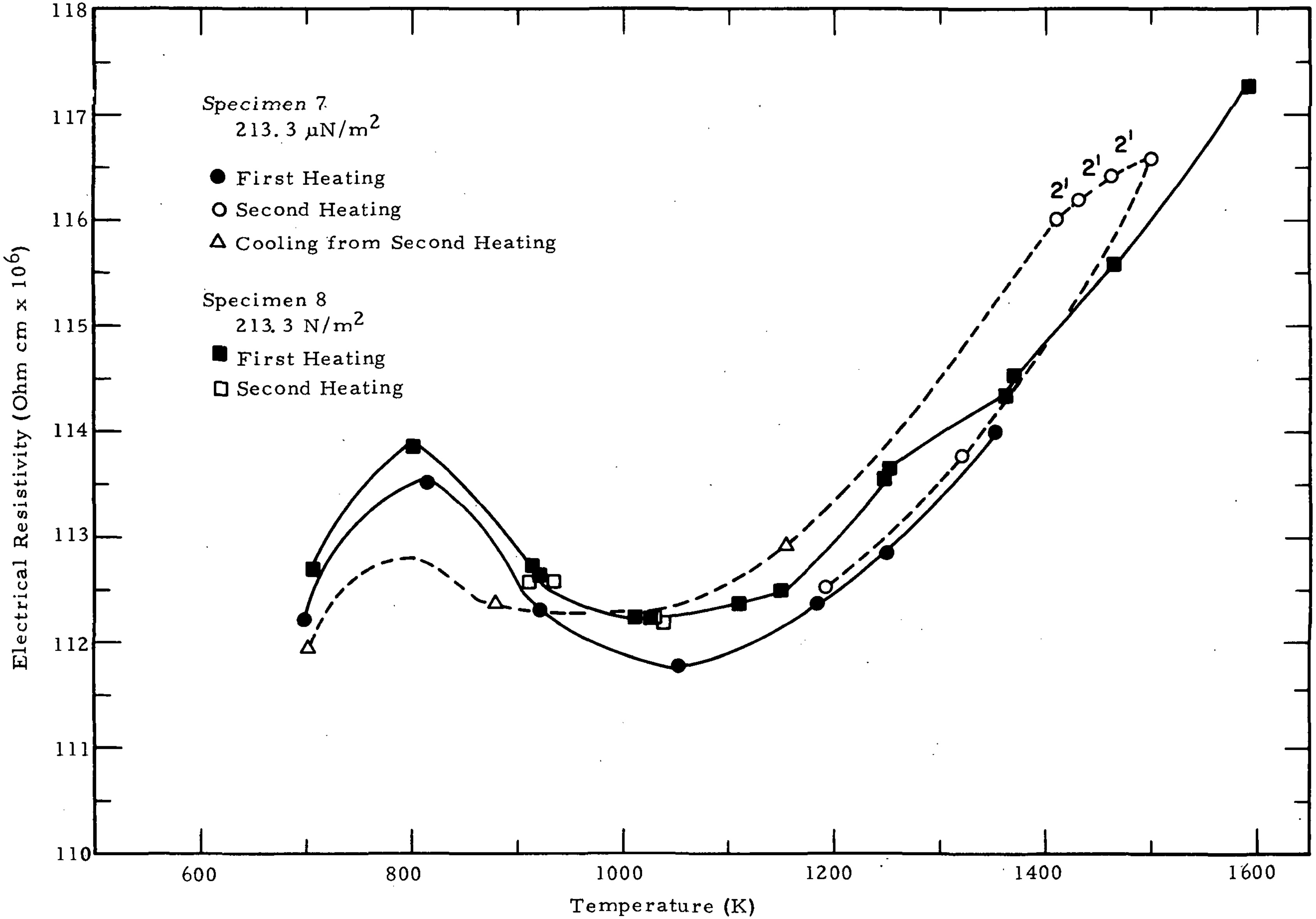


Figure 54 - ELECTRICAL RESISTIVITY OF TD-NiCr FOR POLISHED SURFACE FINISH AS A FUNCTION OF TEMPERATURE AND PRESSURE

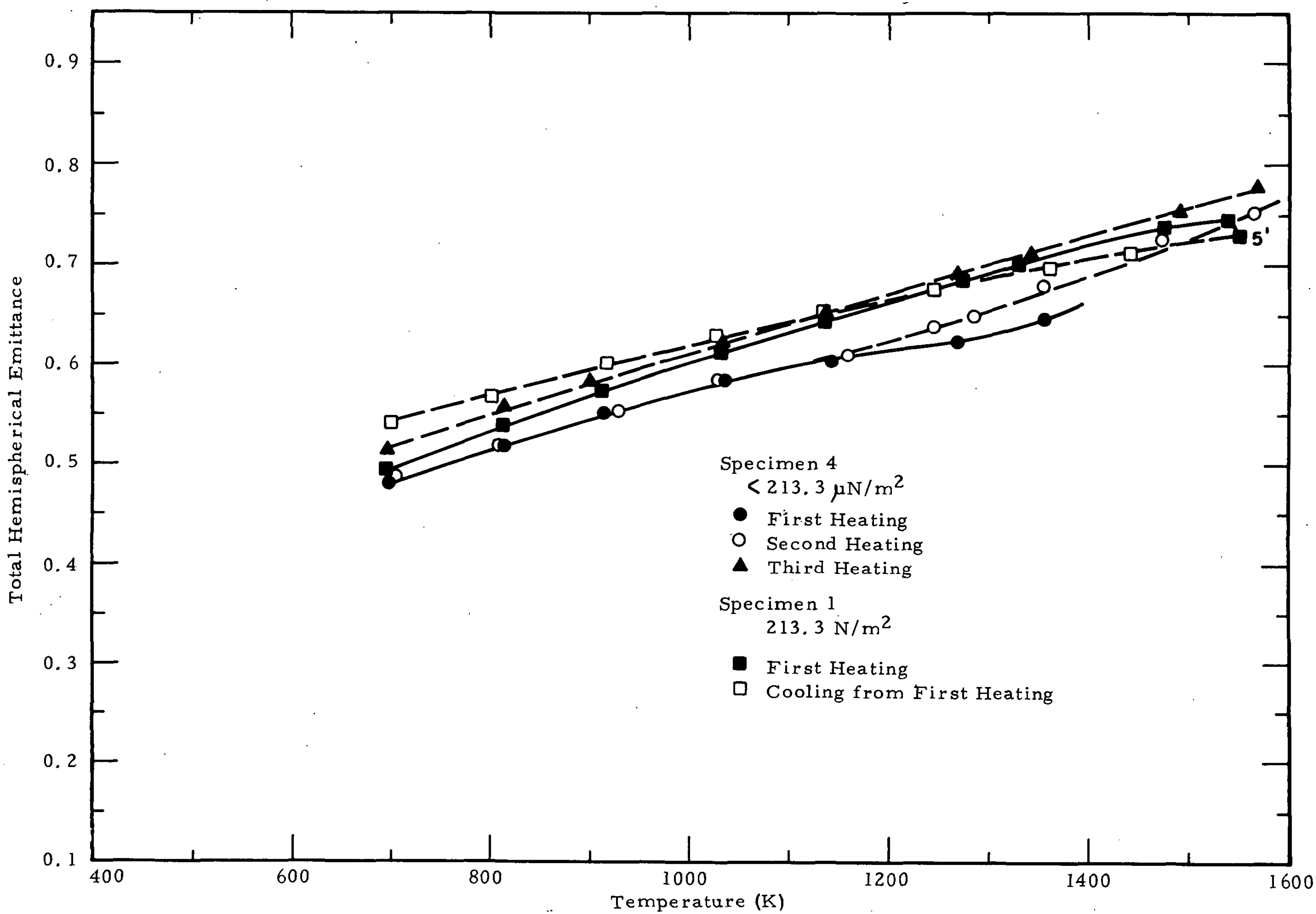


Figure 55 - TOTAL HEMISPHERICAL EMITTANCE OF TD-NiCr FOR AS-RECEIVED SURFACE OXIDIZED IN AIR FOR 0.5 HOUR AT 1311K AS A FUNCTION OF TEMPERATURE AND PRESSURE

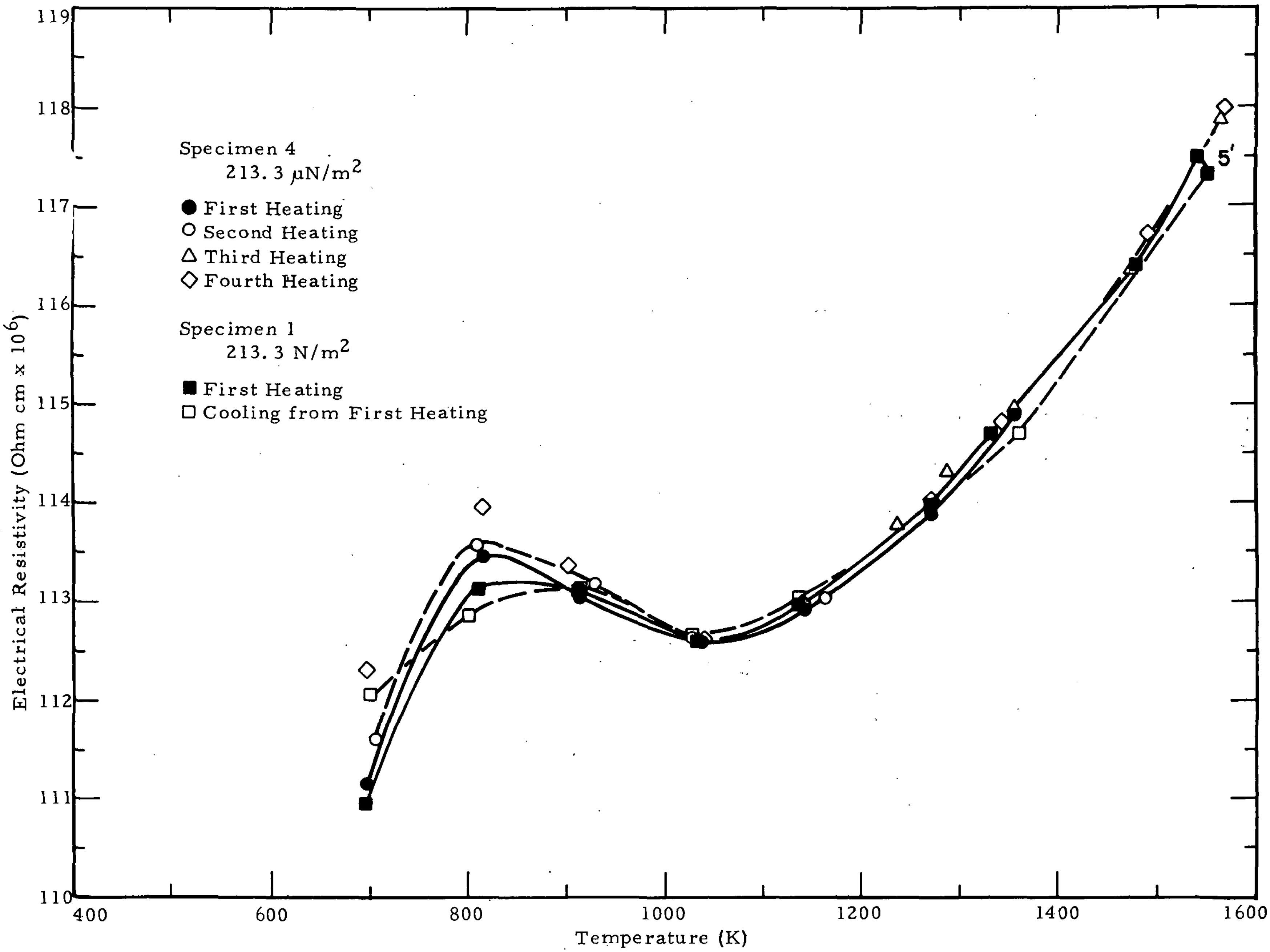


Figure 56 - ELECTRICAL RESISTIVITY OF TD-NiCr FOR AS-RECEIVED SURFACE OXIDIZED IN AIR FOR 0. 5 HOUR AT 1311K AS A FUNCTION OF TEMPERATURE AND PRESSURE

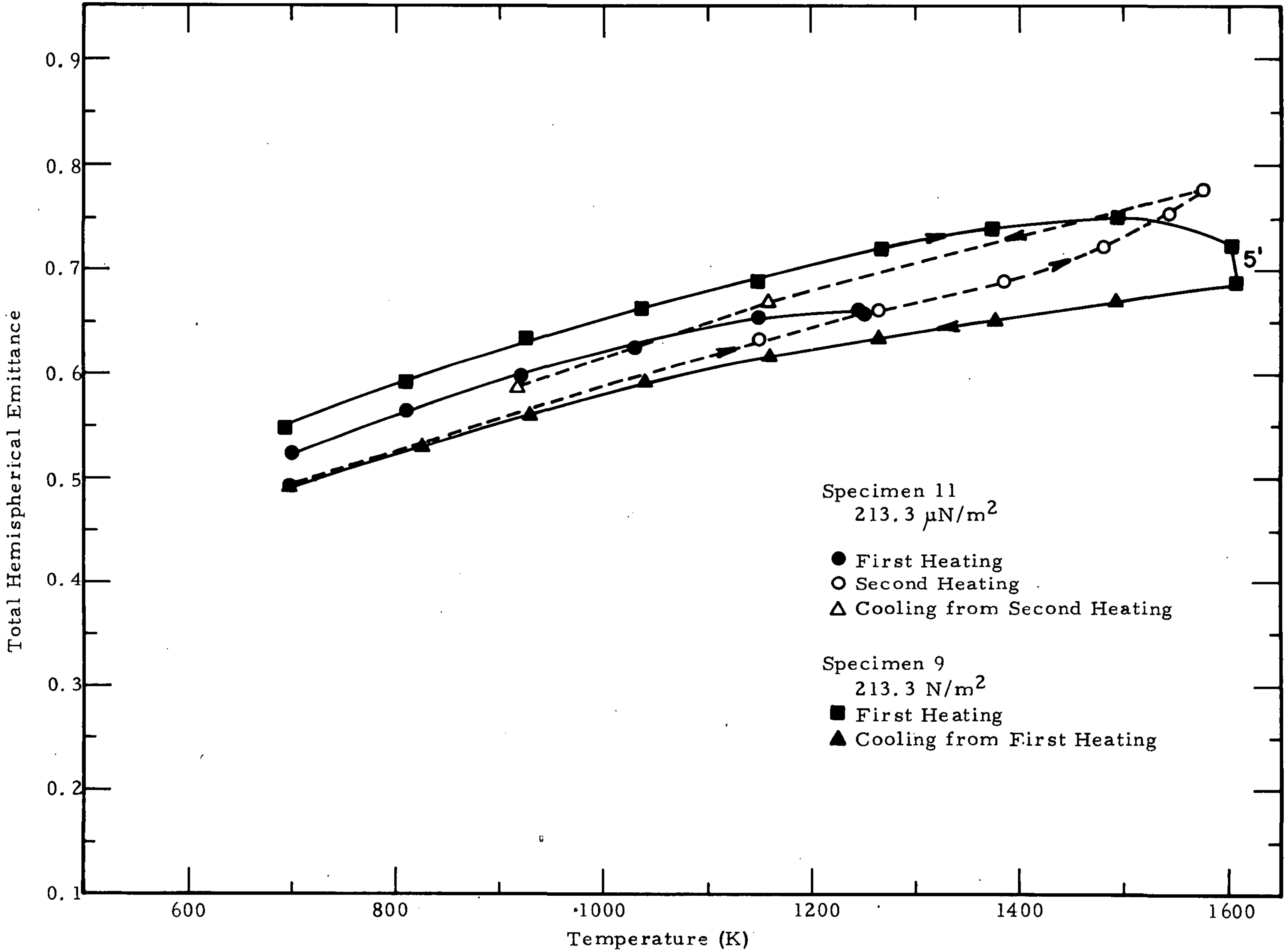


Figure 57 - TOTAL HEMISPHERICAL EMITTANCE OF TD-NiCr FOR POLISHED SURFACE OXIDIZED IN AIR FOR 0.5 HOUR AT 1311K AS A FUNCTION OF TEMPERATURE AND PRESSURE

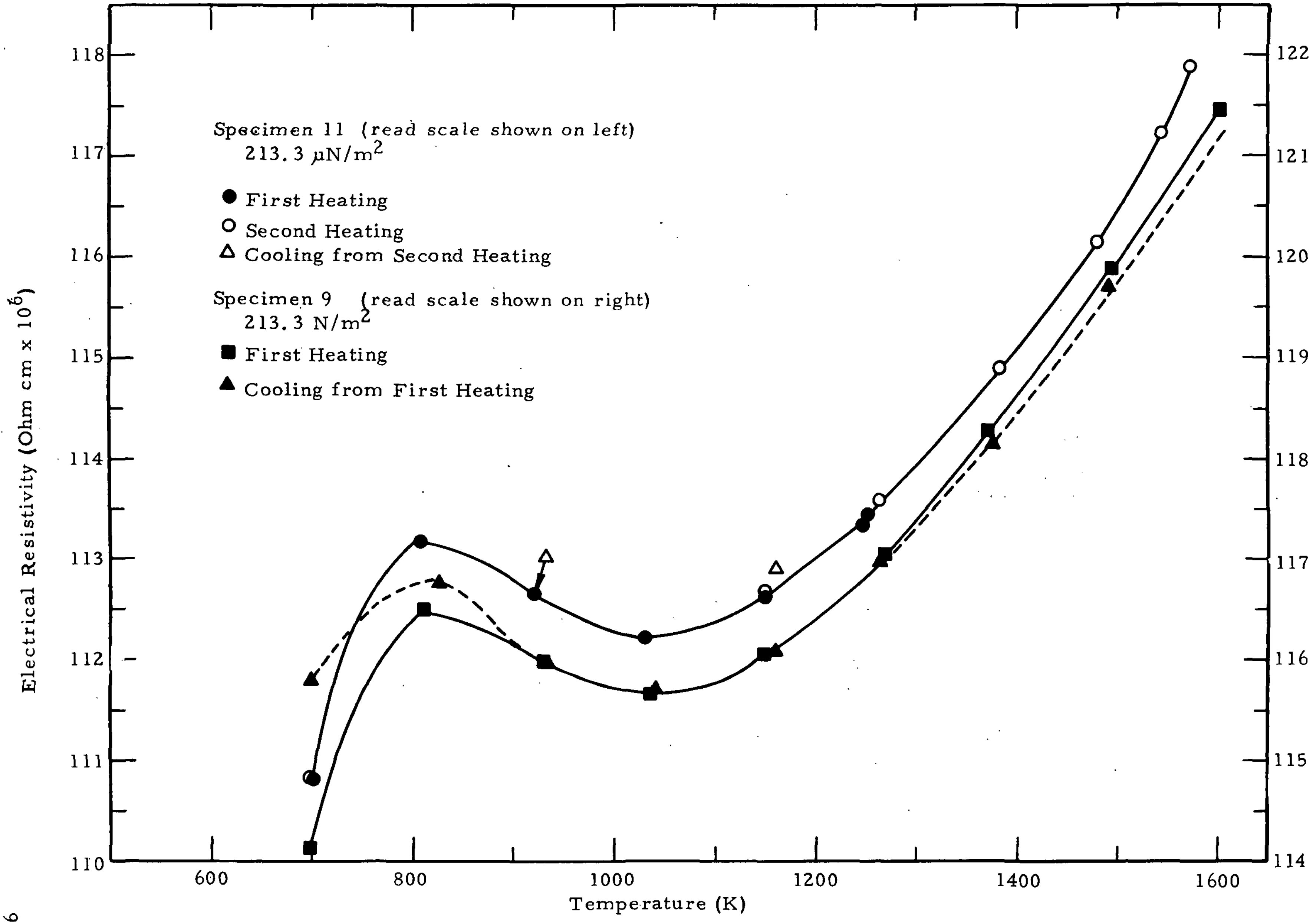


Figure 58 - ELECTRICAL RESISTIVITY OF TD-NiCr FOR POLISHED SURFACE OXIDIZED IN AIR FOR 0.5 HOUR AT 1311K AS A FUNCTION OF TEMPERATURE AND PRESSURE

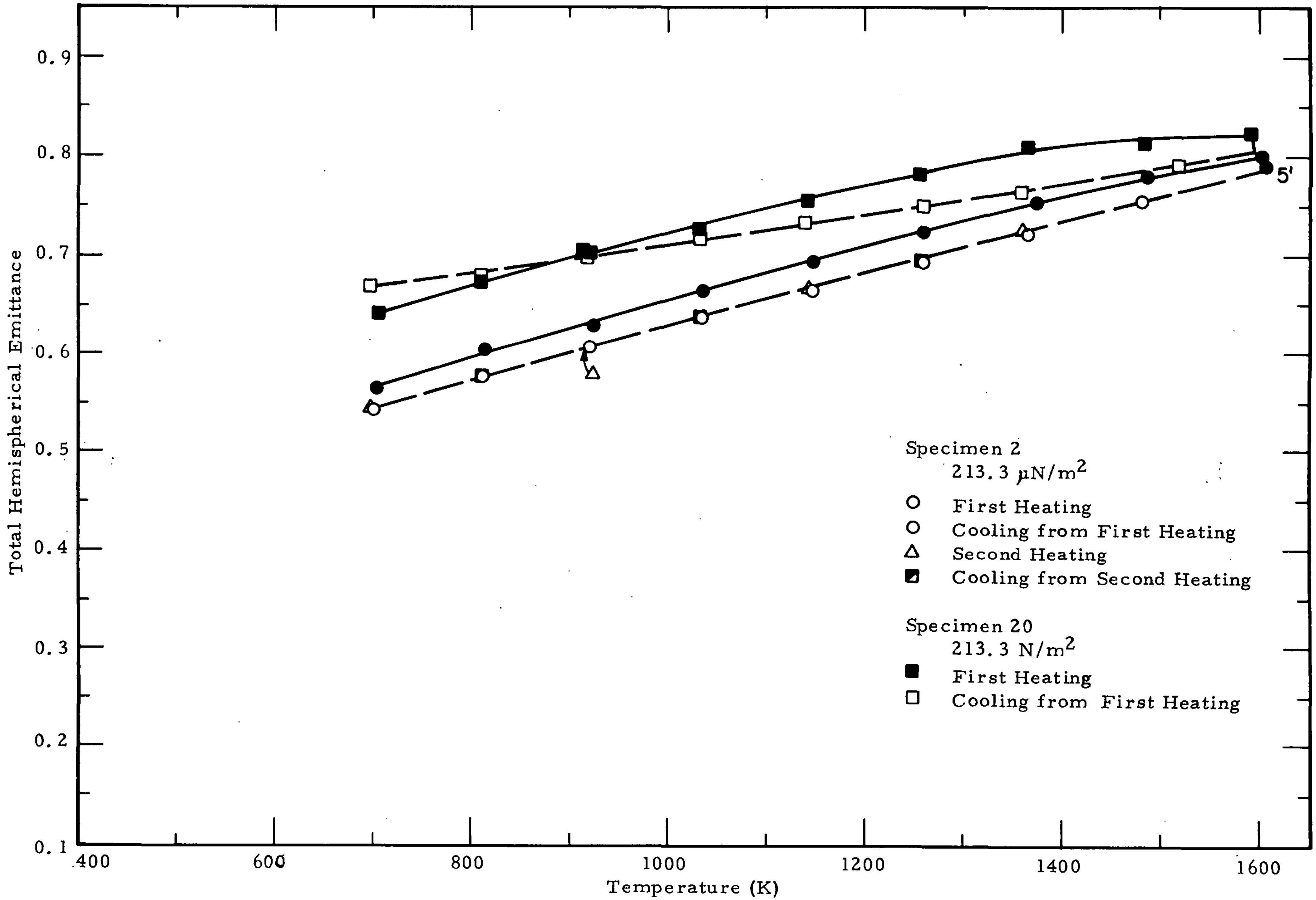


Figure 59 - TOTAL HEMISPHERICAL EMITTANCE OF TD-NiCr FOR AS-RECEIVED SURFACE OXIDIZED IN AIR FOR 0.5 HOUR AT 1311K AND AT 213.3 N/m^2 FOR 25 HOURS AT 1422K AS A FUNCTION OF TEMPERATURE AND PRESSURE

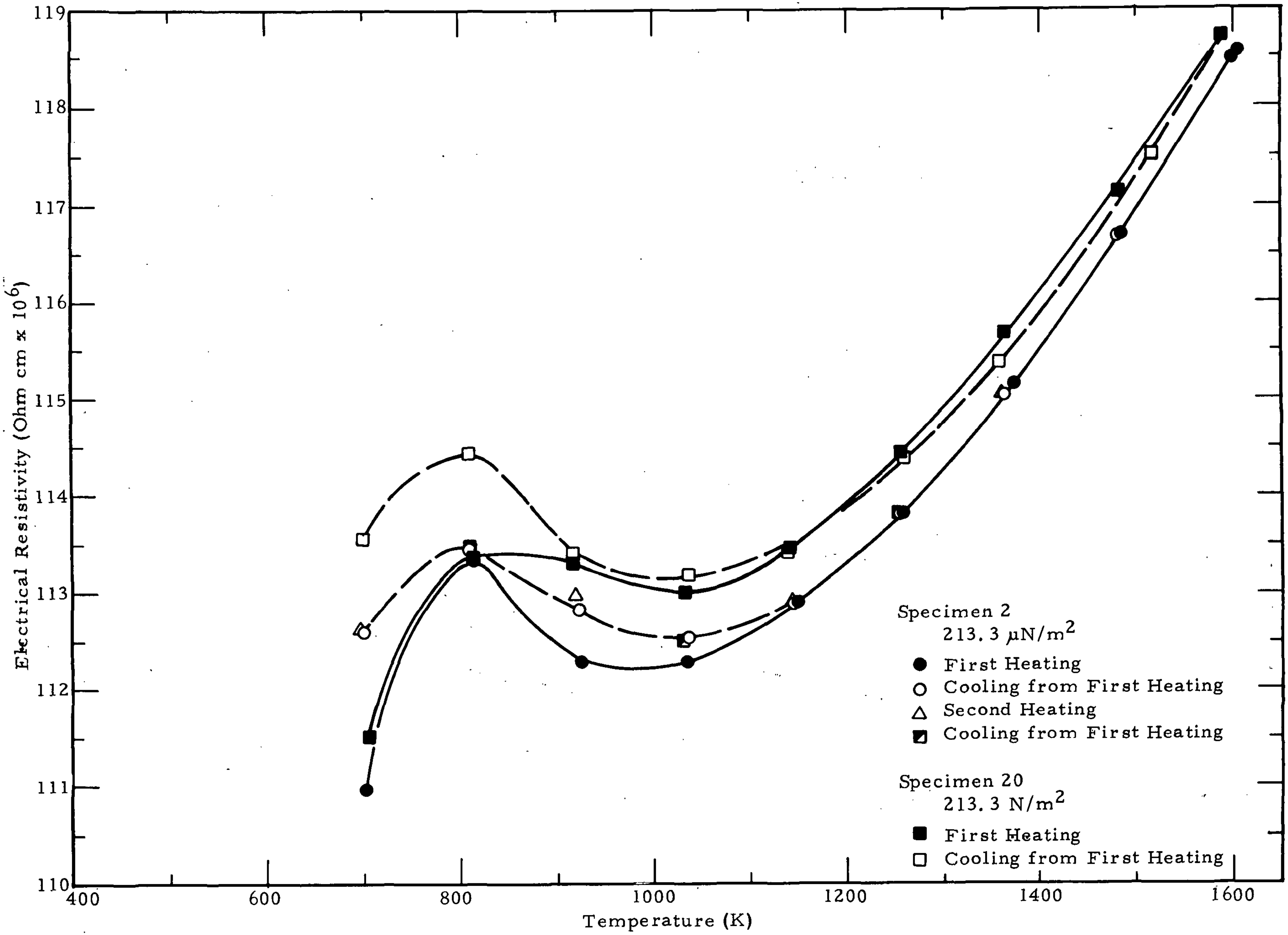


Figure 60 - ELECTRICAL RESISTIVITY OF TD-NiCr FOR AS-RECEIVED SURFACE OXIDIZED IN AIR FOR 0.5 HOUR AT 1311K AND AT 213.3 N/m^2 FOR 25 HOURS AT 1422K AS A FUNCTION OF TEMPERATURE AND PRESSURE

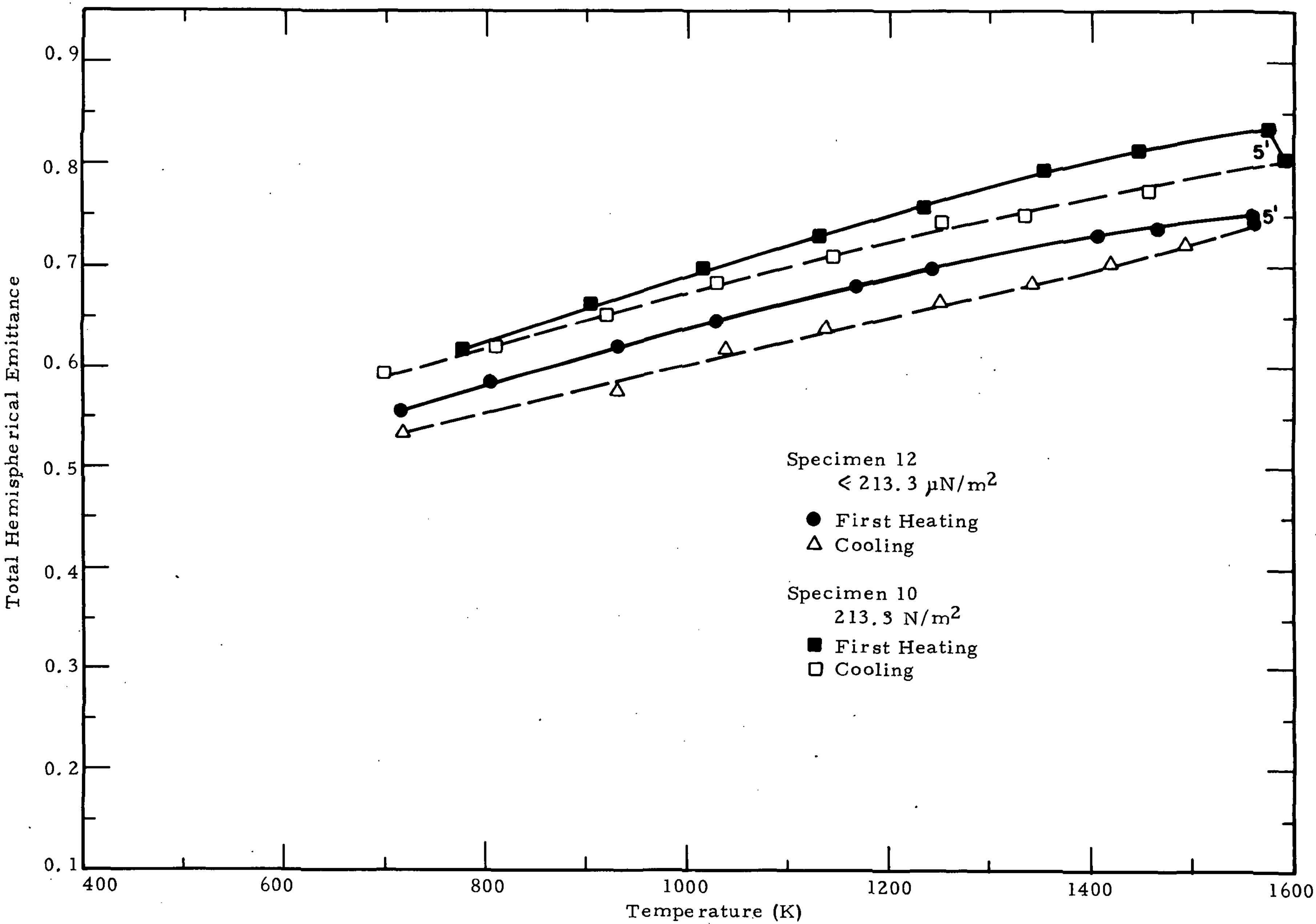


Figure 61 - TOTAL HEMISPHERICAL EMITTANCE OF TD-NiCr FOR POLISHED SURFACE OXIDIZED IN AIR FOR 0.5 HOUR AT 1311K AND AT 213.3 N/m^2 FOR 25 HOURS AT 1422K AS A FUNCTION OF TEMPERATURE AND PRESSURE

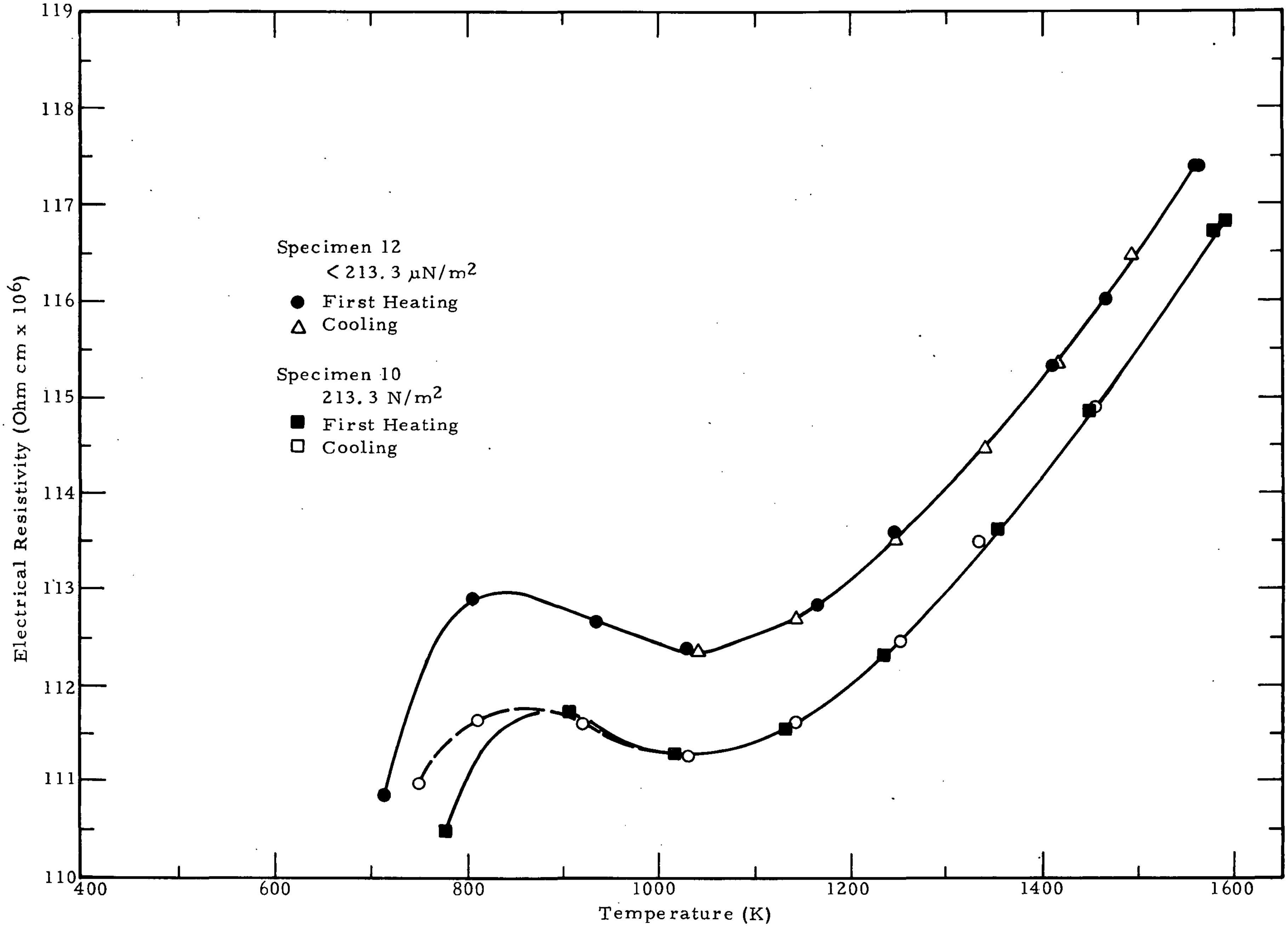


Figure 62 - ELECTRICAL RESISTIVITY OF TD-NiCr FOR POLISHED SURFACE OXIDIZED IN AIR FOR 0.5 HOUR AT 1311K AND AT 213.3 N/m^2 FOR 25 HOURS AT 1422K AS A FUNCTION OF TEMPERATURE AND PRESSURE

TASK II-3 SPECIFIC HEAT

Specific heat determinations were made using the multiproperty apparatus. The sample configuration was similar to that used for emissivity measurements with the samples of 0. 103 cm TD-NiCr, 55. 9 cm long and 0. 9525 cm wide, clamped between electrodes. One of the electrodes was movable to permit sample expansion and contraction. Voltage probes were spot-welded one inch apart in the central section of the sample. Three chromel-alumel thermocouples were attached to the sample - one between the voltage probes, one 2. 54 cm above the upper voltage probe, and the other one 2. 54 cm below the lower voltage probe.

The sample temperature was controlled by passing current through the sample from a regulated DC power supply. The power level to the sample was abruptly changed from one level to another and the resulting rate of change in sample temperature was measured. Both increased and decreased power levels (heating and cooling curves, respectively) were used in obtaining the data. The specific heat (c_p) was calculated using the equation:

$$c_p = \frac{(EI)_{final} - (EI)_{eq}}{m \, dT/dt} \qquad (9)$$

where m is the mass of the sample between the voltage probes. $(EI)_{eq}$ is the product of the voltage drop and current flow required to maintain this mass of sample at a temperature T, $(EI)_{final}$ is the product of the voltage drop and current flow associated with this sample mass at T while the sample temperature is changing at the rate of dT/dt, also measured at T. The data was recorded using an integrated digital voltmeter, crystal clock and a mini-computer system. Data as a function of time for E, I, and T at the three locations was taken during the transients and also during steady state experiments performed immediately before and after the transients. In those cases where the current level was decreased to a new level during the transient, $(EI)_{final}$ is less than $(EI)_{eq}$ and dT/dt is negative (cooling curves). In those cases where the current level was increased to a new level during the transient, $(EI)_{final}$ was greater than $(EI)_{eq}$ and dT/dt was positive (heating curves). The rate of change of temperature could be controlled by regulating the difference between $(EI)_{final}$ and $(EI)_{eq}$. Thus it was quite easy to change experimental conditions substantially and still obtain data at the same temperature. Two corrections to the raw data were made. One of these corrections is caused by the fact the thermocouples acted as miniature voltage probes in addition to acting as thermocouples (i. e., there was a small voltage added or subtracted from the normal thermal emf output). This added voltage is due to the pair of thermocouple wires not being located in exactly the same horizontal plane on the sample so that they picked up some of the voltage gradient associated with the DC heating. This offset could readily be determined by taking a series of steady state measurements with the current flow first in one direction and then reversed. The second correction arises from the finite integration time of the integrating digital voltmeter (IDVM). While the time interval between each closing of the gate on the IDVM was measured to ten microseconds using a crystal clock, each reading corresponded to the signal integrated over a specified period (usually 166.67 milliseconds). Thus when the signals were not changing linearly with time, it was necessary to employ some rather simple mathematical manipulations to relate the recorded output with the actual signals.

The results obtained on a sample of TD-NiCr are given in Table N and plotted in Figure 63. The second column of Table N gives the heating or cooling rate employed in that particular experiment. It can be seen that these rates were varied by about a factor of two at each temperature interval in order to insure a wide variety of experimental conditions. At least three separate measurements were made at each preselected temperature.

Because of chromium evolution, data on the as-received sample was not taken above 1150K. Instead, the thermocouples and voltage probes were removed and the sample oxidized by heating in air at 1366K for ten minutes. Then new voltage probes and thermocouples were attached and additional data was taken on the oxidized sample under high vacuum. Data was taken near 800 and 1100K on both the oxidized and unoxidized sample and the results are in good agreement (Table N and Figure 63). However, the sample surface was not stable enough above 1450K to obtain accurate specific heat data above this temperature so the high temperature data is not reported here.

The curve joining the data between 550 and 800K (Figure 63) is dotted to emphasize the fact that a curie transformation occurs in this region and could increase the value of the specific heat above those indicated by a smooth curve.

TABLE N

SPECIFIC HEAT OF TD-NiCr AS A FUNCTION OF TEMPERATURE

Conditions	Rate (K/sec.)	Temp. (K)	c_p (10^{-3} Joules/kg K)
Unoxidized Heating	2.925	379	0.4533
" "	3.508	332	0.4505
" "	4.319	348	0.4552
" "	1.646	313	0.4400
" "	2.632	501	0.4930
" "	4.473	529	0.4929
" "	5.250	524	0.4954
" "	3.823	810	0.5419
" "	4.781	812	0.5437
Unoxidized Cooling	2.176	810	0.5464
Unoxidized Heating	6.656	1151	0.645
" "	6.323	1151	0.677
Unoxidized Cooling	4.497	1142	0.637
Oxidized Heating	2.952	800	0.547
" "	6.544	1130	0.655
" "	11.294	1130	0.645
Oxidized Cooling	2.673	1350	0.752
Oxidized Heating	2.684	1350	0.706
" "	4.889	1350	0.715
" "	12.317	1412	0.729
" "	9.789	1414	0.753
Oxidized Cooling	6.657	1412	0.724

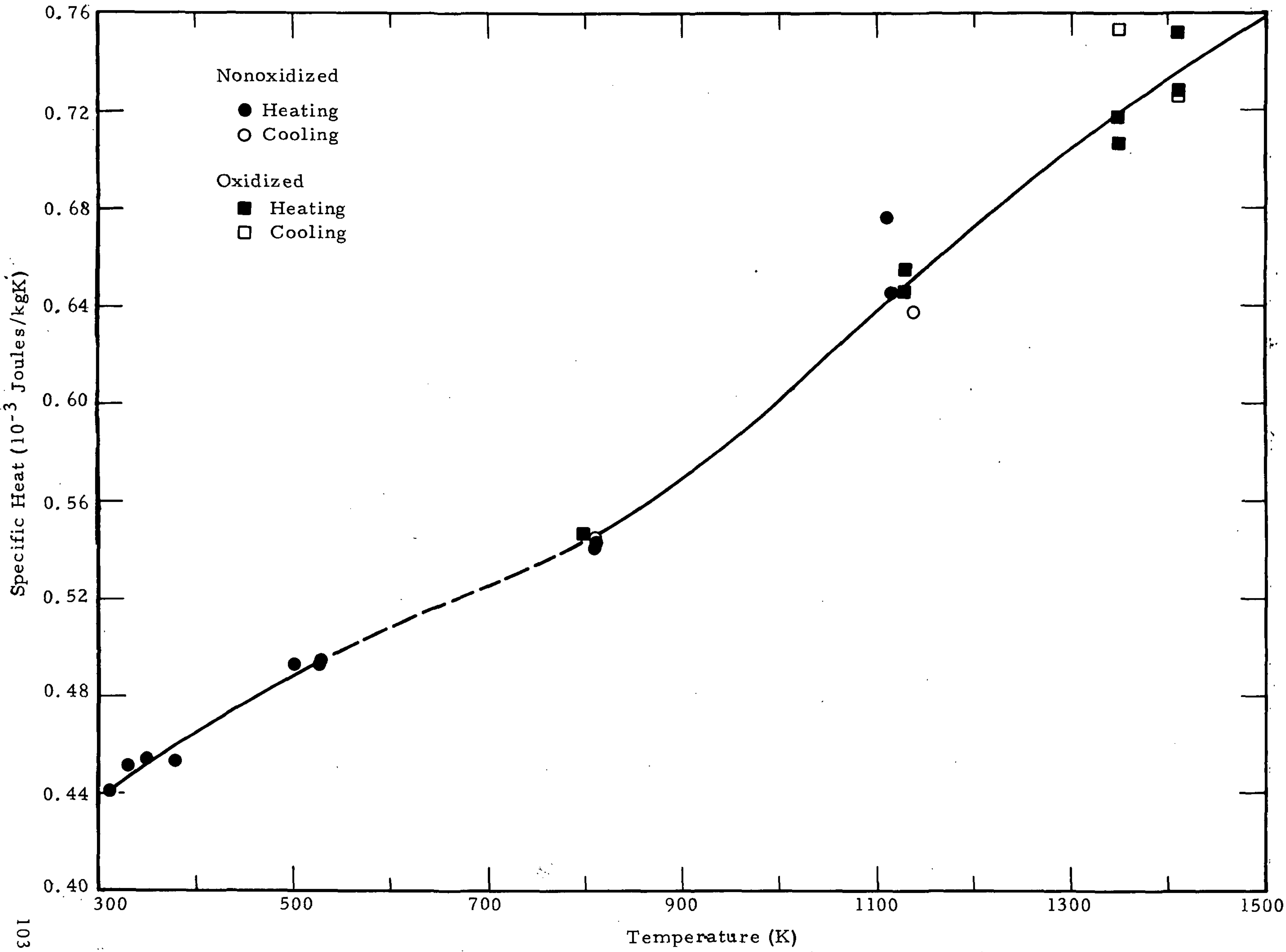


Figure 63 - SPECIFIC HEAT OF TD-NiCr AS A FUNCTION OF TEMPERATURE

TASK II-4 THERMAL CONDUCTIVITY AND THERMAL DIFFUSIVITY

Because of limitations imposed by the unfavorable surface to volume ratio of the thin specimens at low temperatures (300-900K), thermal conductivity measurements were made on TD-NiCr over this temperature range using the Kohlrausch variant of direct electrical heating methods. Although this method can be used in the multiproperty apparatus, a second apparatus, equipped specifically for this method, was employed. The data obtained using the Kohlrausch method is listed in Table O and shown in Figure 64. Heat loss corrections for the Kohlrausch method became excessive above 900K using the sample geometry available. However, the rate of heat radiated from the surface above 1000K became sufficient to utilize the normal procedures employed in the multiproperty apparatus. Thermal conductivity data was obtained from 1000 to 1200K using this apparatus. These values are also listed in Table O and shown in Figure 64. However, above 1200K the hemispherical total emittance became too unstable and nonuniform to permit accurate thermal conductivity determinations. Thus, it was not feasible to directly measure the thermal conductivity of the TD-NiCr specimens above 1200K.

Thermal conductivity values could be calculated from thermal diffusivity values over the entire temperature range from 300 to 1500K. These values are associated with the conductivity across the 0.040 in. thick specimens rather than along the specimens. However, comparisons of the conductivity values measured across the sample, parallel to the rolling direction and normal to the rolling direction, were found to be within the combined experimental error over the range where all the measurements were feasible (300-1200K). Therefore, the thermal conductivity was assumed to be isotropic and the values obtained above 1200K perpendicular to the surface were assumed to apply to the directions normal and parallel to the rolling direction.

Thermal conductivity values are calculated from diffusivity (α) values using the well-known relation $\lambda = \alpha c_p \delta$ where c_p is the specific heat and δ is the density. The density was found to be 8.375 gm $\cdot$ cm^{-3} by direct length and weight measurements.

The thermal diffusivity values were obtained using the standard laser flash technique. In this method, the front face of the sample is subjected to a momentary energy flux from a laser and the resulting temperature response of the rear face is measured. The thermal diffusivity is computed from the equation $\alpha = 0.139\ell^2/t_{1/2}$ where ℓ is the sample thickness and $t_{1/2}$ is the time required for the rear face temperature to reach one-half of its maximum rise. Because of the thin sample used, $t_{1/2}$ values were about 44 milliseconds at room temperature decreasing to 28 milliseconds at 1500K. Since the laser pulse time (0.8 milliseconds) was not negligible in comparison to $t_{1/2}$, especially at the higher temperatures, it was necessary to apply a "finite pulse time correction" following the procedure of Taylor and Cape.[Ref. 10] The maximum correction was 3%.

The diffusivity values, along with the resulting thermal conductivity values, are given in Table P. The conductivity values are included in Figure 64. Since the diffusivity and specific heat values are accurate within three and two percent, respectively, the calculated thermal conductivity values are accurate well within 5%. From the figure, it can be seen that, with only a few exceptions, all the thermal conductivity results using the three techniques can be represented within 5% by a straight line increasing from 13.1 $Wm^{-1}K^{-1}$ at 300K to 35.7 $Wm^{-1}K^{-1}$ at 1500K. The equation for thermal conductivity values of TD-NiCr is:

$$\lambda \; (W \cdot m^{-1} \cdot K^{-1}) = 7.45 + 0.018833\,T, \; (300 < T < 1500K) \qquad (10)$$

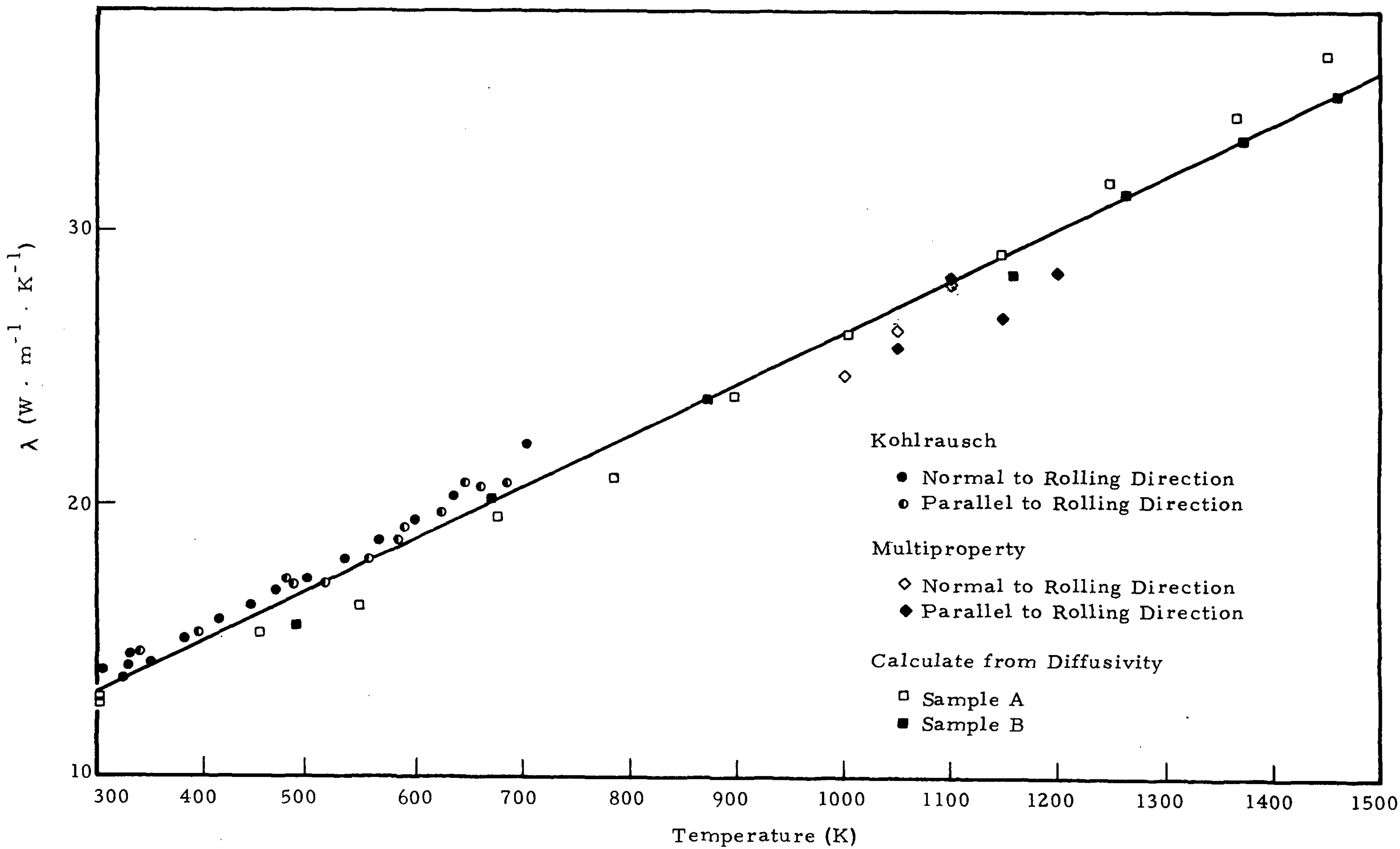


Figure 64 - THERMAL CONDUCTIVITY OF TD-NiCr AS A FUNCTION OF SHEET DIRECTION AND TEMPERATURE

TABLE O

THERMAL CONDUCTIVITY FOR TD-NiCr AS A FUNCTION OF SHEET DIRECTION AND TEMPERATURE

Method	Orientation	Specimen No.	Temp. (K)	λ ($W \cdot m^{-1} \cdot K^{-1}$)
Kohlrausch	Normal	1	303	14.0
"	"	"	320	14.2
"	"	"	334	14.5
"	"	"	303	13.0
"	"	"	324	13.6
"	"	"	351	14.2
"	"	"	384	15.1
"	"	"	416	15.8
"	"	"	446	16.4
"	"	"	468	16.8
"	"	"	497	17.3
"	"	"	532	18.0
"	"	"	565	19.5
"	"	"	635	20.3
"	"	"	667	21.0
"	"	"	702	22.3
"	"	"	305	13.4
"	"	"	329	14.1
Kohlrausch	Parallel	2	342	14.6
"	"	"	350	14.3
"	"	"	478	17.4
"	"	"	323	13.5
"	"	"	395	15.2
"	"	"	488	17.0
"	"	"	555	18.0
"	"	"	587	19.3
"	"	"	619	20.1
"	"	"	647	20.9
"	"	"	329	13.3
"	"	"	410	15.4
"	"	"	514	17.2
"	"	"	588	18.8
"	"	"	624	19.7

TABLE O (CONT.)

THERMAL CONDUCTIVITY FOR TD-NiCr AS A FUNCTION OF SHEET DIRECTION AND TEMPERATURE

Method	Orientation	Specimen No.	Temp. (K)	λ $(W \cdot m^{-1} \cdot K^{-1})$
Kohlrausch	Parallel	2	660	20.7
"	"	"	691	20.8
"	"	"	668	20.1
"	"	"	718	21.4
"	"	"	776	23.5
"	"	"	793	22.2
"	"	"	834	24.4
Multiproperty	Normal	3	1000	24.8
"	"	"	1050	26.5
"	"	"	1100	28.2
"	"	4	1050	25.8
"	"	"	1100	28.4
"	"	"	1150	27.0
"	"	"	1200	28.5

TABLE P

THERMAL DIFFUSIVITY AND THERMAL CONDUCTIVITY FOR TD-NiCr AS A FUNCTION OF TEMPERATURE

Specimen No.	$\alpha (cm^2 \cdot sec^{-1})$	$c_p (J \cdot gm^{-1} \cdot K^{-1})$	Temp. (K)	λ* $(W \cdot m^{-1} \cdot K^{-1})$
A	0.03415	0.439	300	12.6
"	0.03430	0.439	300	12.7
"	0.03819	0.477	450	15.3
"	0.03915	0.498	544	16.3
"	0.04482	0.522	675	19.6
"	0.04615	0.542	783	21.0
"	0.05068	0.566	897	24.0
"	0.05239	0.600	1003	26.3
"	0.05329	0.656	1148	29.3
"	0.05519	0.689	1250	31.8
"	0.05619	0.726	1368	34.2
"	0.05830	0.748	1455	36.5
B	0.03518	0.438	295	12.9
"	0.03809	0.485	485	15.5
"	0.04670	0.520	667	20.3
"	0.05108	0.559	868	23.9
"	0.05152	0.658	1157	28.4
"	0.05432	0.693	1265	31.5
"	0.05500	0.725	1370	33.4
"	0.05587	0.748	1460	35.0

* $\lambda = 10^2 \alpha \ c_p \sigma$, where $\sigma = 8.375 \ gm/cm^3$

SUMMARY OF RESULTS

To obtain design data necessary for the use of thin sheet TD-NiCr, the mechanical properties of two heats each of 0.025 and 0.051 cm thick sheet were characterized. Ten mechanical properties were measured over the temperature range from ambient to 1589K on specimens taken, in general, parallel and normal to the sheet rolling direction. These tests indicated that the mechanical properties were dependent both on the sheet thickness and test direction. Usually the 0.051 cm thick sheet was stronger than the 0.025 cm thick sheet, and the strength of specimens taken parallel to the sheet rolling direction was, in general, greater than the strength of specimens taken normal to the rolling direction. For either sheet thickness (0.025 or 0.051 cm), the heat-to-heat variations in mechanical properties were usually small.

With regard to the actual mechanical property measurements, several interesting observations were made:

a) Thin sheet TD-NiCr has, in general, little tensile ductility at elevated temperatures ($T \geq 922K$).

b) The severe microstructural damage observed in many creep-rupture tested TD-NiCr specimens may limit the usefulness of the creep-rupture data.

c) The stresses necessary to produce 0.1 and 0.2% creep in 100 hours were similar.

d) TD-NiCr does not appear to be notch sensitive.

Additionally, physical properties were studied as a function of temperature to obtain design data. Physical properties were measured on one heat of 0.103 cm sheet. These properties were found to be independent of testing direction. For example, linear thermal expansion and thermal conductivity were found to be essentially equal for specimens taken parallel or normal to the sheet rolling direction. Total hemispherical emittance was found to be quite dependent on the surface conditions as unoxidized surfaces tended to have unstable emittances while oxidized specimens exhibited much more stable emittances.

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APPENDIX A

TENSILE DATA ANALYSIS

For each heat, temperature, and orientation with respect to the rolling direction, the three measurements (where available) of

- ultimate tensile strength
- 0.02% tensile yield strength
- 0.2% tensile yield strength
- elongation

were treated by a statistical analysis to determine mean values and 90 and 95% confidence limits about the means.

Because the observed fluctuations in the measurements of each property arise as the sums of a large number of independent contributions, the central limit theorem justifies the assumption that they are normally distributed. In this case, $1-\alpha$ confidence limits on the mean $\bar{x}$ are given by:

$$\bar{x} \pm t_{1-\alpha/2,\ n-1} \frac{s}{\sqrt{n}} \qquad (11)$$

where s is the square root of the sample variance:

$$s^2 = \frac{1}{n-1} \sum_i (x_i - \bar{x})^2 \qquad (12)$$

where $t_{1-\alpha/2,\ n-1}$ is the $1-\alpha/2$ percentage point of the t distribution having n-1 degrees of freedom, and n is the number of measurements.

A similar data analysis program was used for evaluating the bearing and compression test data and Poisson's Ratio.

APPENDIX B

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

TABLE 1

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3636

Temperature: 297K   Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-D-1-14	Parallel		891.5	486.3	635.4	12.0
T-D-2-52			942.6	488.1	621.4	16.1
T-D-4-59			920.4	513.7	610.7	16.1
		Avg.	918.2	496.0	622.5	14.7
		90% C. L. (±)	43.2	25.8	20.9	4.0
		95% C. L. (±)	63.6	38.1	30.7	5.9
T-D-1-10	Normal		865.1	511.7	593.8	20.6
T-D-2-15			828.8	469.3	559.5	21.9
T-D-4-33			845.1	471.7	565.6	20.0
		Avg.	846.3	484.2	573.0	20.8
		90% C. L. (±)	30.7	40.1	30.9	1.6
		95% C. L. (±)	45.2	59.2	45.5	2.4
T-D-4-21	45°		846.3	534.5	607.3	15.7
T-D-4-16			832.8	491.1	603.1	13.6
T-D-4-15			811.7	497.2	593.3	12.2
		Avg.	830.3	507.6	601.2	13.8
		90% C. L. (±)	29.5	39.6	12.1	3.0
		95% C. L. (±)	43.4	58.4	17.9	4.4

TABLE 2

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3636

Temperature: 922K   Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-D-1-34	Parallel		404.3	279.6	349.2	7.1
T-D-3-14			438.4	278.7	364.3	7.5
T-D-5-2			390.0	266.3	353.3	8.6
		Avg.	410.9	274.9	355.6	7.7
		90% C. L. (±)	41.9	12.5	13.1	1.3
		95% C. L. (±)	61.8	18.4	19.4	1.9
T-D-1-26	Normal		339.9	277.2	322.5	5.2
T-D-2-30			360.5	282.5	330.8	8.0
T-D-3-55			375.6	290.7	328.6	7.4
		Avg.	358.7	283.5	327.3	6.9
		90% C. L. (±)	30.3	11.4	7.2	2.5
		95% C. L. (±)	44.6	16.8	10.6	3.7
T-D-1-4	45°		378.2	303.2	351.1	6.6
T-D-3-3			312.9	263.6	312.9	4.6
T-D-4-22			349.3	291.1	333.3	3.2
		Avg.	346.8	286.0	332.4	4.8
		90% C. L. (±)	55.2	34.2	32.2	2.9
		95% C. L. (±)	81.3	50.5	47.4	4.2

TABLE 3

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3636

Temperature: 1144K   Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-D-1-52	Parallel		202.9	171.7	186.4	2.5
T-D-3-33			212.3	187.0	197.1	2.8
T-D-5-13			196.5	--	--	1.8
		Avg.	203.9	179.3	191.8	2.4
		90% C. L. (±)	13.4	--	--	0.9
		95% C. L. (±)	19.7	--	--	1.3
T-D-1-32	Normal		190.0	161.8	189.2	0.9
T-D-2-40			187.2	170.1	185.8	1.3
T-D-3-64			180.6	118.9	178.4	0.9
		Avg.	185.9	150.3	184.5	1.0
		90% C. L. (±)	8.1	46.3	--	0.4
		95% C. L. (±)	11.9	68.2	--	0.6
T-D-1-20	45°		197.1	181.0	197.1	2.1
T-D-3-4			204.7	195.6	204.7	1.9
T-D-4-31			202.3	186.4	195.9	1.5
		Avg.	201.4	187.7	199.2	1.8
		90% C. L. (±)	6.5	12.4	8.0	0.5
		95% C. L. (±)	9.6	18.3	11.8	0.8

TABLE 4

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3636

Temperature: 1255K   Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-D-2-1	Parallel		149.1	132.1	149.1	0.9
T-D-3-58			156.1	138.9	155.4	1.4
T-D-5-21			158.3	151.9	158.3	1.5
		Avg.	154.5	141.0	154.3	1.3
		90% C. L. (±)	8.1	17.0	7.9	0.5
		95% C. L. (±)	11.9	25.1	11.7	0.8
T-D-1-38	Normal		142.1	134.2	--	0.7
T-D-3-10			145.8	143.0	--	0.8
T-D-4-24			141.0	135.2	--	0.8
		Avg.	143.0	137.5	--	0.8
		90% C. L. (±)	4.2	8.1	--	0.1
		95% C. L. (±)	6.2	12.0	--	0.1
T-D-1-21	45°		148.3	143.9	--	0.9
T-D-2-46			144.6	139.0	--	0.9
T-D-4-32			158.5	154.5	--	0.7
		Avg.	150.5	145.8	--	0.8
		90% C. L. (±)	12.2	13.4	--	0.2
		95% C. L. (±)	18.0	19.7	--	0.3

TABLE 5

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3636

Temperature: 1366K   Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-D-2-12	Parallel		126.8	110.9	--	0.9
T-D-4-2			125.8	107.7	125.8	0.9
T-D-5-30			127.1	118.6	127.1	1.1
		Avg.	126.6	112.4	126.5	1.0
		90% C. L. (±)	1.2	9.5	4.3	0.2
		95% C. L. (±)	1.8	13.9	8.6	0.3
T-D-1-48	Normal		108.2	96.5	--	0.5
T-D-3-31			107.8	104.4	--	0.7
T-D-5-34			110.5	106.6	110.5	0.7
		Avg.	108.8	102.5	--	0.6
		90% C. L. (±)	2.5	8.9	--	0.2
		95% C. L. (±)	3.7	13.1	--	0.3
T-D-2-6	45°		112.6	108.5	--	0.7
T-D-3-21			121.4	111.0	121.4	1.1
T-D-5-8			127.1	109.8	--	1.0
		Avg.	120.4	109.8	--	0.9
		90% C. L. (±)	12.3	2.1	--	0.4
		95% C. L. (±)	18.2	3.1	--	0.5

TABLE 6

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3636

Temperature: 1477K **Thickness:** 0.051 cm

Specimen No.	Specimen Direction		U.T.S. (MN/m^2)	0.02% Y.S. (MN/m^2)	0.2% Y.S. (MN/m^2)	Elongation (%)
T-D-2-22	Parallel		98.2	--	--	0.8
T-D-4-11			104.6	89.3	104.6	1.0
T-D-5-40			105.6	90.7	105.6	1.0
		Avg.	102.8	90.0	105.1	0.9
		90% C.L. (±)	6.8	--	--	0.2
		95% C.L. (±)	10.0	--	--	0.3
T-D-1-58	Normal		82.1	79.4	--	0.7
T-D-3-37			84.1	79.8	--	0.7
T-D-4-45			84.8	82.0	--	1.0
		Avg.	83.7	80.4	--	0.8
		90% C.L. (±)	2.4	2.3	--	0.3
		95% C.L. (±)	3.5	3.4	--	0.4
T-D-2-7	45°		89.8	--	--	0.9
T-D-1-3			91.2	90.6	--	0.8
T-D-5-16			99.8	86.8	--	0.8
		Avg.	93.6	88.7	--	0.8
		90% C.L. (±)	9.1	--	--	0.1
		95% C.L. (±)	13.4	--	--	0.1

TABLE 7

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3636

Temperature: 1589K **Thickness:** 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-D-2-34	Parallel		76.3	74.2	--	0.6
T-D-5-39			88.5	--	--	0.5
T-D-5-11			85.5	75.7	--	1.1
		Avg.	83.4	75.0	--	0.7
		90% C. L. (±)	10.6	4.8	--	0.5
		95% C. L. (±)	15.7	9.7	--	0.8
T-D-1-65	Normal		59.9	57.2	--	0.8
T-D-4-63			68.3	66.9	--	0.6
T-D-4-52			69.6	63.0	--	0.5
		Avg.	65.9	62.4	--	0.6
		90% C. L. (±)	8.8	8.3	--	0.3
		95% C. L. (±)	13.0	12.2	--	0.4
T-D-2-47	45°		73.1	--	--	0.6
T-D-5-48			76.8	62.9	--	0.8
		Avg.	75.0	--	--	0.7
		90% C. L. (±)	11.5	--	--	0.6
		95% C. L. (±)	23.2	--	--	1.3

TABLE 8

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3637

Temperature: 297K Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-G-1-1	Parallel		876.5	539.7	662.1	10.0
T-G-4-25			861.9	526.7	656.0	9.2
T-G-6-25			856.1	569.3	679.6	6.0
		Avg.	864.8	545.2	665.9	8.4
		90% C. L. (±)	17.7	36.7	20.6	3.6
		95% C. L. (±)	26.1	54.1	30.4	5.3
T-G-1-4	Normal		806.0	439.9	670.8	13.7
T-G-4-19			781.6	482.6	601.2	7.0
T-G-6-31			813.7	502.7	607.3	13.2
		Avg.	800.4	475.1	626.4	11.3
		90% C. L. (±)	28.3	54.1	64.9	6.3
		95% C. L. (±)	41.6	79.7	95.7	9.3
T-G-1-32	45°		839.5	502.2	625.1	12.4
T-G-4-7			787.2	523.0	623.4	8.7
T-G-6-29			845.5	584.4	655.6	11.7
		Avg.	824.1	536.5	634.7	10.9
		90% C. L. (±)	54.1	72.1	30.5	3.3
		95% C. L. (±)	79.7	106.2	45.0	4.9

TABLE 9

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3637

Temperature: 922K Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-G-2-29	Parallel		385.2	342.5	385.2	0.8
T-G-5-19			354.5	245.6	337.8	0.7
T-G-3-34			329.6	--	--	0.5
		Avg.	356.5	294.1	361.5	0.7
		90% C. L. (±)	46.9	--	--	0.3
		95% C. L. (±)	69.2	--	--	0.4
T-G-5-31	Normal		336.3	327.9	--	0.5
T-G-6-11			377.8	340.0	377.8	0.5
T-G-7-23			323.7	291.2	--	0.5
		Avg.	345.9	319.7	--	0.5
		90% C. L. (±)	47.7	42.8	--	--
		95% C. L. (±)	70.3	63.1	--	--
T-G-2-9	45°		377.6	288.4	--	0.5
T-G-2-25			380.3	321.8	378.9	0.5
T-G-5-44			369.2	296.5	--	0.7
		Avg.	375.7	302.2	--	0.6
		90% C. L. (±)	9.7	29.4	--	0.2
		95% C. L. (±)	14.3	43.3	--	0.3

TABLE 10

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3637

Temperature: 1144K   Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-G-2-4	Parallel		189.2	159.5	189.2	1.1
T-G-5-14			191.9	154.8	191.9	0.8
T-G-7-28			164.4	144.4	164.4	0.6
		Avg.	181.8	152.9	181.8	0.8
		90% C. L. (±)	25.5	13.1	25.5	0.4
		95% C. L. (±)	37.6	19.2	37.6	0.6
T-G-2-12	Normal		185.5	165.5	--	0.6
T-G-5-11			162.0	155.1	--	0.4
T-G-7-9			147.1	137.6	--	0.2
		Avg.	164.9	152.7	--	0.4
		90% C. L. (±)	32.6	23.7	--	0.3
		95% C. L. (±)	48.1	35.0	--	0.5
T-G-2-8	45°		194.3	169.2	--	0.7
T-G-5-16			177.2	149.5	--	0.3
T-G-7-29			159.9	121.7	159.9	0.4
		Avg.	177.1	146.8	--	0.5
		90% C. L. (±)	29.0	40.3	--	0.4
		95% C. L. (±)	42.7	59.3	--	0.5

TABLE 11

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3637

Temperature: 1255K Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-G-3-8	Parallel		119.5	119.5	--	0.5
T-G-4-32			127.2	114.8	--	0.7
T-G-5-28			138.4	117.8	138.4	0.4
		Avg.	128.4	117.3	--	0.5
		90% C. L. ($\pm$)	16.1	4.0	--	0.3
		95% C. L. ($\pm$)	23.7	5.9	--	0.4
T-G-3-26	Normal		138.1	125.9	--	0.4
T-G-4-42			92.9	89.2	--	0.3
T-G-7-3			130.3	--	--	0.5
		Avg.	120.4	107.5	--	0.4
		90% C. L. ($\pm$)	40.7	--	--	0.2
		95% C. L. ($\pm$)	60.0	--	--	0.2
T-G-1-34	45°		134.3	131.7	--	0.5
T-G-4-23			130.3	--	--	0.4
T-G-7-14			124.9	109.3	--	0.6
		Avg.	129.8	120.5	--	0.5
		90% C. L. ($\pm$)	8.0	--	--	0.2
		95% C. L. ($\pm$)	11.8	--	--	0.2

TABLE 12

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3637

Temperature: 1366K   Thickness: 0.025 cm

Specimen No.	Specimen Direction		U.T.S. (MN/m^2)	0.02% Y.S. (MN/m^2)	0.2% Y.S. (MN/m^2)	Elongation (%)
T-G-1-26	Parallel		91.6	83.9	--	0.6
T-G-4-27			83.4	--	--	0.4
T-G-7-17			97.6	75.7	97.6	0.5
		Avg.	90.8	79.8	--	0.5
		90% C.L. (±)	12.0	--	--	0.2
		95% C.L. (±)	17.7	--	--	0.2
T-G-3-2	Normal		97.0	96.2	--	0.4
T-G-5-38			104.6	86.4	--	0.4
T-G-8-1			82.6	73.1	--	0.4
		Avg.	94.7	85.2	--	0.4
		90% C.L. (±)	18.8	19.5	--	--
		95% C.L. (±)	27.8	28.8	--	--
T-G-3-19	45°		100.9	77.2	--	0.4
T-G-5-45			107.1	82.6	--	0.6
T-G-8-16			98.8	78.4	--	0.6
		Avg.	102.3	79.4	--	0.5
		90% C.L. (±)	7.2	4.8	--	0.2
		95% C.L. (±)	10.7	7.0	--	0.3

TABLE 13

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3637

Temperature: 1477K Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-G-3-12	Parallel		70.9	--	--	0.4
T-G-6-7			87.7	78.9	--	0.8
T-G-8-10			83.4	83.0	--	0.4
		Avg.	80.6	81.0	--	0.5
		90% C. L. (±)	14.7	12.7	--	0.4
		95% C. L. (±)	21.6	25.6	--	0.6
T-G-4-2	Normal		75.8	71.5	--	--
T-G-6-21			71.9	--	--	1.1
T-G-8-21			66.5	--	--	0.7
		Avg.	71.4	--	--	0.9
		90% C. L. (±)	7.9	--	--	1.3
		95% C. L. (±)	11.6	--	--	2.5
T-G-3-22	45°		78.8	75.8	--	0.7
T-G-6-1			80.7	78.3	--	--
T-G-8-17			87.3	76.3	--	0.4
		Avg.	82.3	76.8	--	0.6
		90% C. L. (±)	7.6	2.2	--	0.9
		95% C. L. (±)	11.2	3.3	--	1.9

TABLE 14

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3637

Temperature: 1589K Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-G-6-39	Parallel		59.2	--	--	0.7
T-G-8-25			69.8	--	--	0.5
T-G-5-2			68.0	43.9	--	0.8
		Avg.	65.7	--	--	0.7
		90% C. L. ($\pm$)	9.5	--	--	0.3
		95% C. L. ($\pm$)	14.1	--	--	0.4
T-G-7-11	Normal		58.5	48.8	--	0.5
T-G-8-38			47.5	47.5	--	0.5
T-G-3-4			53.2	53.2	--	0.3
		Avg.	53.0	49.8	--	0.4
		90% C. L. ($\pm$)	9.3	5.0	--	0.2
		95% C. L. ($\pm$)	13.7	7.4	--	0.3
T-G-4-6	45°		63.4	51.1	--	0.8
T-G-6-2			65.6	54.7	--	0.5
T-G-8-31			61.9	59.8	--	0.3
		Avg.	63.7	55.2	--	0.5
		90% C. L. ($\pm$)	3.1	7.4	--	0.4
		95% C. L. ($\pm$)	4.6	10.9	--	0.6

TABLE 15

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3697

Temperature: 297K   Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-H-1-38	Parallel		846.2	570.2	634.0	9.8
T-H-2-20			802.4	463.6	566.5	9.5
T-H-4-41			840.0	542.8	632.0	9.9
		Avg.	829.6	525.5	610.8	9.7
		90% C. L. (±)	40.0	93.3	64.7	0.4
		95% C. L. (±)	58.9	137.5	95.4	0.5
T-H-1-32	Normal		729.6	516.3	567.8	14.7
T-H-2-34			714.0	444.6	521.5	17.9
T-H-4-31			750.6	516.2	570.6	18.3
		Avg.	731.4	492.4	553.3	17.0
		90% C. L. (±)	31.0	69.8	46.4	3.3
		95% C. L. (±)	45.6	102.8	68.4	4.9
T-H-1-9	45°		725.3	525.4	590.2	8.3
T-H-2-46			759.2	494.5	558.7	14.6
T-H-4-37			721.6	543.6	600.7	7.1
		Avg.	735.4	521.1	583.2	10.0
		90% C. L. (±)	34.9	41.8	36.8	6.8
		95% C. L. (±)	51.4	61.6	54.3	10.0

TABLE 16

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3697

Temperature: 922K   Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-H-1-48	Parallel		409.4	330.2	399.1	0.8
T-H-3-31			376.2	282.5	356.0	0.9
T-H-5-14			358.9	328.7	359.6	0.7
		Avg.	381.5	313.8	371.6	0.8
		90% C. L. (±)	43.3	45.8	40.3	0.2
		95% C. L. (±)	63.9	67.5	59.4	0.2
T-H-1-40	Normal		343.7	330.4	--	0.4
T-H-3-38			333.7	281.7	333.7	0.9
T-H-5-21			327.9	--	--	0.3
		Avg.	335.1	306.0	--	0.5
		90% C. L. (±)	13.5	--	--	0.5
		95% C. L. (±)	19.9	--	--	0.8
T-H-1-55	45°		350.4	313.5	350.4	0.8
T-H-5-8			365.5	307.0	365.5	0.6
T-H-4-36			379.8	331.3	376.3	1.1
		Avg.	365.2	317.3	364.1	0.8
		90% C. L. (±)	24.7	21.2	21.9	0.4
		95% C. L. (±)	36.5	31.2	32.3	0.6

TABLE 17

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3697

Temperature: 1144K **Thickness:** 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-H-1-24	Parallel		172.0	146.8	--	1.4
T-H-3-23			159.9	--	--	0.9
T-H-5-10			145.7	145.7	--	0.5
		Avg.	159.2	146.3	--	0.9
		90% C. L. ($\pm$)	22.2	3.7	--	0.8
		95% C. L. ($\pm$)	32.8	7.5	--	1.1
T-H-	Normal					
T-H-3-30			138.7	--	--	0.3
T-H-5-2			158.1	--	--	0.4
		Avg.	148.4	--	--	0.4
		90% C. L. ($\pm$)	61.3	--	--	0.3
		95% C. L. ($\pm$)	123.3	--	--	0.6
T-H-1-18	45°		153.2	--	--	0.5
T-H-3-41			133.2	115.8	--	0.4
T-H-5-7			141.8	120.0	--	1.0
		Avg.	142.7	117.9	--	0.6
		90% C. L. ($\pm$)	16.9	13.0	--	0.5
		95% C. L. ($\pm$)	25.0	26.2	--	0.8

TABLE 18

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3697

Temperature: 1255K   Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-H-1-26	Parallel		123.8	123.8	--	0.6
T-H-4-48			112.7	--	--	0.4
T-H-2-42			113.8	113.8	--	1.3
		Avg.	116.7	118.8	--	0.8
		90% C. L. (±)	10.3	--	--	0.8
		95% C. L. (±)	15.2	--	--	1.2
T-H-1-23	Normal		96.5	--	--	0.3
T-H-3-16			113.4	113.4	--	0.6
T-H-5-47			112.7	--	--	0.3
		Avg.	107.5	--	--	0.4
		90% C. L. (±)	16.1	--	--	0.3
		95% C. L. (±)	23.7	--	--	0.4
T-H-1-17	45°		104.3	--	--	0.2
T-H-3-4			101.3	--	--	0.5
T-H-4-44			117.4	117.4	--	0.3
		Avg.	107.7	--	--	0.3
		90% C. L. (±)	14.4	--	--	0.3
		95% C. L. (±)	21.2	--	--	0.4

TABLE 19

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3697

Temperature: 1366K Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-H-2-9	Parallel		87.8	85.6	--	0.7
T-H-3-55			110.1	100.0	--	0.9
T-H-5-18			99.0	--	--	0.5
		Avg.	99.0	92.8	--	0.7
		90% C. L. (±)	18.8	--	--	0.3
		95% C. L. (±)	27.8	--	--	0.5
T-H-2-2	Normal		70.3	--	--	0.3
T-H-3-44			59.5	--	--	0.4
T-H-5-32			53.8	--	--	0.5
		Avg.	61.2	--	--	0.4
		90% C. L. (±)	14.1	--	--	0.2
		95% C. L. (±)	20.8	--	--	0.2
T-H-2-30	45°		75.7	--	--	0.7
T-H-3-50			78.8	--	--	0.4
T-H-5-25			82.6	--	--	0.7
		Avg.	79.0	--	--	0.6
		90% C. L. (±)	5.8	--	--	0.3
		95% C. L. (±)	8.6	--	--	0.4

TABLE 20

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3697

Temperature: 1477K Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-H-4-6	Parallel		70.5	--	--	0.6
T-H-5-35			71.2	--	--	0.1
T-H-4-14			87.4	85.5	--	0.1
		Avg.	76.4	--	--	0.3
		90% C. L. (±)	16.1	--	--	0.5
		95% C. L. (±)	23.8	--	--	0.7
T-H-2-16	Normal		59.9	--	--	0.8
T-H-4-1			62.7	--	--	0.3
T-H-5-41			59.0	--	--	0.1
		Avg.	60.6	--	--	0.4
		90% C. L. (±)	3.3	--	--	0.6
		95% C. L. (±)	4.8	--	--	0.9
T-H-2-36	45°		59.6	--	--	0.2
T-H-4-12			73.6	61.7	--	0.5
T-H-5-46			55.5	--	--	0.3
		Avg.	62.9	--	--	0.3
		90% C. L. (±)	15.9	--	--	0.3
		95% C. L. (±)	23.5	--	--	0.4

TABLE 21

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3697

Temperature: 1589K Thickness: 0.025 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-H-2-39	Parallel		54.8	53.4	--	0.5
T-H-5-52			65.7	--	--	0.2
T-H-3-14			62.4	59.8	--	0.5
		Avg.	61.0	56.6	--	0.4
		90% C. L. (±)	9.4	20.2	--	0.3
		95% C. L. (±)	13.9	40.6	--	0.4
T-H-2-24	Normal		48.4	42.2	--	0.3
T-H-4-20			44.5	44.5	--	0.2
T-H-5-48			42.7	35.1	--	0.4
		Avg.	45.2	40.6	--	0.3
		90% C. L. (±)	4.9	8.3	--	0.2
		95% C. L. (±)	7.2	12.2	--	0.2
T-H-2-37	45°		46.8	--	--	0.4
T-H-3-42			53.9	--	--	0.3
T-H-5-26			44.2	--	--	0.3
		Avg.	48.3	--	--	0.3
		90% C. L. (±)	8.4	--	--	0.1
		95% C. L. (±)	12.4	--	--	0.1

TABLE 22

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3712

Temperature: 297K Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-J-1-66	Parallel		877.1	479.8	567.2	15.3
T-J-3-33			877.0	465.1	554.4	19.0
T-J-5-17			861.6	470.8	557.0	14.9
		Avg.	871.9	471.9	559.5	16.4
		90% C. L. (±)	15.1	12.5	11.4	3.8
		95% C. L. (±)	22.2	18.5	16.7	5.6
T-J-1-10	Normal		799.6	427.6	520.2	20.6
T-J-3-3			795.1	442.8	513.6	21.5
T-J-4-21			807.5	438.8	524.0	22.8
		Avg.	800.7	436.4	519.3	21.6
		90% C. L. (±)	10.7	13.3	8.8	1.9
		95% C. L. (±)	15.7	19.6	13.0	2.7
T-J-1-1	45°		782.3	469.7	550.7	12.8
T-J-3-10			795.8	468.9	537.9	21.1
T-J-7-10			782.3	477.9	544.7	15.3
		Avg.	786.8	472.2	544.4	16.4
		90% C. L. (±)	13.1	8.5	10.8	7.2
		95% C. L. (±)	19.3	12.5	15.9	10.6

TABLE 23

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3712

Temperature: 922K Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-J-2-10	Parallel		339.7	253.4	317.0	2.9
T-J-6-10			301.9	267.7	287.7	3.2
T-J-8-14			326.1	297.5	320.9	2.0
		Avg.	322.6	272.9	308.5	2.7
		90% C. L. (±)	32.2	37.9	30.6	1.1
		95% C. L. (±)	47.5	55.9	45.1	1.6
T-J-2-19	Normal		263.2	230.5	255.2	1.3
T-J-3-30			286.3	251.3	284.9	1.4
T-J-5-27			293.3	241.8	287.4	1.3
		Avg.	280.9	241.2	275.8	1.3
		90% C. L. (±)	26.6	17.6	30.2	0.1
		95% C. L. (±)	39.1	25.9	44.5	0.1
T-J-2-12	45°		319.0	263.8	306.1	1.8
T-J-4-19			300.9	265.1	298.9	1.7
T-J-6-3			298.5	267.9	297.0	1.5
		Avg.	306.1	265.6	300.7	1.7
		90% C. L. (±)	18.9	3.5	8.0	0.3
		95% C. L. (±)	27.9	5.2	11.8	0.4

TABLE 24

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3712

Temperature: 1144K Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-J-1-39	Parallel		157.3	136.9	157.3	0.9
T-J-4-15			182.0	141.4	179.4	1.7
T-J-6-8			174.9	140.7	172.2	2.3
		Avg.	171.4	139.7	169.6	1.6
		90% C. L. ($\pm$)	21.4	4.1	18.9	1.2
		95% C. L. ($\pm$)	31.5	6.0	27.9	1.7
T-J-1-34	Normal		142.1	127.9	142.1	0.8
T-J-3-27			158.5	148.6	158.5	1.6
T-J-5-13			174.7	159.7	174.7	0.8
		Avg.	158.5	145.4	158.4	1.1
		90% C. L. ($\pm$)	27.5	27.2	27.5	0.8
		95% C. L. ($\pm$)	40.5	40.1	40.5	1.1
T-J-4-19	45°		164.3	153.8	164.3	1.0
T-J-4-10			166.7	154.7	166.7	1.0
T-J-5-5			179.8	165.0	178.1	1.0
		Avg.	170.3	157.8	169.7	1.0
		90% C. L. ($\pm$)	14.1	10.5	12.4	--
		95% C. L. ($\pm$)	20.7	15.4	18.2	--

TABLE 25

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3712

Temperature: 1255K Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-J-1-29	Parallel		146.8	141.6	--	0.8
T-J-4-7			150.4	123.0	149.7	1.1
		Average	148.6	132.3	--	1.0
		90% C. L. ($\pm$)	11.3	58.6	--	0.9
		95% C. L. ($\pm$)	22.7	117.9	--	1.9
T-J-1-15	Normal		123.8	116.0	--	0.8
T-J-2-25			136.6	119.4	136.6	0.8
T-J-6-31			133.0	129.8	--	0.7
		Average	131.1	121.7	--	0.8
		90% C. L. ($\pm$)	--	--	--	0.1
		95% C. L. ($\pm$)	--	--	--	0.1
T-J-1-2	45°		147.0	122.1	--	1.0
T-J-3-37			144.5	143.6	--	1.0
T-J-5-21			149.1	140.9	--	0.8
		Average	146.9	135.5	--	0.9
		90% C. L. ($\pm$)	3.8	19.7	--	0.2
		95% C. L. ($\pm$)	5.6	29.0	--	0.3

TABLE 26

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3712

Temperature: 1366K Thickness: 0.051 cm

Specimen No.	Specimen Direction		U.T.S. (MN/m^2)	0.02% Y.S. (MN/m^2)	0.2% Y.S. (MN/m^2)	Elongation (%)
T-J-2-7	Parallel		126.2	99.3	125.6	1.1
T-J-2-17			129.7	93.6	128.7	0.9
T-J-7-7			126.9	107.1	126.9	0.9
		Avg.	127.6	100.0	127.1	1.0
		90% C.L. (±)	3.1	11.5	2.6	0.2
		95% C.L. (±)	4.6	16.9	3.8	0.3
T-J-2-23	Normal		98.5	96.3	--	0.9
T-J-6-5			101.9	92.6	--	0.5
T-J-8-17			104.8	81.6	--	0.7
		Avg.	101.7	90.2	--	0.7
		90% C.L. (±)	5.3	12.9	--	0.3
		95% C.L. (±)	7.8	19.0	--	0.5
T-J-2-13	45°		115.1	--	--	0.9
T-J-2-30			110.6	104.7	--	0.3
T-J-8-20			113.4	108.4	--	0.7
		Avg.	113.0	106.6	--	0.6
		90% C.L. (±)	3.9	11.6	--	0.5
		95% C.L. (±)	5.7	23.3	--	0.8

TABLE 27

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3712

Temperature: 1477K   Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-J-3-16	Parallel		99.6	82.1	--	1.1
T-J-4-32			99.9	88.6	--	1.0
T-J-6-16			95.1	--	--	1.0
		Avg.	98.2	85.3	--	1.0
		90% C. L. (±)	4.5	--	--	0.1
		95% C. L. (±)	6.6	--	--	0.1
T-J-2-27	Normal		86.1	85.4	--	1.0
T-J-4-3			70.5	70.5	--	1.0
T-J-7-2			84.2	--	--	1.1
		Avg.	80.3	77.9	--	1.0
		90% C. L. (±)	14.4	--	--	0.1
		95% C. L. (±)	21.2	--	--	0.1
T-J-3-9	45°		94.9	94.3	--	1.0
T-J-4-24			89.5	88.1	--	0.8
T-J-8-1			98.5	93.8	--	0.8
		Avg.	94.3	92.1	--	0.9
		90% C. L. (±)	7.7	5.8	--	0.2
		95% C. L. (±)	11.3	8.5	--	0.3

TABLE 28

TENSILE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat No. 3712

Temperature: 1589K Thickness: 0.051 cm

Specimen No.	Specimen Direction		U. T. S. (MN/m^2)	0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)	Elongation (%)
T-J-3-19	Parallel		79.7	72.1	--	0.5
T-J-5-3			83.4	82.4	--	0.6
T-J-7-13			79.4	77.3	--	0.8
		Average	80.9	77.3	--	0.6
		90% C. L. ($\pm$)	3.8	8.7	--	0.3
		95% C. L. ($\pm$)	5.5	12.8	--	0.4
T-J-2-52	Normal		66.3	66.3	--	0.5
T-J-6-11			69.6	66.5	--	0.6
T-J-7-48			68.7	67.9	--	0.6
		Average	68.2	66.9	--	0.6
		90% C. L. ($\pm$)	2.9	1.4	--	0.1
		95% C. L. ($\pm$)	4.2	2.1	--	0.1
T-J-6-28	45°		78.0	76.6	--	0.8
T-J-7-34			70.3	65.8	--	0.8
T-J-8-26			76.0	--	--	0.6
		Average	74.8	71.2	--	0.7
		90% C. L. ($\pm$)	6.7	--	--	0.2
		95% C. L. ($\pm$)	9.9	--	--	0.3

APPENDIX C

COMPRESSION PROPERTIES OF TD-NiCr ALLOY SHEET

TABLE 29

COMPRESSION PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636 Material Thickness: 0.051 cm

Specimen Number	Specimen Direction	Temperature (K)		0.02% Y.S. (MN/m^2)	0.2% Y.S. (MN/m^2)
CO-D-1-1	Parallel	297		546.5	644.9
CO-D-2-55				517.1	642.3
CO-D-4-14				523.9	607.2
			Average	529.2	631.5
			90% C. L. (±)	25.9	35.5
			95% C. L. (±)	38.2	52.3
CO-D-1-2	Normal	297		584.9	687.1
CO-D-2-49				615.0	692.0
CO-D-4-30				559.9	649.1
			Average	586.6	676.1
			90% C. L. (±)	46.5	39.6
			95% C. L. (±)	68.5	58.4
CO-D-1-5	Parallel	922		337.6	(a)
CO-D-2-25				372.9	(a)
CO-D-4-17				(a)	(a)
			Average	355.3	--
			90% C. L. (±)	--	--
			95% C. L. (±)	--	--
CO-D-1-22	Normal	922		364.2	411.9
CO-D-4-37				352.1	408.8
			Average	358.2	410.3
			90% C. L. (±)		
			95% C. L. (±)		

TABLE 29 (CONT.)

COMPRESSION PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636				Material Thickness: 0.051 cm	
Specimen Number	Specimen Direction	Temperature (K)		0.02% Y.S. (MN/m^2)	0.2% Y.S. (MN/m^2)
CO-D-1-19	Parallel	1144		230.9	(a)
CO-D-3-1				185.2	239
CO-D-4-28				(a)	(a)
			Average	208.1	--
			90% C.L. (±)	--	--
			95% C.L. (±)	--	--
CO-D-1-28	Normal	1144		234.3	(a)
CO-D-3-2				197.5	218.7
CO-D-4-38				200.7	220.1
			Average	210.8	219.4
			90% C.L. (±)	34.4	--
			95% C.L. (±)	50.6	--

Notes:

(a) Chart indicates specimen may have "buckled" before this value was obtained. Data would not be valid.

TABLE 30

COMPRESSION PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712				Material Thickness: 0.051 cm	
Specimen Number	Specimen Direction	Temperature (K)		0.02% Y. S. (MN/m^2)	0.2% Y. S. (MN/m^2)
CO-J-1-3	Parallel	297		428.5	(a)
CO-J-3-7				543.9	614.2
CO-J-5-25				530.8	681.1
			Average	501.1	647.6
			90% C. L. (±)	106.6	--
			95% C.L. (±)	157.1	--
CO-J-1-4	Normal	297		471.9	558.4
CO-J-3-11				502.1	548.7
CO-J-5-26				486.4	556.7
			Average	486.8	554.6
			90% C. L. (±)	25.5	8.7
			95% C. L. (±)	37.6	12.8
CO-J-1-23	Parallel	922		(a)	(a)
CO-J-3-35				290	(a)
CO-J-6-2				(a)	(a)
			Average	--	--
			90% C. L. (±)	--	--
			95% C. L. (±)	--	--
CO-J-1-20	Normal	922		(a)	(a)
CO-J-3-36				345.2	385.5
CO-J-6-1				334.9	367.0
			Average	340.1	376.2
			90% C. L. (±)	--	--
			95% C. L. (±)	--	--

TABLE 30 (CONT.)

COMPRESSION PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712 Material Thickness: 0.051 cm

Specimen Number	Specimen Direction	Temperature (K)		0.02% Y.S. (MN/m^2)	0.2% Y.S. (MN/m^2)
CO-J-1-32	Parallel	1144		157.0	(a)
CO-J-4-11				172.0	(a)
CO-J-6-22				147.9	(a)
			Average	159.0	--
			90% C. L. (±)	20.5	--
			95% C. L. (±)	30.2	--
CO-J-1-37	Normal	1144		251.4	(a)
CO-J-4-12				182.1	206.9
CO-J-6-23				189.2	203.0
			Average	207.6	204.9
			90% C. L. (±)	64.2	--
			95% C. L. (±)	94.7	--

Notes:

(a) Chart indicates specimen may have "buckled" before this value was obtained. Data would not be valid.

APPENDIX D

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

TABLE 31

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636			Material Thickness: 0.051 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-D-1-56	Parallel	1144	158.6	0.2	2.2
CR-D-4-57			158.6	4.7	1.7
CR-D-2-21			151.7	3.2	2.1
CR-D-5-10			151.7	6.7	1.8
CR-D-3-9			144.8	33.3	1.8
CR-D-1-7			137.9	49.1	2.1
CR-D-3-42			137.9	12.0	1.0
CR-D-4-19			134.5	69.7	1.7
CR-D-2-41			134.5	171.3	2.7
CR-D-4-1			132.5	132.3	2.3
CR-D-5-31			131.0	274.9	2.7
CR-D-1-37			124.1	925.0 (a)	0.5
CR-D-1-51	Normal	1144	129.7	0.6	1.3
CR-D-3-40			127.6	1.7	3.1
CR-D-2-38			124.1	41.5	4.0
CR-D-5-23			124.1	0.2	1.3
CR-D-1-11			117.2	1.0 (b)	--
CR-D-2-16			117.2	26.7	3.2
CR-D-4-23			117.2	12.7	3.8
CR-D-1-33			110.3	114.6	5.0
CR-D-3-25			110.4	45.5	5.5
CR-D-4-46			106.9	253.1	4.9
CR-D-3-61			103.4	398.0	5.7
CR-D-2-63			100.0	571.5 (a)	2.2

TABLE 31 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636			Material Thickness: 0.051 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-D-4-60	Parallel	1255	127.6	1.1	1.2
CR-D-1-43			124.1	2.9	3.8
CR-D-3-15			117.2	4.3	2.7
CR-D-5-12			117.2	8.6	2.6
CR-D-2-23			113.8	33.2	3.1
CR-D-4-39			113.8	11.9	2.5
CR-D-2-2			110.3	36.5	2.6
CR-D-5-38			103.4	115.7	2.6
CR-D-1-9			96.5	186.1	4.3
CR-D-4-3			96.5	346.0	3.0
CR-D-2-43			93.1	326.6	2.2
CR-D-3-44			93.1	239.2	3.4
CR-D-3-28	Normal	1255	94.5	0.3	1.4
CR-D-1-57			93.1	1.1	2.6
CR-D-3-48			93.1	0.6	2.2
CR-D-2-18			89.6	363.9	3.8
CR-D-2-64			86.2	41.2	5.3
CR-D-5-25			86.2	16.5	3.7
CR-D-1-39			82.7	82.7	5.8
CR-D-3-63			82.7	20.0	4.2
CR-D-1-13			75.8	154.9	1.7
CR-D-4-25			75.8	208.1	4.7
CR-D-2-56			72.4	310.7	7.0
CR-D-4-53			72.4	210.7 (c)	--

TABLE 31 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636 — Material Thickness: 0.051 cm

Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-D-5-19	Parallel	1366	93.1	2.2	2.1
CR-D-4-41			89.6	4.7	2.3
CR-D-2-31			79.3	8.8	3.0
CR-D-4-5			79.3	11.3	2.3
CR-D-1-45			72.4	50.4	2.2
CR-D-3-50			72.4	35.9	2.0
CR-D-1-15			68.9	117.1	0.5
CR-D-3-17			68.9	48.6	3.7
CR-D-2-51			65.5	148.1	3.7
CR-D-5-1			62.1	206.3	3.5
CR-D-2-4			62.1	60.0 (b)	--
CR-D-5-41			60.7	425.0 (a)	0.9
CR-D-1-25	Normal	1366	68.9	0.4	3.5
CR-D-4-56			65.5	1.4	2.3
CR-D-1-41			62.1	9.0	5.5
CR-D-2-66			62.1	3.3	6.6
CR-D-5-27			58.6	7.3	4.6
CR-D-1-59			55.2	26.3	7.7
CR-D-3-49			55.2	26.8	11.2
CR-D-4-27			53.8	67.8	13.9
CR-D-3-30			51.7	220.6	46.4
CR-D-3-65			51.7	74.6	18.8
CR-D-2-26			48.3	377.5 (a)	24.0
CR-D-2-58			48.3	128.5 (c)	--

TABLE 31 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636 Material Thickness: 0.051 cm

Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-D-2-33	Parallel	1477	65.5	1.1	1.8
CR-D-4-47			65.5	3.0	1.4
CR-D-1-17			58.6	6.5	1.7
CR-D-5-3			58.6	13.8	1.2
CR-D-2-53			51.7	16.8	4.5
CR-D-5-22			51.7	31.9	1.3
CR-D-5-44			48.3	80.4	0.6
CR-D-2-11			44.8	63.8	4.3
CR-D-3-34			44.8	87.8	15.4
CR-D-1-53			41.4	176.4	1.4
CR-D-3-52			41.4	224.7	1.8
CR-D-4-10			37.9	450.1 (a)	1.3
CR-D-3-32	Normal	1477	48.3	0.4	2.1
CR-D-1-29			44.8	2.0	4.1
CR-D-5-32			42.7	3.7	7.8
CR-D-2-60			41.4	18.9	24.0
CR-D-4-9			41.4	9.9	13.7
CR-D-3-54			37.9	11.3	25.9
CR-D-1-42			34.5	73.0	11.6
CR-D-4-34			34.5	307.1 (a)	83.0
CR-D-4-61			33.1	307.1 (a)	66.4
CR-D-3-11			31.0	331.1 (a)	54.6
CR-D-2-28			27.6	483.6 (a)	38.4
CR-D-1-62			24.1	198.1	10.9

TABLE 31 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636 **Material Thickness:** 0.051 cm

Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-D-3-36	Parallel	1589	44.8	0.3	1.8
CR-D-1-55			41.4	2.7	2.2
CR-D-1-35			34.5	13.8	6.5
CR-D-2-14			31.0	11.2	-- (d)
CR-D-3-53			31.0	20.6	3.8
CR-D-5-29			29.6	72.0	43.2
CR-D-2-35			27.6	45.5	4.1
CR-D-3-7			24.1	177.8	-- (d)
CR-D-4-12			22.1	303.2 (a)	23.5
CR-D-1-31	Normal	1589	34.5	0.1	0.9
CR-D-4-64			31.0	1.9	14.3
CR-D-5-33			29.6	0.9	5.5
CR-D-2-36			27.6	4.0	21.5
CR-D-4-43			20.7	43.6	9.1
CR-D-1-64			17.2	50.8	12.0
CR-D-3-13			17.2	111.3	39.8
CR-D-3-38			15.2	351.9 (a)	6.5
CR-D-2-61			13.8	400.6 (a)	13.5

Notes:

(a) Discontinued at time shown
(b) Void; pin hole failure
(c) Furnace burned out; test discontinued
(d) Elongation not available due to fracture condition

TABLE 32

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637 Material Thickness: 0.025 cm

Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-G-1-8	Parallel	1144	137.9	F.O.L.(e)	0.4
CR-G-3-9			131.0	0.1	0.5
CR-G-3-35			127.6	1.8	1.8
CR-G-2-26			124.1	351.7	2.6
CR-G-4-26			124.1	20.0	2.2
CR-G-7-33			124.1	160.2	2.6
CR-G-6-24			120.7	167.8	2.1
CR-G-7-16			120.7	166.0	2.3
CR-G-5-4			117.2	426.5 (a)	4.1
CR-G-1-7			117.2	75.5	2.0
CR-G-5-29			113.8	377.7 (a)	2.0
CR-G-1-17			110.3	548.7 (a)	--
CR-G-7-2	Normal	1144	124.1	0.5	nil
CR-G-6-22			120.7	4.5	2.9
CR-G-8-18			120.7	1.5	2.9
CR-G-3-31			113.8	5.6	1.9
CR-G-3-5			110.3	117.3	3.5
CR-G-4-20			110.3	15.7	1.9
CR-G-5-10			106.9	16.6	3.1
CR-G-2-20			103.4	20.3	2.7
CR-G-3-30			102.0	409.7 (a)	2.3
CR-G-4-41			100.0	1.5	0.8
CR-G-1-22			96.5	765.3 (a)	--
CR-G-7-22			96.5	423.7 (a)	3.6
CR-G-5-35			93.1	447.8 (a)	3.7
CR-G-1-2			89.6	102.2	1.0

TABLE 32 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637			Material Thickness: 0.025 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-G-1-10	Parallel	1255	103.4	F.O.L.(e)	0.9
CR-G-4-9			96.5	F.O.L.(e)	0.4
CR-G-6-26			95.1	F.O.L.(e)	1.3
CR-G-1-24			93.1	6.1	4.3
CR-G-7-18			91.0	131.0	2.9
CR-G-8-24			91.0	23.2	2.2
CR-G-2-28			89.6	9.0	1.2
CR-G-4-28			89.6	75.8	3.4
CR-G-5-15			87.6	253.7	2.2
CR-G-7-36			87.6	198.6	2.8
CR-G-3-11			86.2	473.6 (a)	2.2
CR-G-5-43			86.2	401.7 (a)	1.8
CR-G-6-32	Normal	1255	100.0	2.9	2.4
CR-G-5-39			96.5	0.6	2.4
CR-G-4-36			89.6	7.6	2.6
CR-G-3-23			82.7	112.0	3.5
CR-G-5-23			82.7	11.0	3.8
CR-G-7-24			82.7	43.5	4.2
CR-G-1-3			72.4	44.5	3.0
CR-G-2-22			72.4	106.1	5.7
CR-G-8-20			71.0	357.7	2.8
CR-G-7-7			70.3	494.2 (a)	2.2
CR-G-4-1			68.9	402.5 (a)	3.0
CR-G-1-29			65.5	504.3 (a)	1.5

TABLE 32 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637 Material Thickness: 0.025 cm

Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-G-4-11	Parallel	1366	75.8	0.2 (b)	--
CR-G-6-5			75.8	10.6	3.3
CR-G-2-30			68.9	19.2	5.1
CR-G-3-13			68.9	1.1	2.5
CR-G-2-3			65.5	87.1	4.4
CR-G-4-30			65.5	16.5	6.0
CR-G-8-26			63.4	307.3	35.2
CR-G-5-18			62.1	17.0	5.8
CR-G-7-20			62.1	163.2	16.7
CR-G-8-6			60.0	454.7 (a)	21.5
CR-G-6-36			58.6	338.6 (a)	14.4
CR-G-1-11			56.7	425.3 (a)	nil
CR-G-5-25	Normal	1366	65.5	1.8	4.7
CR-G-7-26			65.5	2 min.(f)	0.6
CR-G-8-22			63.4	2.9	4.0
CR-G-2-33			62.1	7.4	6.1
CR-G-4-38			62.1	4.6	9.6
CR-G-2-11			55.2	22.7	8.5
CR-G-4-3			55.2	59.9	11.6
CR-G-7-8			53.8	186.0	35.7
CR-G-6-34			53.1	423.9 (a)	25.6
CR-G-8-34			52.4	425.5 (a)	47.8
CR-G-3-25			51.7	379.7 (a)	29.4
CR-G-6-12			51.7	115.7	14.9
CR-G-1-6			48.3	425.3 (a)	0.4

TABLE 32 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637			Material Thickness: 0.025 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-G-3-15	Parallel	1477	55.2	0.1	1.0
CR-G-6-38			53.1	64.0	71.8
CR-G-7-19			51.7	11.6	4.4
CR-G-3-6			51.7	2.7	14.1
CR-G-1-14			48.3	19.5	48.1
CR-G-4-29			48.3	6.5	3.6
CR-G-6-27			44.8	144.4	44.4
CR-G-2-27			42.7	45.1	7.3
CR-G-2-32			41.4	74.4 (g)	39.8
CR-G-8-9			41.4	304.1 (a)	64.5
CR-G-2-6			37.9	310.4 (a)	34.8
CR-G-3-27	Normal	1477	51.7	1.9	8.7
CR-G-7-25			48.3	4.5	25.9
CR-G-1-18			44.8	0.8	1.8
CR-G-6-19			44.8	78.1	81.3
CR-G-2-13			41.4	187.2 (h)	--
CR-G-5-34			41.4	22.7 (i)	57
CR-G-2-34			37.9	40.6	34.3
CR-G-6-42			37.9	17.0 (c)	--
CR-G-4-37			187.7 (i)	187.7 (i)	--
CR-G-8-37			34.5	144.1	-- (c)
CR-G-6-18			34.5	2.5	1.1
CR-G-4-5			33.1	212.3	30.9
CR-G-8-2			31.9	404.3 (a)	--

TABLE 32 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637 Material Thickness: 0.025 cm

Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-G-2-16	Parallel	1589	37.2	4.4	-- (d)
CR-G-1-16			27.6	16.5	-- (d)
CR-G-3-7			24.1	150.2	-- (d)
CR-G-6-20	Normal	1589	37.9	0.1	1.2
CR-G-2-18			31.0	1.2	7.6
CR-G-4-18			31.0	1.6	11.5
CR-G-5-8			27.6	2.6	19.8
CR-G-3-1			21.1	193.1	53.8

Notes:

(a) Discontinued at time shown
(b) Void; pin hole failure
(c) Furnace burned out; test discontinued
(d) Elongation not available due to fracture condition
(e) Failed on loading
(f) Time of failure is approximate
(g) Recording thermocouples failed; test discontinued
(h) Void; temperature controller malfunction
(i) Failed when frame was bumped

TABLE 33

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697			Material Thickness: 0.025 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-H-1-1	Parallel	1144	137.9	F.O.L.(e)	1.3
CR-H-1-47			127.6	F.O.L.(e)	nil
CR-H-3-56			127.6	F.O.L.(e)	0.2
CR-H-3-11			125.5	400.2 (a)	0.8
CR-H-2-17			124.1	F.O.L.(e)	0.2
CR-H-5-34			124.1	F.O.L.(e)	1.1
CR-H-5-13			122.7	428.4 (a)	--
CR-H-4-17			122.0	398.2 (a)	0.5
CR-H-4-47			120.7	425.5 (a)	0.1
CR-H-2-43			120.7	399.8 (a)	nil
CR-H-3-32			118.6	404.3 (a)	0.4
CR-H-1-28			117.2	499.5 (a)	nil
CR-H-1-10	Normal	1144	110.3	F.O.L.(e)	0.9
CR-H-1-13			103.4	F.O.L.(e)	0.6
CR-H-1-51			100.0	F.O.L.(e)	0.7
CR-H-1-29			96.5	F.O.L.(e)	-- (b)
CR-H-2-13			96.5	30 sec. (f)	0.6
CR-H-2-33			89.6	0.2	0.4
CR-H-3-7			86.2	423.9 (a)	0.3
CR-H-3-47			86.2	0.2	0.3
CR-H-3-29			82.7	1 min. (f)	0.4
CR-H-4-25			79.3	F.O.L.(e)	1.0
CR-H-5-31			77.2	379.5 (a)	0.3
CR-H-4-52			75.8	519.6 (a)	0.2
CR-H-5-5			72.4	400.0 (a)	0.3

TABLE 33 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697			Material Thickness: 0.025 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-H-3-34	Parallel	1255	106.9	15 sec. (f)	0.9
CR-H-4-49			104.8	F.O.L. (e)	1.4
CR-H-4-7			103.4	429.6 (a)	0.9
CR-H-5-15			103.4	337.9	1.3
CR-H-5-36			102.0	2 min. (f)	0.4
CR-H-4-34			101.4	423.5 (a)	0.6
CR-H-3-13			100.0	188.7	0.5
CR-H-1-35			96.5	215.1	0.8
CR-H-2-44			96.5	495.6 (a)	0.6
CR-H-1-3			89.6	99.2	1.3
CR-H-1-49			89.6	400.9 (a)	0.3
CR-H-2-19			86.2	394.5 (a)	1.1
CR-H-1-12	Normal	1255	86.2	F.O.L. (e)	nil
CR-H-1-31			75.8	F.O.L. (e)	0.5
CR-H-1-53			68.9	2 min. (f)	0.3
CR-H-2-15			65.5	F.O.L. (e)	0.8
CR-H-5-33			63.4	F.O.L. (e)	0.2
CR-H-2-35			62.1	2 min. (f)	0.1
CR-H-5-20			62.1	351.8 (a)	0.2
CR-H-4-54			61.4	423.9 (a)	0.2
CR-H-4-27			60.0	428.7 (a)	0.4
CR-H-4-3			58.6	429.3 (a)	0.4
CR-H-3-15			55.2	400.5 (a)	0.5
CR-H-3-37			48.3	406.3 (a)	0.2

TABLE 33 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697 Material Thickness: 0.025 cm

Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-H-1-37	Parallel	1366	93.1	30 sec. (f)	0.4
CR-H-2-6			75.8	F.O.L.(e)	1.0
CR-H-5-38			73.8	F.O.L.(e)	-- (b)
CR-H-1-5			72.4	53.2	2.2
CR-H-2-21			72.4	118.7	2.5
CR-H-4-38			68.9	36.4	0.8
CR-H-3-20			65.5	30.5	1.1
CR-H-5-17			65.5	44.5	1.1
CR-H-2-48			62.1	129.4	0.2
CR-H-4-9			62.1	F.O.L.(e)	3.1
CR-H-3-35			58.6	302.3	0.5
CR-H-4-51			58.6	297.8	2.0
CR-H-1-14	Normal	1366	62.1	F.O.L.(e)	1.0
CR-H-2-1			60.0	F.O.L.(e)	0.6
CR-H-3-6			58.6	69.2	3.9
CR-H-1-33			58.6	F.O.L.(e)	0.2
CR-H-2-25			55.2	F.O.L.(e)	nil
CR-H-4-30			53.1	0.1	0.7
CR-H-5-22			53.1	F.O.L.(e)	0.3
CR-H-2-53			51.7	188.7	1.5
CR-H-4-56			51.7	220.7	4.2
CR-H-4-19			51.7	306.0 (a)	5.3
CR-H-3-17			48.3	263.1	4.1

TABLE 33 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697			Material Thickness: 0.025 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-H-4-13	Parallel	1477	68.9	9.6	1.3
CR-H-5-9			68.9	4 sec. (f)	0.3
CR-H-1-39			62.1	3.9	0.6
CR-H-4-40			62.1	4.9	1.0
CR-H-2-8			51.7	13.2	2.4
CR-H-1-25			48.3	21.0	1.9
CR-H-5-51			48.3	46.5	-- (b)
CR-H-5-19			44.8	99.6	0.3
CR-H-1-36			41.4	65.0	1.4
CR-H-5-54			39.3	307.2 (a)	6.4
CR-H-1-41	Normal	1477	48.3	5 sec. (f)	0.6
CR-H-4-22			44.8	2.9	0.8
CR-H-3-43			43.4	4.0	1.0
CR-H-4-21			41.4	F.O.L. (e)	0.4
CR-H-4-32			41.4	5 sec. (f)	0.4
CR-H-5-1			39.3	42.3	4.5
CR-H-5-24			37.9	268.3	23.0
CR-H-5-42			35.9	1 min. (f)	0.7
CR-H-1-20			34.5	382.5 (a)	20.7

TABLE 33 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697			Material Thickness: 0.025 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-H-3-54	Parallel	1589	44.8	0.9	2.2
CR-H-5-11			44.8	2.0	2.5
CR-H-1-45			37.9	7.0	5.3
CR-H-3-24			34.5	30 sec. (f)	0.4
CR-H-3-21			34.5	15 sec. (f)	0.3
CR-H-3-1			29.6	104.9	42.0
CR-H-1-27			27.6	91.0 (i)	-- (b)
CR-H-4-42			27.6	48.5	-- (d)
CR-H-2-10			24.1	144.4	18.5
CR-H-2-5	Normal	1589	41.4	F. O. L.(e)	0.3
CR-H-3-5			37.9	1 min. (f)	6.6
CR-H-1-22			24.1	185.7	35.6

Notes:

(a) Discontinued at time shown
(b) Void; pin hole failure
(d) Elongation not available due to fracture condition
(e) Failed on loading
(f) Time of failure is approximate
(i) Failed when frame was bumped.

TABLE 34

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712 | Material Thickness: 0.051 cm

Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-J-6-9	Parallel	1144	158.6	0.9	2.1
CR-J-4-34			151.7	2.4	2.9
CR-J-7-14			148.2	1.0	1.8
CR-J-3-14			148.2	3 min. (f)	-- (b)
CR-J-4-38			144.8	10.9	1.4
CR-J-5-32			141.3	61.9	1.4
CR-J-1-40			137.9	41.6	2.1
CR-J-6-40			137.9	142.2	1.6
CR-J-1-30			134.4	448.0 (a)	1.0
CR-J-2-42			134.4	66.0	-- (b)
CR-J-3-39			134.4	147.3	3.8
CR-J-1-7			131.0	168.5	1.9
CR-J-5-37			128.9	449.7 (a)	1.0
CR-J-3-17			127.6	498.6 (a)	0.8
CR-J-5-28	Normal	1144	131.0	1 min. (f)	1.4
CR-J-2-49			127.6	1.5	3.1
CR-J-3-22			124.1	2.7	1.9
CR-J-6-46			124.1	2.1	2.8
CR-J-7-3			120.7	16.2	2.5
CR-J-4-46			120.7	13.1	2.5
CR-J-1-33			117.2	22.6	2.2
CR-J-4-23			110.3	77.9	2.6
CR-J-1-8			106.9	127.5	1.0
CR-J-3-47			106.9	96.4	2.7
CR-J-5-45			104.8	88.5	2.4
CR-J-1-47			103.4	400.7 (a)	2.0

TABLE 34 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712			Material Thickness: 0.051 cm		
Specimen Number	**Specimen Direction**	**Temperature (K)**	**Stress (MN/m^2)**	**Rupture Life (hrs.)**	**Elongation (%)**
CR-J-5-2	Parallel	1255	131.0	0.4	1.9
CR-J-3-40			127.6	2.1	2.4
CR-J-2-9			117.2	21.0	0.8
CR-J-2-43			117.2	7.7	1.9
CR-J-4-39			113.8	8.1	2.3
CR-J-3-21			110.3	24.6	2.0
CR-J-6-18			106.9	22.7	1.7
CR-J-6-41			106.9	48.8	1.8
CR-J-7-31			103.4	3.4	-- (b)
CR-J-1-44			103.4	412.0	2.3
CR-J-5-38			103.4	85.9	2.4
CR-J-2-40			101.4	447.4 (a)	1.5
CR-J-1-41			100.0	473.4 (a)	0.8
CR-J-1-26			96.5	503.3 (a)	1.2
CR-J-5-46	Normal	1255	103.4	0.8	2.6
CR-J-2-2			96.5	1.4	3.3
CR-J-7-23			96.5	3.3	2.8
CR-J-3-48			93.1	2.7	4.3
CR-J-4-29			89.6	22.0	2.5
CR-J-1-11			82.7	40.1	2.4
CR-J-1-48			82.7	214.0	2.7
CR-J-2-50			79.3	50.0	1.6
CR-J-6-12			75.8	400.7 (a)	2.3
CR-J-3-24			72.4	134.0	1.7
CR-J-4-47			70.3	495.5 (a)	2.4
CR-J-6-48			68.9	405.5 (a)	1.5

TABLE 34 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712			Material Thickness: 0.051 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-J-2-11	Parallel	1366	96.5	1.4	1.5
CR-J-4-6			96.5	0.4	1.2
CR-J-3-41			82.7	7.4	1.4
CR-J-1-42			79.3	18.8	1.7
CR-J-2-39			79.3	9.6	1.0
CR-J-1-28			68.9	61.8	2.0
CR-J-4-35			68.9	31.8	1.4
CR-J-5-39			65.5	187.8	0.8
CR-J-6-42			63.4	326.1	2.6
CR-J-8-5			62.1	356.0 (a)	0.1
CR-J-5-18			58.6	424.1 (a)	0.2
CR-J-7-6			58.6	359.5	0.8
CR-J-5-47	Normal	1366	75.8	0.1	2.1
CR-J-6-49			72.4	0.3	1.5
CR-J-1-49			68.9	1.7	3.7
CR-J-4-43			68.9	3.6	3.4
CR-J-5-10			62.1	4.5	1.6
CR-J-2-4			58.6	6.2	2.5
CR-J-3-5			51.7	64.3	5.7
CR-J-3-29			50.0	320.7	19.2
CR-J-2-46			48.3	35.5	1.5
CR-J-3-49			48.3	162.3	7.7
CR-J-6-14			44.8	412.0 (a)	5.1

TABLE 34 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712 Material Thickness: 0.051 cm

Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-J-4-41	Parallel	1477	65.5	0.8	-- (d)
CR-J-6-43			65.5	4.9	1.8
CR-J-3-42			62.1	7.0	1.4
CR-J-5-42			62.1	3.5	1.1
CR-J-2-37			55.2	14.6	0.9
CR-J-7-34			51.7	21.9	1.0
CR-J-1-45			51.7	10.7	0.4
CR-J-4-13			48.3	37.3	2.1
CR-J-6-38			48.3	124.1	1.1
CR-J-3-43			46.2	130.1	2.0
CR-J-5-30			44.8	142.7	-- (d)
CR-J-2-44			42.7	216.2 (i)	1.3
CR-J-1-14	Normal	1477	44.8	1.8	1.6
CR-J-7-42			44.8	2.0	1.9
CR-J-1-52			42.7	2.4	2.1
CR-J-6-32			42.7	2.9	2.2
CR-J-4-1			41.4	55.0	47.7
CR-J-8-9			41.4	3.3	1.4
CR-J-4-44			40.0	12.0	9.8
CR-J-2-21			37.9	350.1 (a)	63.8

TABLE 34 (CONT.)

CREEP-RUPTURE PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712			Material Thickness: 0.051 cm		
Specimen Number	Specimen Direction	Temperature (K)	Stress (MN/m^2)	Rupture Life (hrs.)	Elongation (%)
CR-J-4-37	Parallel	1589	44.8	1.4	0.5
CR-J-8-12			44.8	1.5	1.5
CR-J-2-6			41.4	3.0	-- (d)
CR-J-6-26			37.9	16.7	1.5
CR-J-2-41			37.9	9.2	-- (d)
CR-J-5-41			34.5	21.5	-- (d)
CR-J-3-44			31.0	133.9	-- (d)
CR-J-3-38			27.6	183.2	49.9
CR-J-1-17	Normal	1589	31.0	0.7	1.3
CR-J-2-48			31.0	1.6	4.5
CR-J-3-46			27.6	42.9	7.2
CR-J-4-20			24.1	38.4 (i)	7.1
CR-J-5-14			24.1	130.7	90.3
CR-J-3-2			22.1	89.4	50.0
CR-J-6-34			18.6	249.4	41.1

Notes:

(a) Discontinued at time shown
(b) Void; pin hole failure
(d) Elongation not available due to fracture condition
(f) Time of failure is approximate
(i) Failed when frame was bumped

APPENDIX E

CREEP STRENGTH DATA ANALYSIS

For each heat, orientation, and temperature, the creep strength data have been treated by a least-squares regression analysis to determine a curve of the form:

$$\log \epsilon_{100} = A + B \log \sigma \qquad (13)$$

which is equivalent to:

$$\epsilon_{100} = C\sigma^{B} \qquad (14)$$

where ϵ_{100} is the creep strain at 100 hours, is stress, and A and B are constants, to be determined by the regression $C = 10^A$.

The least-squares regression criterion involves the minimization of the sum of the squares of the deviations of the input values of the dependent variable from the corresponding values given by the regression curve. Thus, the technique considers deviations in only one dimension of the two-dimensional space over which the regression curve is defined, namely that corresponding to the dependent variable, while ignoring entirely any "deviation" (uncertainty) in the dimension corresponding to the independent variable. It is therefore clearly in the spirit of the technique to choose as the dependent variable that in which there is greatest uncertainty, or potential error of measurement.

For this reason, log has been chosen as the independent variable and $\log \epsilon_{100}$ as the dependent variable, as indicated in Equation (13). In each case, the stress required to produce 0.1 and 0.2% creep strain is determined by solving the resulting regression equations for the appropriate value of $\log \sigma$.

Because the observed values of the residuals arise as the sum of a large number of independent contributions, the central limit theorem justifies the assumption that they are normally distributed. The mean square about the regression (denoted s^2) is given by

$$s^2 = \frac{\sum_i (\log \sigma_{calc,\, i} - \log \sigma_{meas,\, i})^2}{n - 2} \tag{15}$$

and estimates their variance, where n is the number of data points. Then $1-\alpha$ confidence bounds (where α is the risk level) on the mean of q future observations of $\log \epsilon_{100}$ are given by:

$$\log \epsilon_{100\ calc} \pm s\, t_{1-\alpha/2,\, n-2} \left[\frac{1}{q} + \frac{1}{n} + \frac{(\log \sigma - [\log \sigma]_{avg})^2}{\sum_i (\log \sigma_i - [\log \sigma]_{avg})^2} \right]^{1/2} \tag{16}$$

where $t_{1-\alpha/2,\, n-2}$ is the $1-\alpha/2$ percentage point of the t distribution having n-2 degrees of freedom, $\log \sigma_i$ involves experimental stress levels and $\log \sigma$ is a selected stress level corresponding to $\log \epsilon_{100\ calc}$. In this program, q is taken to be 1, yielding confidence bounds such that one additional observation of $\log \epsilon_{100}$ at the given value of $\log \sigma$ will, with $100\,(1-\alpha)\%$ confidence, fall within the calculated limits. The third term within the brackets accounts for the uncertainty in the determination of the slope by the regression technique. Because of the restricted number of points included in these regressions, engineering judgment must be applied to evaluate the validity of the calculated slopes. It is therefore inappropriate to include in the confidence limits an evaluation of the slopes based solely on the limited amount of data considered in the regressions, and this term has been neglected in computing the reported values.

These confidence bound equations are solved in a manner similar to the regression equations to yield 90 and 95% confidence bounds on the calculated values of $\log \epsilon_{100}$. Note that the reported values of the confidence limits on stress are not uniform in the positive and negative directions; the nonlinearity arises from the adjustment of the calculated value of $\log \sigma$ by an additive confidence limit before exponentiation.

The creep strength data are reported in Tables 35 through 66, Appendix F. Data points which were included in the regression analyses are indicated by asterisks. To avoid undue influence on the regression line of data representing strain values far from the region of interest, most data points below 0.05% and above 1% creep strain were disregarded in the regression analyses. This seems particularly important in the regime of low strain, where scatter is pronounced. The majority of the remaining data clearly indicate a consistent pattern of behavior, represented by isotherms which are approximately parallel within each heat and orientation. Using this pattern as a guide, data points were selected for inclusion in the regression analyses by comparison of these plots at various temperatures, considering also the creep strength tests in which failures occurred before 100 hours and appropriate creep-rupture data. There remained only a few anomalous data points; these were disregarded in the regression analysis.

The following data sets exhibited insufficient consistency to justify regression analysis:

Heat 3636 (0.051 cm)	Parallel	1366K
Heat 3637 (0.025 cm)	Parallel	1477K
Heat 3697 (0.025 cm)	Normal	1144K

APPENDIX F

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

TABLE 35

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636
Specimen Direction: Parallel
Material Thickness: 0.051 cm
Temperature: 1144K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-D-1-8	110.3	0.02	0.04	0.06	0.07	0.09	0.09	141.5
*C-D-1-46	117.2	0.02	0.04	0.07	0.10	0.12	0.13	109.3
*C-D-3-45	120.7	0.02	0.04	0.11	0.18	0.22	--	100.0
*C-D-2-20	124.1	0.02	0.05	0.12	0.24	0.35	0.40	123.0
*C-D-3-8	127.6	0.02	0.03	0.08	0.18	0.28	0.30	123.3
*C-D-4-40	131.0	0.05	0.10	0.21	0.43	0.65	0.75	116.1

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	112.4	+6.0 -5.7	+8.0 -7.4
0.2	119.7	+6.4 -6.1	+8.6 -8.0

*Data from this specimen was used for the regression analysis.

TABLE 36

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636 | Material Thickness: 0.051 cm
Specimen Direction: Parallel | Temperature: 1255K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
C-D-1-16	48.3	0.01	0.02	0.04	0.05	0.06	0.06	113.8
C-D-1-54	55.2	(a)	--	--	--	--	--	18.9
C-D-2-32	58.6	(b)	--	--	--	--	--	125.7
*C-D-3-51	82.7	0.01	0.02	0.05	0.08	0.09	0.10	116.5
*C-D-5-46	86.2	0.02	0.03	0.04	0.06	0.11	0.12	110.6
*C-D-5-20	89.6	0.03	0.05	0.09	0.13	0.16	0.16	101.9
*C-D-4-42	89.6	0.03	0.06	0.13	0.32	0.61	0.69	112.7
*C-D-3-16	96.5	0.04	0.08	0.17	0.57	1.33	1.73	122.8

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	84.0	+7.0 -6.4	+ 9.7 - 8.6
0.2	87.2	+7.3 -6.7	+10.1 - 9.0

Notes:

(a) Void; controller malfunction
(b) Void; extensometer erratic

*Data from this specimen was used for the regression analysis.

TABLE 37

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636 | Material Thickness: 0.051 cm
Specimen Direction: Parallel | Temperature: 1366K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
C-D-2-3	27.6	0.01	0.02	0.03	0.08	0.11	0.11	101.0
C-D-1-36	31.0	--	--	--	0.01	0.02	0.02	118.2
C-D-3-35	34.5	(b)	--	--	--	--	--	115.7
C-D-2-42	48.3	0.01	0.02	0.05	0.08	0.10	0.10	101.2
C-D-4-4	55.2	0.03	0.04	0.06	0.07	0.08	0.08	117.7
C-D-4-48	62.1	0.02	0.03	0.03	0.04	0.05	0.05	110.1
C-D-5-4	65.5	0.03	0.06	0.09	0.17	0.31	--	125.9 (c)
C-D-4-50	68.9	0.03	0.04	0.07	0.22	--	--	79.5 (c)

Notes:

(b) Void; extensometer erratic
(c) Failed at time shown

Data shown above is insufficient for regression analysis.

TABLE 38

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636 | Material Thickness: 0.051 cm
Specimen Direction: Parallel | Temperature: 1477K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
C-D-2-13	24.1	(b)	--	--	--	--	--	100.3
C-D-2-44	31.0	0.01	0.01	0.01	0.02	0.02	--	98.5
*C-D-1-44	37.9	0.02	0.03	0.05	0.08	0.09	0.09	110.7
*C-D-4-20	39.3	0.01	0.02	0.04	0.09	0.13	0.16	127.9
*C-D-3-43	41.4	0.02	0.03	0.04	0.11	0.35	1.01	125.9
C-D-5-45	42.7	--	0.01	0.02	0.03	0.04	0.04	125.0

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	38.0	+2.5 -2.3	+5.6 -4.8
0.2	39.8	+2.6 -2.4	+5.8 -5.0

Notes:

(b) Void; extensometer erratic

*Data from this specimen was used for the regression analysis.

TABLE 39

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636
Specimen Direction: Normal

Material Thickness: 0.051 cm
Temperature: 1144K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-D-1-40	72.4	0.01	0.02	0.05	0.11	0.15	0.16	125.6
*C-D-2-17	75.8	0.02	0.03	0.07	0.11	0.15	0.16	118.1
*C-D-2-37	79.3	0.01	0.02	0.05	0.09	0.12	0.12	116.3
*C-D-2-62	80.7	0.01	0.03	0.09	0.17	0.22	0.24	114.7
*C-D-3-39	82.7	0.01	0.03	0.13	0.33	0.51	0.51	100.0
*C-D-1-12	82.7	0.03	0.07	0.23	0.59	0.91	0.98	115.0

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	72.1	+9.9 -8.7	+13.3 -11.1
0.2	76.8	+10.6 -9.2	+14.2 -11.9

*Data from this specimen was used for the regression analysis.

TABLE 40

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636
Specimen Direction: Normal
Material Thickness: 0.051 cm
Temperature: 1255K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
C-D-1-24	41.4	0.03	0.04	0.05	0.06	0.06	0.06	121.6
*C-D-2-19	51.7	0.01	0.02	0.04	0.06	0.08	0.08	101.4
*C-D-2-39	55.2	0.02	0.04	0.07	0.12	0.15	0.15	100.0
*C-D-3-47	56.5	0.02	0.07	0.24	0.71	1.27	1.49	117.2
*C-D-3-12	58.6	0.02	0.06	0.15	0.40	0.75	0.91	118.3
*C-D-1-49	62.1	0.02	0.07	0.30	1.30	1.92	2.85	308.6

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	51.8	+5.5	+7.6
		-4.9	-6.6
0.2	53.8	+5.7	+7.9
		-5.1	-6.9

*Data from this specimen was used for the regression analysis.

TABLE 41

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636 | Material Thickness: 0.051 cm
Specimen Direction: Normal | Temperature: 1366K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
C-D-1-60	20.7	0.01	0.02	0.03	0.05	0.08	0.08	101.1
C-D-2-27	27.6	(d)	--	--	--	--	--	138.9
*C-D-2-57	33.1	0.01	0.02	0.03	0.05	0.08	0.08	101.2
*C-D-2-29	35.9	0.01	0.03	0.06	0.11	0.15	0.16	120.1
*C-D-4-44	36.5	0.01	0.02	0.07	0.16	0.22	0.22	100.0
*C-D-3-57	37.9	0.01	0.02	0.08	0.31	0.84	1.27	121.0
C-D-3-24	48.3	0.02	0.08	0.57	6.6	26.0	29.7	121.0

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	33.8	+3.7	+5.7
		-3.2	-4.8
0.2	35.4	+3.8	+6.0
		-3.4	-5.0

Notes:

(d) Void; defective extensometer

*Data from this specimen was used for the regression analysis.

TABLE 42

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3636 | Material Thickness: 0.051 cm
Specimen Direction: Normal | Temperature: 1477K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-D-2-59	20.7	0.01	0.02	0.03	0.04	0.04	0.04	99.9
*C-D-1-30	22.1	0.01	0.02	0.04	0.07	0.09	0.10	110.8
*C-D-3-29	22.1	nil	0.02	0.06	0.14	0.20	0.21	110.6
*C-D-1-63	23.4	0.01	0.02	0.05	0.12	0.23	0.32	128.0
C-D-5-35	24.1	0.05	0.18	--	--	--	--	8.0 (c)
C-D-4-6	27.6	0.01	0.04	0.17	1.55	11.5	11.5	100.0

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	21.5	+2.1 -1.9	+3.4 -2.8
0.2	22.6	+2.2 -2.0	+3.6 -3.0

Notes:

(c) Failed at time shown

*Data from this specimen was used for the regression analysis.

TABLE 43

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637　　Material Thickness: 0.025 cm
Specimen Direction: Parallel　　Temperature: 1144K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-G-7-34	86.2	0.03	0.06	0.11	0.15	0.17	0.17	119.7
*C-G-5-21	89.6	0.02	0.03	0.06	0.10	0.12	0.12	99.9
*C-G-4-33	89.6	0.03	0.12	0.30	0.54	0.68	0.68	101.5
*C-G-8-13	93.1	0.02	0.03	0.07	0.13	0.16	0.17	115.6
*C-G-4-13	94.5	0.03	0.12	0.28	0.48	0.61	0.63	114.8
*C-G-3-10	96.5	0.04	0.33	0.78	1.13	1.28	1.28	99.7
C-G-2-2	106.9	(e)	--	--	--	--	--	--
C-G-4-31	113.8	(e)	--	--	--	--	--	--

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	83.7	+11.8 -10.2	+15.7 -13.2
0.2	87.8	+12.4 -10.8	+16.5 -13.8

Notes:

(e) Failed on loading in pin area

*Data from this specimen was used for the regression analysis.

TABLE 44

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637 | Material Thickness: 0.025 cm
Specimen Direction: Parallel | Temperature: 1255K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-G-2-5	48.3	0.01	0.03	0.04	0.04	0.04	0.04	100.0
C-G-5-3	51.7	nil	nil	nil	0.01	0.01	0.01	116.0
*C-G-6-8	53.1	nil	nil	0.01	0.02	0.03	0.03	116.1
C-G-8-7	55.2	nil	nil	nil	0.01	0.01	0.01	100.0
*C-G-3-14	58.6	0.06	0.34	0.80	1.25	1.45	1.45	114.8
*C-G-1-15	65.5	0.01	0.11	0.38	0.74	0.99	1.01	111.3

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	52.8	+20.8 -14.8	+33.6 -20.4
0.2	55.6	+21.9 -15.6	+35.4 -21.5

*Data from this specimen was used for the regression analysis.

TABLE 45

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637 | Material Thickness: 0.025 cm
Specimen Direction: Parallel | Temperature: 1366K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-G-5-5	44.8	0.02	0.03	0.05	0.08	0.11	0.12	112.8
*C-G-8-11	46.2	nil	0.01	0.01	0.03	0.06	0.07	118.0
*C-G-8-35	48.3	0.01	0.02	0.04	0.16	0.35	0.40	113.0
*C-G-4-12	51.7	0.01	0.06	0.22	0.43	0.52	0.52	102.0
*C-G-6-17	51.7	0.03	0.05	0.11	0.30	0.63	0.84	120.7
*C-G-2-17	58.6	0.04	0.06	0.13	0.38	1.00	1.42	111.4

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	44.4	+6.0 -5.2	+8.1 -6.7
0.2	47.7	+6.5 -5.6	+8.7 -7.3

*Data from this specimen was used for the regression analysis.

TABLE 46

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637 — Material Thickness: 0.025 cm
Specimen Direction: Parallel — Temperature: 1477K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
C-G-8-27	20.7	0.01	0.02	0.03	0.05	0.07	0.08	129.1
C-G-1-25	20.7	0.01	0.02	0.08	0.29	0.60	0.60	100.2
C-G-8-28	25.5	nil	0.02	0.06	0.12	0.15	--	124.0
C-G-3-16	27.6	0.02	0.05	0.37	4.5	9.2	10.4	118.4
C-G-6-6	31.0	0.01	0.03	0.06	0.18	0.35	0.46	113.0
C-G-7-27	32.4	0.01	0.03	0.16	1.18	3.32	3.32	99.6
C-G-5-20	37.9	0.01	0.04	0.24	1.8	--	--	71.7 (c)

Notes:

(c) Failed at time shown

Data shown above is insufficient for regression analysis.

TABLE 47

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637
Specimen Direction: Normal

Material Thickness: 0.025 cm
Temperature: 1144K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-G-7-39	65.5	0.01	0.03	0.09	0.18	0.23	0.24	112.9
*C-G-3-32	68.9	nil	0.02	0.05	0.10	0.13	0.14	117.4
*C-G-5-9	75.8	0.01	0.07	0.22	0.43	0.56	0.58	112.8
*C-G-2-21	82.7	0.02	0.14	0.43	0.81	1.04	1.04	100.0
*C-G-6-43	91.7	0.02	0.13	0.40	0.70	0.84	0.84	100.9
*C-G-1-5	96.5	0.02	0.18	0.50	0.88	1.10	1.16	112.7

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	57.0	+14.0 -11.1	+18.9 -14.1
0.2	65.6	+16.1 -12.8	+21.8 -16.3

*Data from this specimen was used for the regression analysis.

TABLE 48

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637 Material Thickness: 0.025 cm
Specimen Direction: Normal Temperature: 1255K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-G-4-4	41.4	0.01	0.02	0.03	0.04	0.05	0.05	115.9
*C-G-6-44	44.8	nil	0.01	0.04	0.09	0.13	0.14	117.3
*C-G-8-5	46.9	0.02	0.04	0.08	0.15	0.22	0.24	122.8
*C-G-5-26	48.3	0.02	0.05	0.16	0.36	0.52	0.52	101.9
*C-G-2-37	51.7	0.02	0.09	0.32	0.70	0.99	1.04	113.9
C-G-1-19	62.1	0.01	0.07	0.26	0.63	0.90	0.94	110.7

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	43.4	+1.4 -1.3	+2.0 -1.9
0.2	45.6	+1.4 -1.4	+2.1 -2.0

*Data from this specimen was used for the regression analysis.

TABLE 49

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637 — Material Thickness: 0.025 cm
Specimen Direction: Normal — Temperature: 1366K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
C-G-2-15	24.1	nil	nil	0.01	0.01	0.03	0.03	115.2
*C-G-3-3	31.0	0.01	0.02	0.04	0.05	0.06	0.07	116.5
*C-G-7-1	32.4	0.01	0.04	0.06	0.12	0.23	0.27	114.9
*C-G-5-33	34.5	0.01	0.03	0.06	0.20	0.48	0.63	115.5
*C-G-4-17	37.9	0.03	0.04	0.07	0.17	0.35	0.46	116.6
*C-G-8-19	37.9	0.01	0.03	0.12	0.34	0.64	0.80	125.9

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	30.4	+6.1 -5.0	+8.7 -6.7
0.2	33.1	+6.7 -5.5	+9.5 -7.3

*Data from this specimen was used for the regression analysis.

TABLE 50

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3637 | Material Thickness: 0.025 cm
Specimen Direction: Normal | Temperature: 1477K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-G-2-19	15.2	nil	0.02	0.03	0.03	0.04	0.04	100.0
*C-G-3-24	15.9	0.01	0.01	0.03	0.05	0.06	0.06	100.0
*C-G-7-10	17.2	0.01	0.03	0.06	0.17	0.34	0.42	116.0
*C-G-8-3	18.6	0.01	0.02	0.04	0.10	0.22	0.26	117.3
*C-G-4-39	18.6	0.01	0.01	0.03	0.10	0.22	0.22	100.0
*C-G-5-27	20.7	0.01	0.02	0.07	0.31	1.01	1.30	113.9

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	16.2	+1.8 -1.5	+2.5 -2.1
0.2	17.4	+1.9 -1.7	+2.7 -2.2

*Data from this specimen was used for the regression analysis.

TABLE 51

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697 | Material Thickness: 0.025 cm
Specimen Direction: Parallel | Temperature: 1144K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-H-1-6	82.7	0.01	0.02	0.03	0.03	0.04	0.05	119.0
*C-H-1-46	93.1	0.01	0.03	0.06	0.08	0.10	0.10	112.4
*C-H-2-49	96.5	0.02	0.03	0.06	0.09	0.10	0.11	111.4
*C-H-3-25	110.3	0.01	0.03	0.07	0.11	0.14	0.14	101.1
*C-H-4-8	124.1	0.08	0.16	0.22	0.27	0.30	0.30	99.4
C-H-5-12	137.9	0.20	0.37	--	--	--	--	2.8 (c)

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	97.7	+11.7 -10.4	+16.3 -13.9
0.2	114.1	+13.7 -12.2	+19.1 -16.3

Notes:

(c) Failed at time shown

*Data from this specimen was used for the regression analysis.

TABLE 52

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697 | Material Thickness: 0.025 cm
Specimen Direction: Parallel | Temperature: 1255K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-H-2-11	55.2	0.01	0.01	0.01	0.02	0.02	0.02	97.3
*C-H-1-15	65.5	0.01	0.01	0.02	0.03	0.03	0.04	123.9
*C-H-3-33	68.9	0.02	0.05	0.11	0.15	0.17	0.17	113.5
*C-H-2-51	75.8	0.03	0.07	0.11	0.15	0.17	0.17	100.0
*C-H-4-18	93.1	0.03	0.07	0.14	0.23	0.27	0.28	121.6
C-H-5-16	103.4	--	--	--	--	--	--	(f)

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	72.5	+27.9 -20.0	+40.2 -25.7
0.2	82.8	+31.9 -22.9	+46.0 -29.4

Notes:

(f) Failed in 2 minutes

*Data from this specimen was used for the regression analysis.

TABLE 53

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697 | Material Thickness: 0.025 cm
Specimen Direction: Parallel | Temperature: 1366K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-H-3-51	48.3	0.02	0.02	0.04	0.06	0.09	0.09	119.0
C-H-4-39	51.7	--	--	--	--	--	--	(g)
*C-H-2-38	51.7	0.01	0.03	0.06	0.13	0.20	0.20	101.6
*C-H-1-34	55.2	0.03	0.05	0.10	0.16	0.19	0.20	122.0
*C-H-2-18	62.1	0.02	0.05	0.11	0.23	0.37	0.37	100.1
*C-H-3-12	65.5	0.02	0.04	0.09	0.17	0.36	0.36	100.3
C-H-5-39	66.9	--	--	--	--	--	--	(h)

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	46.7	+6.8 -5.9	+ 9.5 - 7.8
0.2	55.0	+8.0 -6.9	+11.3 - 9.3

Notes:

(g) Temperature to 2200°F prior to loading; test not loaded
(h) Failed on loading

*Data from this specimen was used for the regression analysis.

TABLE 54

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697
Specimen Direction: Parallel
Material Thickness: 0.025 cm
Temperature: 1477K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-H-2-50	27.6	0.01	0.02	0.02	0.03	0.03	0.03	120.9
C-H-3-52	30.3	0.02	0.04	0.07	--	--	--	42.4 (i)
*C-H-4-5	30.3	0.01	0.01	0.02	0.02	0.03	0.03	99.3
*C-H-4-15	31.0	0.01	0.02	0.06	0.10	0.12	0.13	124.1
*C-H-5-53	31.7	0.01	0.01	0.05	0.21	0.45	0.57	128.1
*C-H-3-22	33.1	0.02	0.04	0.07	0.17	0.45	0.52	113.5
*C-H-5-28	33.1	nil	0.01	0.04	0.18	0.52	0.87	137.3

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	30.1	+2.9 -2.6	+3.9 -3.4
0.2	31.3	+3.0 -2.7	+4.1 -3.5

Notes:

(i) Control thermocouple malfunction; temperature to ambient at time shown. Test discontinued.

*Data from this specimen was used for the regression analysis.

TABLE 55

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697 | Material Thickness: 0.025 cm
Specimen Direction: Normal | Temperature: 1144K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
C-H-1-44	55.2	0.01	0.02	0.03	0.04	0.05	0.05	100.0
C-H-3-18	75.8	0.01	0.02	0.04	0.07	0.09	0.09	101.9
C-H-4-24	79.3	0.02	0.03	0.05	0.08	0.10	0.10	100.0
C-H-5-4	80.7	0.02	0.04	0.06	0.08	0.09	0.09	101.1
C-H-2-23	82.7	--	--	--	--	--	--	(f)

Notes:

(f) Failed in 3 minutes

Data shown above is insufficient for regression analysis.

TABLE 56

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697
Specimen Direction: Normal

Material Thickness: 0.025 cm
Temperature: 1255K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-H-1-19	62.1	0.04	0.05	0.08	0.10	0.11	0.12	136.8
*C-H-2-32	62.1	0.03	0.06	0.11	0.18	0.23	0.24	123.5
*C-H-2-4	65.5	0.02	0.05	0.12	0.18	0.20	0.20	99.8
C-H-5-23	67.6	0.05	0.14	--	--	--	--	10.5 (c)
C-H-4-28	68.9	0.05	0.10	0.19	0.25	--	--	91.1 (c)
C-H-3-26	72.4	--	--	--	--	--	--	(h)

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	55.3	+80.5 -32.6	+282.7 - 46.2
0.2	65.2	+94.9 -38.5	+333.0 - 54.4

Notes:

(c) Failed at time shown
(h) Failed on loading

*Data from this specimen was used for the regression analysis.

TABLE 57

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697
Specimen Direction: Normal

Material Thickness: 0.025 cm
Temperature: 1366K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-H-2-12	37.9	0.01	0.02	0.03	0.06	0.10	0.10	117.3
*C-H-5-43	39.3	0.03	0.04	0.08	0.16	0.22	0.24	116.4
*C-H-4-29	41.4	0.01	0.05	0.15	0.26	0.31	0.32	121.0
*C-H-1-21	48.3	0.02	0.04	0.11	0.22	0.30	0.30	99.3
C-H-3-28	49.6	0.02	0.04	0.07	--	--	--	56.3 (c)
C-H-3-39	51.7	0.04	0.08	0.23	0.58	--	--	79.2 (c)

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	33.1	+18.0	+29.9
		-11.5	-15.5
0.2	40.5	+22.1	+36.6
		-14.1	-19.1

Notes:

(c) Failed at time shown

*Data from this specimen was used for the regression analysis.

TABLE 58

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3697
Specimen Direction: Normal

Material Thickness: 0.025 cm
Temperature: 1477K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown 0.1	1	10	50	100	Final	Test Duration (Hrs.)
*C-H-2-27	20.7	0.02	0.03	0.06	0.09	0.11	0.11	123.1
*C-H-5-44	20.7	0.02	0.03	0.05	0.09	0.17	0.22	113.0
*C-H-5-40	22.1	nil	nil	0.01	0.11	0.30	0.42	128.0
*C-H-3-19	22.1	0.01	0.02	0.07	0.20	0.38	0.43	113.3
*C-H-2-55	24.1	nil	0.01	0.03	0.14	0.31	0.45	137.1
*C-H-2-3	24.1	0.01	0.02	0.07	0.23	0.47	0.47	98.9

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours: Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	18.8	+2.3 -2.0	+3.2 -2.6
0.2	21.0	+2.6 -2.3	+3.6 -3.0

*Data from this specimen was used for the regression analysis.

TABLE 59

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712
Specimen Direction: Parallel

Material Thickness: 0.051 cm
Temperature: 1144K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-J-6-25	113.8	0.01	0.02	0.04	0.06	0.07	0.07	101.2
*C-J-4-8	124.1	0.03	0.05	0.10	0.19	0.25	0.25	101.4
*C-J-1-27	127.6	0.03	0.07	0.14	0.28	0.40	0.41	113.1
*C-J-2-18	131.0	0.04	0.06	0.14	0.28	0.41	0.44	113.7
*C-J-7-32	134.4	0.06	0.13	0.30	0.63	0.91	1.05	137.0
*C-J-5-19	141.3	0.05	0.12	0.33	0.77	1.20	--	116.0 (j)
C-J-8-27	110.3	0.01	0.03	0.05	0.08	0.10	0.10	112.0
C-J-6-44	110.9	0.02	0.03	0.05	0.07	0.08	0.08	123.2
C-J-3-45	103.4	0.01	0.02	0.03	0.04	0.05	0.05	101.1
C-J-8-29	103.4	0.01	0.02	0.04	0.06	0.08	0.08	100.0

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	116.0	+3.4 -3.3	+4.5 -4.3
0.2	122.0	+3.6 -3.5	+4.8 -4.6

Notes:

(j) Specimen failed at time shown; 100 hr. creep value is extrapolated

*Data from this specimen was used for the regression analysis.

TABLE 60

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712
Specimen Direction: Parallel
Material Thickness: 0.051 cm
Temperature: 1255K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-J-1-31	82.7	0.01	0.02	0.04	0.07	0.08	0.08	113.3
C-J-2-36	89.6	--	--	--	--	--	--	65.9 (k)
*C-J-4-14	89.6	0.02	0.04	0.07	0.11	0.14	0.14	116.6
*C-J-7-8	93.1	0.01	0.03	0.06	0.14	0.24	0.24	101.7
*C-J-7-15	93.1	0.03	0.05	0.11	0.20	0.27	0.30	117.5
*C-J-8-6	100.0	0.02	0.04	0.11	0.29	0.49	0.49	99.7
*C-J-5-31	103.4	0.06	0.12	0.39	0.65	0.98	0.98	101.1
C-J-7-41	79.3	0.01	0.03	0.05	0.07	0.08	0.08	100.6
C-J-5-44	79.3	0.01	0.02	0.03	0.03	0.04	0.04	100.0
C-J-8-26	72.4	0.01	0.01	0.01	0.02	0.02	0.02	101.0
C-J-2-45	72.4	0.02	0.03	0.04	0.05	0.06	0.06	113.2

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	85.1	+2.3 -2.2	+3.1 -3.0
0.2	90.8	+2.5 -2.4	+3.3 -3.2

Notes:

(k) Unloaded; erratic readings

*Data from this specimen was used for the regression analysis.

TABLE 61

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712 | Material Thickness: 0.051 cm
Specimen Direction: Parallel | Temperature: 1366K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
C-J-1-38	44.8	0.01	0.01	0.02	0.02	0.02	0.02	113.4
C-J-3-18	55.2	--	--	--	--	--	--	20.5 (1)
C-J-4-33	55.2	--	--	--	--	--	--	101.9 (b)
*C-J-6-7	62.1	0.02	0.03	0.04	0.05	0.06	0.06	101.3
*C-J-8-13	68.9	0.01	0.01	0.03	0.08	0.19	0.29	119.2
C-J-5-1	72.4	0.02	0.03	0.06	0.15	--	--	88.2 (c)
C-J-4-31	75.8	0.02	0.05	0.18	--	--	--	29.4 (c)
C-J-6-39	82.7	0.07	0.11	0.29	--	--	--	14.7 (c)
C-J-7-40	48.3	0.01	0.01	0.01	0.01	0.01	0.01	112.1
C-J-7-37	48.3	0.01	0.01	0.01	0.01	0.01	0.01	101.3
C-J-7-36	41.4	0.01	0.02	0.06	0.11	0.15	0.15	99.9
C-J-8-28	41.4	0.01	0.02	0.04	0.08	0.10	0.10	100.4

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	64.9	+3.4 -3.2	+7.3 -6.5
0.2	68.5	+3.6 -3.4	+7.7 -6.9

Notes:

(1) Discontinued at time shown; possible loose extensometer
(b) Void; extensometer erratic
(c) Failed at time shown

*Data from this specimen was used for the regression analysis.

TABLE 62

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712 Material Thickness: 0.051 cm
Specimen Direction: Parallel Temperature: 1477K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-J-4-36	31.0	0.01	0.02	0.02	0.03	0.03	0.03	100.3
*C-J-1-43	34.5	0.01	0.02	0.03	0.04	0.05	0.05	102.2
*C-J-5-40	37.9	0.01	0.03	0.05	0.06	0.07	0.07	123.0
C-J-8-7	41.4	0.01	0.02	0.02	0.03	0.03	0.03	115.5
*C-J-6-24	42.7	0.02	0.02	0.05	0.14	0.46	0.46	99.7
C-J-3-20	42.7	0.04	0.06	0.08	0.14	--	--	94.6 (c)
C-J-2-8	31.0	nil	nil	0.01	0.02	0.02	0.02	94.5
C-J-4-42	31.0	0.01	0.02	0.05	0.07	0.09	0.10	117.1
C-J-6-17	24.1	nil	nil	0.01	0.03	0.04	0.05	118.3
C-J-7-35	24.1	0.01	0.01	0.01	0.02	0.03	0.03	106.3

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	36.9	+8.0 -6.5	+12.6 - 9.3
0.2	40.1	+8.7 -7.1	+13.7 -10.1

Notes:

(c) Failed at time shown

*Data from this specimen was used for the regression analysis.

TABLE 63

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712 — Material Thickness: 0.051 cm
Specimen Direction: Normal — Temperature: 1144K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-J-4-22	75.8	0.01	0.03	0.06	0.10	0.12	0.12	100.1
*C-J-5-29	75.8	0.02	0.04	0.08	0.13	0.16	0.16	119.8
*C-J-3-4	82.7	0.01	0.04	0.11	0.19	0.23	0.26	136.8
*C-J-7-21	82.7	0.01	0.04	0.11	0.19	0.24	0.25	117.5
*C-J-2-3	89.6	0.02	0.08	0.22	0.39	0.56	0.61	122.5
*C-J-1-9	103.4	0.08	0.22	0.47	0.73	0.84	0.84	101.3
C-J-3-53	68.9	0.01	0.02	0.05	0.08	0.10	0.10	112.2
C-J-7-47	68.9	0.01	0.02	0.04	0.06	0.07	0.07	99.8
C-J-6-51	62.1	0.01	0.01	0.02	0.03	0.04	0.04	100.0
C-J-3-52	62.1	nil	0.01	0.02	0.03	0.04	0.04	113.1

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	70.7	+5.2 -4.8	+7.0 -6.3
0.2	79.4	+5.9 -5.4	+7.9 -7.1

*Data from this specimen was used for the regression analysis.

TABLE 64

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712
Specimen Direction: Normal
Material Thickness: 0.051 cm
Temperature: 1255K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-J-2-20	55.2	0.01	0.02	0.04	0.07	0.10	0.10	101.9
*C-J-6-13	55.2	0.01	0.03	0.07	0.12	0.15	0.15	101.2
*C-J-7-27	58.6	0.03	0.03	0.06	0.10	0.17	0.20	116.4
*C-J-3-28	58.6	0.04	0.06	0.10	0.18	0.25	0.29	138.7
*C-J-4-30	65.5	0.02	0.05	0.17	0.38	0.54	0.54	99.8
*C-J-1-12	68.9	0.03	0.11	0.35	0.64	0.79	0.79	101.2
C-J-7-43	51.7	0.01	0.02	0.04	0.05	0.06	0.06	100.0
C-J-4-50	51.7	0.01	0.02	0.05	0.09	0.11	0.12	123.4
C-J-7-46	44.8	0.01	0.02	0.04	0.06	0.07	0.07	99.8
C-J-8-10	44.8	0.01	0.01	0.02	0.02	0.03	0.03	100.2

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	53.5	+2.7 -2.5	+3.6 -3.4
0.2	58.1	+2.9 -2.8	+4.0 -3.7

*Data from this specimen was used for the regression analysis.

TABLE 65

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712
Specimen Direction: Normal
Material Thickness: 0.051 cm
Temperature: 1366K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-J-2-22	37.9	0.01	0.01	0.02	0.04	0.05	0.08	115.8
*C-J-1-51	39.3	0.01	0.02	0.05	0.12	0.32	0.45	119.8
C-J-6-33	39.3	--	--	--	--	--	--	(g)
*C-J-3-31	41.4	0.01	0.02	0.05	0.12	0.22	0.22	99.4
*C-J-1-16	41.4	0.01	0.02	0.04	0.11	0.25	0.26	102.1
*C-J-8-8	43.4	nil	0.01	0.03	0.12	0.25	0.33	114.8
C-J-5-9	48.3	0.01	0.04	0.19	1.1	2.9	4.1	121.6
C-J-1-35	34.5	nil	nil	nil	0.01	0.02	0.02	111.0
C-J-7-44	34.5	0.01	0.03	0.07	0.12	0.15	0.15	113.0
C-J-5-52	27.6	nil	0.01	0.02	0.04	0.05	0.05	117.1
C-J-7-45	27.6	nil	0.01	0.01	0.01	0.01	0.01	103.3

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	37.7	+7.4 -6.1	+10.5 - 8.1
0.2	40.7	+8.0 -6.6	+11.3 - 8.8

Notes:

(g) Temperature to 2100°F prior to loading; test not loaded

*Data from this specimen was used for the regression analysis.

TABLE 66

CREEP STRENGTH PROPERTIES OF TD-NiCr ALLOY SHEET

Heat Number: 3712
Specimen Direction: Normal

Material Thickness: 0.051 cm
Temperature: 1477K

Specimen Number	Stress (MN/m^2)	Creep Strain (%) at Time (Hrs.) Shown						Test Duration (Hrs.)
		0.1	1	10	50	100	Final	
*C-J-4-45	24.1	0.01	0.02	0.05	0.08	0.10	0.10	100.0
*C-J-5-12	25.5	0.01	0.02	0.03	0.03	0.04	0.04	100.3
*C-J-3-50	25.5	0.01	0.02	0.03	0.07	0.11	0.16	129.3
*C-J-8-15	27.6	0.01	0.02	0.05	0.15	0.33	0.33	102.1
*C-J-2-47	27.6	0.02	0.03	0.05	0.14	0.50	0.61	118.5
C-J-1-50	31.0	0.02	0.04	0.19	2.5	11.6	13.3	109.8
C-J-7-1	24.1	nil	nil	0.01	0.01	0.02	0.03	118.6
C-J-5-51	24.1	0.01	0.03	0.05	0.10	0.15	0.15	101.2
C-J-4-49	17.2	nil	0.01	0.01	0.01	0.01	0.01	111.2
C-J-1-53	17.2	0.01	0.01	0.01	0.01	0.01	0.01	113.1

RESULTS OF REGRESSION ANALYSIS

Creep Strain (Percent)	Stress to Produce Given Creep Strain in 100 Hours		
	Average (MN/m^2)	90 Percent Confidence Limits	95 Percent Confidence Limits
0.1	25.0	+3.5 -3.0	+5.0 -4.1
0.2	26.3	+3.7 -3.2	+5.3 -4.3

*Data from this specimen was used for the regression analysis.

APPENDIX G

BEARING PROPERTIES OF TD-NiCr ALLOY SHEET

TABLE 67

BEARING PROPERTIES OF TD-NiCr ALLOY SHEET*

Heat Number: 3636				Material Thickness: 0.051 cm	
Specimen Number	Specimen Direction	Temperature (K)		Ultimate Bearing Strength (MN/m^2)	Bearing Y. S. (MN/m^2)
B-D-1-6	Parallel	297		1020	1160
B-D-3-6				1410	1280
			Average	1215	1120
B-D-1-27	Normal	297		1230	1230
B-D-3-59				1380	--
			Average	1305	--
B-D-1-18	Parallel	922		847	768
B-D-3-18				810	--
			Average	828	--
B-D-1-61	Normal	922		902	826
B-D-4-35				794	--
			Average	848	--
B-D-2-5	Parallel	1144		398	353
B-D-5-9				388	351
			Average	393	352
B-D-2-45	Normal	1144		384	374
B-D-4-36				428	416
			Average	406	395
B-D-2-67	Parallel	1366		253	227
B-D-5-18				259	220
			Average	256	224
B-D-2-65	Normal	1366		255	232
B-D-5-17				254	233
			Average	254	232

TABLE 67 (CONT.)

BEARING PROPERTIES OF TD-NiCr ALLOY SHEET*

Heat Number: 3636			Material Thickness: 0.051 cm		
Specimen Number	Specimen Direction	Temperature (K)		Ultimate Bearing Strength (MN/m^2)	Bearing Y. S. (MN/m^2)
B-D-2-68	Parallel	1477		225	225
B-D-5-47				179	179
			Average	202	202
B-D-3-26	Normal	1477		218	218
B-D-				225	225
			Average	221	221

*Pin Diameter = .48 cm
Edge Distance Ratio = 2

TABLE 68

BEARING PROPERTIES OF TD-NiCr ALLOY SHEET*

Heat Number: 3637 Material Thickness: 0.025 cm

Specimen Number	Specimen Direction	Temperature (K)		Ultimate Bearing Strength (MN/m^2)	Bearing Y. S. (MN/m^2)
B-G-1-13	Parallel	297		615	615
B-G-5-30				747	699
			Average	681	657
B-G-1-30	Normal	297		704	704
B-G-7-15				692	692
			Average	698	698
B-G-2-7	Parallel	922		570	570
B-G-6-16				477	477
			Average	523	523
B-G-2-24	Normal	922		618	618
B-G-8-15				448	--
			Average	533	--
B-G-3-21	Parallel	1144		211	211
B-G-7-5				257	257
			Average	234	234
B-G-3-17	Normal	1144		262	262
B-G-8-29				278	278
			Average	270	270
B-G-6-46	Parallel	1366		158	158
B-G-6-47				201	201
			Average	179	179
B-G-5-41	Normal	1366		216	216
B-G-6-50				193	193
			Average	204	204

TABLE 68 (CONT.)

BEARING PROPERTIES OF TD-NiCr ALLOY SHEET*

Heat Number: 3637			Material Thickness: 0.025 cm		
Specimen Number	Specimen Direction	Temperature (K)		Ultimate Bearing Strength (MN/m^2)	Bearing Y. S. (MN/m^2)
B-G-6-48	Parallel	1477		135	135
B-G-6-49				148	148
			Average	141	141
B-G-6-4	Normal	1477		172	172
B-G-6-51				160	160
			Average	166	166

*Pin Diameter = .48 cm
Edge Distance Ratio = 2

TABLE 69

BEARING PROPERTIES OF TD-NiCr ALLOY SHEET*

Heat Number: 3697 Material Thickness: 0.025 cm

Specimen Number	Specimen Direction	Temperature (K)		Ultimate Bearing Strength (MN/m^2)	Bearing Y. S. (MN/m^2)
B-H-1-16	Parallel	297		665	665
B-H-3-36				765	765
			Average	715	715
B-H-1-7	Normal	297		734	734
B-H-3-48				927	927
			Average	830	830
B-H-1-50	Parallel	922		660	660
B-H-4-10				546	546
			Average	603	603
B-H-1-54	Normal	922		704	704
B-H-4-4				456	--
			Average	580	--
B-H-2-22	Parallel	1144		313	313
B-H-4-35				239	239
			Average	276	276
B-H-2-28	Normal	1144		252	252
B-H-4-43				279	279
			Average	265	265
B-H-2-45	Parallel	1366		213	213
B-H-5-27				155	155
			Average	184	184
B-H-2-56	Normal	1366		224	224
B-H-5-6				208	208
			Average	216	216

TABLE 69 (CONT.)

BEARING PROPERTIES OF TD-NiCr ALLOY SHEET*

Heat Number: 3697			Material Thickness: 0.025 cm		
Specimen Number	Specimen Direction	Temperature (K)		Ultimate Bearing Strength (MN/m^2)	Bearing Y. S. (MN/m^2)
B-H-3-2	Parallel	1477		191	191
B-H-5-50				188	188
			Average	189	189
B-H-5-49	Normal	1477		229	229
				188	188
			Average	208	208

*Pin Diameter = .48 cm
Edge Distance Ratio = 2

TABLE 70

BEARING PROPERTIES OF TD-NiCr ALLOY SHEET*

Heat Number: 3712 Material Thickness: 0.051 cm

Specimen Number	Specimen Direction	Temperature (K)		Ultimate Bearing Strength (MN/m^2)	Bearing Y. S. (MN/m^2)
B-J-1-5	Parallel	297		1234	1163
B-J-6-35				1234	1209
			Average	1234	1186
B-J-1-22	Normal	297		1252	--
B-J-5-4				1046	900
			Average	1149	--
B-J-2-16	Parallel	922		692	678
B-J-7-17				673	635
			Average	682	656
B-J-2-33	Normal	922		734	681
B-J-6-20				706	673
			Average	720	677
B-J-3-34	Parallel	1144		415	401
B-J-8-4				391	349
			Average	403	375
B-J-3-13	Normal	1144		429	406
B-J-7-9				409	389
			Average	419	398
B-J-4-16	Parallel	1366		226	201
B-J-5-20				246	222
			Average	236	211
B-J-3-26	Normal	1366		243	224
B-J-8-19				248	232
			Average	245	228

TABLE 70 (CONT.)

BEARING PROPERTIES OF TD-NiCr ALLOY SHEET*

Heat Number: 3712				Material Thickness: 0.051 cm	
Specimen Number	Specimen Direction	Temperature (K)		Ultimate Bearing Strength (MN/m^2)	Bearing Y. S. (MN/m^2)
B-J-7-36	Parallel	1477		190	190
B-J-7-37				196	189
			Average	193	190
B-J-4-5	Normal	1477.		224	224
B-J-7-38				198	198
			Average	211	211

*Pin Diameter = .48 cm
Edge Distance Ratio = 2

APPENDIX H

FATIGUE DATA ANALYSIS

The fatigue data for each heat and orientation with respect to the rolling direction were treated by a least-squares regression analysis to determine a curve of the form:

$$\log (\sigma - \sigma_0) = A + m \log N_f \tag{17}$$

which is equivalent to:

$$\sigma = B N_f^m + \sigma_0 \tag{18}$$

where σ is the maximum stress, N_f is the number of cycles to failure, and A, m, and σ_0 are constants to be determined by the regression $B = 10^A$.

Beginning with a value 0.1 ksi below the lowest input stress value and reducing it successively by 0.1 ksi, the program iterates on the value of σ_0, performing a least-squares fit of Equation (17) for each value of σ_0. The value of σ_0 for which the resulting fit gives the minimum sum of squares is chosen as the final value.

The program initially performs a fit of the regression model to only those input data points which represent specimen failures. Runout points (specimens which had not failed by the time at which the test was terminated) which occur at a lower stress than that given by the initial regression curve (which was determined by ignoring runouts) do not represent additional information, beyond that contained in the initial regression curve; they are not considered further. Those which occur at a greater stress than that predicted by the initial regression curve clearly should have some influence on the determination of the final regression. They are therefore included as failure points in a subsequent regression which represents an improvement of the initial fit curve as a representation of material behavior.

Confidence limits on log $(\sigma - \sigma_0)$, hence on logσ, are calculated by a formula analagous to that used to calculate confidence limits on log ϵ in the creep strength data analysis. As in the case of creep strength data, we take q = 1 to obtain the confidence bounds on a single future observation of log σ.

APPENDIX I

ROOM TEMPERATURE FATIGUE DATA OF TD-NiCr ALLOY SHEET

TABLE 71

ROOM TEMPERATURE FATIGUE DATA OF TD-NiCr ALLOY SHEET

Heat No.	Specimen No.	Specimen Direction	Stress (MN/m^2)	Cycles to Failure (10^3)
3637	F-G-5-13	Parallel	795	18
	F-G-4-43		795	18
	F-G-6-23		690	71
	F-G-7-21		690	15
	F-G-1-12		620	57
	F-G-2-1		620	63
	F-G-3-28		515	400
	F-G-4-10		515	224
	F-G-5-36		415	2,089
	F-G-6-10		415	822
3637	F-G-6-15	Normal	825	12
	F-G-6-30		825	.1
	F-G-7-4		690	27
	F-G-6-47		690	43
	F-G-2-38		620	61
	F-G-3-29		620	47
	F-G-5-12		515	462
	F-G-5-37		515	216
	F-G-4-21		415	1,207
	F-G-4-40		415	1,096
3712	F-J-5-34	Parallel	795	10
	F-J-5-36		795	14
	F-J-1-25		620	85
	F-J-2-35		620	89
	F-J-3-15		515	370
	F-J-3-32		515	385
	F-J-4-39		480	853
	F-J-4-41		480	458
	F-J-6-37		415	884
	F-J-7-33		415	3,635

TABLE 71 (CONT.)

ROOM TEMPERATURE FATIGUE DATA OF TD-NiCr ALLOY SHEET

Heat No.	Specimen No.	Specimen Direction	Stress (MN/m^2)	Cycles to Failure (10^3)
3712	F-J-3-1	Normal	795	8
	F-J-4-35		795	10
	F-J-1-13		620	41
	F-J-1-36		620	54
	F-J-2-1		515	443
	F-J-2-24		515	368
	F-J-8-21		480	1,303
	F-J-4-36		480	1,261
	F-J-6-6		415	9,800 (a)
	F-J-7-25		415	5,163 (a)

Notes:

(a) Specimen removed without failure

APPENDIX J

LINEAR THERMAL EXPANSION DATA FOR TD-NiCr AS A FUNCTION OF DIRECTION AND TEMPERATURE

TABLE 72

LINEAR THERMAL EXPANSION DATA FOR TD-NiCr AS A FUNCTION OF DIRECTION AND TEMPERATURE

A. Normal to rolling direction.

Specimen No.	Temperature (K)	Percent Expansion
N-1	529.8	0.3398
	855.5	0.8758
	1129.5	1.4137
	1265.2	1.7104
	1360.2	1.9282
	1468.2	2.2016
	1386.5	1.9921
	1132.5	1.4205
	856.8	0.8758
	534.2	0.3405
	863.8	0.8854
	1151.8	1.4655
	1251.8	1.6824
	1368.2	1.9610
	1460.8	2.1840
	1565.2	2.4499
	1362.2	1.9296
	1151.5	1.4679
	536.2	0.3528
N-2	448.2	0.2159
	839.8	0.8409
	1148.5	1.4564
	1361.2	1.9408
	1479.8	2.2206
	1573.2	2.4557
	1340.2	1.8892
	1264.5	1.7189
	835.8	0.8406
	520.2	0.3138
	859.5	0.8822
	1153.5	1.4687
	1253.8	1.6936
	1390.8	2.0037
	1493.2	2.2656
	1571.8	2.4520
	1129.5	1.4481
	387.2	0.1310

TABLE 72 (CONT.)

LINEAR THERMAL EXPANSION DATA FOR TD-NiCr AS A FUNCTION OF DIRECTION AND TEMPERATURE

B. Parallel to rolling direction.

Specimen No.	Temperature (K)	Percent Expansion
P-1	293.2	0.0000
	528.8	0.3465
	841.5	0.8636
	1130.8	1.4156
	1235.5	1.6431
	848.8	0.8673
	532.8	0.3465
	534.8	0.3472
	858.8	0.8866
	1128.8	1.4186
	1256.8	1.6820
	531.8	0.3365
	855.8	0.8684
	1127.8	1.4045
P-2	293.2	0.0000
	535.5	0.3541
	861.2	0.8947
	1154.2	1.4775
	1266.8	1.7290
	1373.5	1.9788
	1480.5	2.2256
	1576.2	2.4658
	1298.8	1.7955
	803.8	0.7723

APPENDIX K

EXPERIMENTAL CONDITIONS FOR EMITTANCE MEASUREMENTS OF TD-NiCr

TABLE 73

EXPERIMENTAL CONDITIONS FOR EMITTANCE MEASUREMENTS OF TD-NiCr

Conditions	Pressure	Specimen No.	Remarks
As-Received	213.3 $\mu N/m^2$	6	used for c_p checkout
As-Received	213.3 N/m^2	5	light gray
Polished	213.3 $\mu N/m^2$	7	metallic, splotchy
Polished	213.3 N/m^2	8	light gray
As-Received (a)	213.3 $\mu N/m^2$	4	greenish cast
As-Received (a)	213.3 N/m^2	1	light gray
Polished (a)	213.3 $\mu N/m^2$	11	greenish cast
Polished (a)	213.3 N/m^2	9	light gray - a few darker spots
As-Received (b)	213.3 $\mu N/m^2$	2	light gray
As-Received (b)	213.3 N/m^2	20	gray
Polished (b)	213.3 $\mu N/m^2$	12	metallic specks - Ni ?
Polished (b)	213.3 N/m^2	10	gray

Notes:

(a) Oxidized in air 1/2 hr. at 1311K.

(b) Oxidized in air 1/2 hr. at 1311K and 213.3 N/m^2 at 1422K for 25 hrs.

APPENDIX L

TOTAL HEMISPHERICAL EMITTANCE DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

TABLE 74

TOTAL HEMISPHERICAL EMITTANCE DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Conditions	Pressure	Spec. No.	Temp. (K)	ϵ_H
As-Received (First Heating)	213.3 $\mu N/m^2$	6	516.2	0.1792
" " "	"	"	697.5	0.2025
" " "	"	"	811.2	0.2209
" " "	"	"	1041.2	0.2404
" " "	"	"	1143.7	0.2507
" " "	"	"	1264.4	0.2594
" " "	"	"	1364.7 (a)	0.2704
As-Received (Second Heating)	213.3 $\mu N/m^2$	6	689.9	0.5002
" " "	"	"	802.4	0.5390
" " "	"	"	1029.4	0.6127
" " "	"	"	1137.2	0.6393
" " "	"	"	1261.8 (b)	0.6718
As-Received (First Heating)	213.3 N/m^2	5	699.4	0.2096
" " "	"	"	805.6	0.2263
" " " (c)	"	"	798.6	0.2340
" " "	"	"	923.6	0.2594
" " " (c)	"	"	914.4	0.2699
" " "	"	"	1018.8	0.3040
" " " (c)	"	"	1005.0	0.3213
" " "	"	"	1139.0	0.4552
" " " (c)	"	"	1114.5	0.4970
" " "	"	"	1233.3	0.5597
" " " (d)	"	"	1361.4	0.6758
" " " (d)	"	"	1479.0	0.7034
" " " (d)	"	"	1585.0	0.7037
As-Received (Second Heating)	213.3 N/m^2	5	702.7	0.5910
" " "	"	"	804.6	0.6083
" " "	"	"	920.4	0.6457
" " "	"	"	1023.9	0.6826

TABLE 74 (CONT.)

TOTAL HEMISPHERICAL EMITTANCE DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Conditions				Pressure	Spec. No.	Temp. (K)	ϵ_H
Polished (First Heating)				213.3 $\mu N/m^2$	7	697.1	0.1887
"	"	"		"	"	818.9	0.2025
"	"	"		"	"	920.5	0.2057
"	"	"		"	"	1056.5	0.2145
"	"	"		"	"	1184.1	0.2224
"	"	"		"	"	1186.2	0.2210
"	"	"		"	"	1251.0	0.2268
"	"	"		"	"	1355.2	0.2363
"	"	"		"	"	1354.4	0.2367
Polished (Second Heating)				213.3 $\mu N/m^2$	7	1192.9	0.2231
"	"	"		"	"	1322.6	0.2378
"	"	"		"	"	1500.3	0.2763
"	"	"	(e)	"	"	1463.0	0.3056
"	"	"	(e)	"	"	1433.2	0.3308
"	"	"	(e)	"	"	1414.3	0.3507
Polished (Cooling Curve)				213.3 $\mu N/m^2$	7	1154.9	0.3054
"	"	"		"	"	883.6	0.2527
"	"	"		"	"	703.9	0.2179
Polished (First Heating)				213.3 N/m^2	8	707.0	0.2111
"	"	"		"	"	803.5	0.2162
"	"	"		"	"	920.5	0.2345
"	"	"	(c)	"	"	913.5	0.2415
"	"	"		"	"	1026.6	0.2750
"	"	"	(c)	"	"	1010.3	0.2931
"	"	"		"	"	1150.1	0.4009
"	"	"	(c)	"	"	1108.8	0.4644
"	"	"		"	"	1253.7	0.5667
"	"	"	(f)	"	"	1249.7	0.5737
"	"	"		"	"	1378.9	0.6221
"	"	"	(c)	"	"	1365.4	0.6452
"	"	"		"	"	1468.7	0.6759
"	"	"	(g)	"	"	1466.5	0.6790
"	"	"		"	"	1592.0	0.6940

TABLE 74 (CONT.)

TOTAL HEMISPHERICAL EMITTANCE DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Conditions	Pressure	Spec. No.	Temp. (K)	ϵ_H
Polished (Second Heating)	213.3 N/m^2	8	1036.1	0.6655
" " "	"	"	922.2	0.6277
As-Received (First Heating) (h)	213.3 $\mu N/m^2$	4	697.0	0.4797
" " "	"	"	814.4	0.5172
" " "	"	"	913.1	0.5506
" " "	"	"	1036.9	0.5834
" " "	"	"	1142.7	0.6035
" " "	"	"	1268.0	0.6253
" " "	"	"	1356.0	0.6451
As-Received (Second Heating) (h)	213.3 $\mu N/m^2$	4	706.2	0.4883
" " "	"	"	807.7	0.5185
" " "	"	"	1027.6	0.5850
" " "	"	"	1162.0	0.6132
" " "	"	"	1245.2	0.6399
" " "	"	"	1286.7	0.6493
" " "	"	"	1356.2	0.6790
" " "	"	"	1473.2	0.7258
" " "	"	"	1564.2	0.7515
As-Received (Third Heating) (h)	213.3 $\mu N/m^2$	4	696.7	0.5146
" " "	"	"	815.0	0.5566
" " "	"	"	900.3	0.5840
" " "	"	"	1035.2	0.6243
" " "	"	"	1137.0	0.6533
" " "	"	"	1269.7	0.6914
" " "	"	"	1342.4	0.7121
" " "	"	"	1489.7	0.7540
" " "	"	"	1568.5	0.7774

TABLE 74 (CONT.)

TOTAL HEMISPHERICAL EMITTANCE DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Conditions	Pressure	Spec. No.	Temp. (K)	ϵ_H
As-Received (First Heating) (h)	213.3 N/m^2	1	695.4	0.4963
" " "	"	"	812.5	0.5401
" " "	"	"	912.5	0.5743
" " "	"	"	1029.9	0.6137
" " "	"	"	1136.0	0.6452
" " "	"	"	1273.4	0.6855
" " "	"	"	1331.8	0.7020
" " "	"	"	1476.1	0.7395
" " "	"	"	1543.4	0.7465
" " " (c)	"	"	1551.7	0.7299
As-Received (Cooling Curve) (h)	213.3 N/m^2	1	1440.9	0.7130
" " "	"	"	1362.7	0.6982
" " "	"	"	1246.3	0.6770
" " "	"	"	1136.0	0.6551
" " "	"	"	1026.4	0.6307
" " "	"	"	916.3	0.6019
" " "	"	"	800.9	0.5677
" " "	"	"	699.2	0.5414
Polished (First Heating) (h)	213.3 μ/m^2	11	701.3	0.5234
" " "	"	"	809.3	0.5639
" " "	"	"	921.0	0.5962
" " "	"	"	1029.7	0.6250
" " "	"	"	1150.3	0.6531
" " "	"	"	1252.0	0.6508
" " "	"	"	1246.0	0.6625
Polished (Second Heating) (h)	213.3 μ/m^2	11	698.0	0.4892
" " "	"	"	1149.1	0.6293
" " "	"	"	1265.9	0.6608
" " "	"	"	1384.4	0.6881
" " "	"	"	1480.2	0.7226
" " "	"	"	1545.4	0.7551
" " "	"	"	1573.4	0.7775
Polished (Cooling Curve) (h)	213.3 $\mu N/m^2$	11	1159.3	0.6692
" " "	"	"	1158.7	0.6703
" " "	"	"	918.5	0.5874

TABLE 74 (CONT.)

TOTAL HEMISPHERICAL EMITTANCE DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Conditions	Pressure	Spec. No.	Temp. (K)	ϵ_H
Polished (First Heating) (h)	213.3 N/m^2	9	695.2	0.5498
" " "	"	"	812.7	0.5916
" " "	"	"	926.3	0.6341
" " "	"	"	1037.0	0.6630
" " "	"	"	1150.1	0.6886
" " "	"	"	1271.2	0.7183
" " "	"	"	1374.2	0.7384
" " "	"	"	1495.0	0.7495
" " "	"	"	1603.4	0.7236
" " " (c)	"	"	1608.2	0.6877
Polished (Cooling Curve) (h)	213.3 N/m^2	9	1492.9	0.6680
" " "	"	"	1378.5	0.6517
" " "	"	"	1265.7	0.6317
" " "	"	"	1158.4	0.6135
" " "	"	"	1042.7	0.5891
" " "	"	"	930.4	0.5595
" " "	"	"	826.9	0.5298
" " "	"	"	699.3	0.4907
As-Received (First Heating) (i)	213.3 $\mu N/m^2$	2	702.1	0.5661
" " "	"	"	813.4	0.6014
" " "	"	"	924.7	0.6299
" " "	"	"	1034.4	0.6638
" " "	"	"	1148.3	0.6947
" " "	"	"	1259.3	0.7232
" " "	"	"	1375.2	0.7523
" " "	"	"	1485.2	0.7797
" " "	"	"	1601.4	0.8007
" " " (c)	"	"	1606.4	0.7911
As-Received (Cooling Curve) (i)	213.3 $\mu N/m^2$	2	1479.7	0.7526
" " "	"	"	1365.4	0.7201
" " "	"	"	1257.0	0.6918
" " "	"	"	1145.1	0.6631
" " "	"	"	1034.4	0.6341
" " "	"	"	922.4	0.6054
" " "	"	"	811.4	0.5740
" " "	"	"	700.2	0.5411

TABLE 74 (CONT.)

TOTAL HEMISPHERICAL EMITTANCE DATA FOR TD-NiCr
FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Conditions	Pressure	Spec. No.	Temp. (K)	ϵ_H
As-Received (Second Heating) (i)	213.3 $\mu N/m^2$	2	697.4	0.5438
" " "	"	"	921.0	0.6061
" " "	"	"	1144.7	0.6667
" " "	"	"	1362.0	0.7256
As-Received (Cooling Curve) (i)	213.3 $\mu N/m^2$	2	1256.0	0.6976
" " "	"	"	1032.7	0.6378
" " "	"	"	812.5	0.5764
As-Received (First Heating) (i)	213.3 N/m^2	20	705.7	0.6462
" " "	"	"	813.0	0.6724
" " "	"	"	920.9	0.7018
" " "	"	"	915.6	0.7022
" " "	"	"	1033.1	0.7266
" " "	"	"	1143.1	0.7550
" " "	"	"	1257.9	0.7811
" " "	"	"	1366.3	0.8103
" " "	"	"	1483.7	0.8127
" " "	"	"	1589.7	0.8240
As-Received (Cooling Curve) (i)	213.3 N/m^2	20	1519.9	0.7893
" " "	"	"	1361.5	0.7633
" " "	"	"	1261.2	0.7485
" " "	"	"	1142.8	0.7340
" " "	"	"	1036.4	0.7179
" " "	"	"	917.6	0.6989
" " "	" "	"	812.5	0.6763
" " "	"	"	699.6	0.6672
Polished (First Heating) (i)	213.3 $\mu N/m^2$	12	714.7	0.5538
" " "	"	"	805.3	0.5834
" " "	"	"	932.5	0.6215
" " "	"	"	1028.4	0.6475
" " "	"	"	1167.2	0.6794
" " "	"	"	1243.9	0.6965
" " "	"	"	1409.7	0.7303
" " "	"	"	1466.2	0.7357
" " "	"	"	1558.9	0.7519
" " " (c)	"	"	1561.8	0.7439

TABLE 74 (CONT.)

TOTAL HEMISPHERICAL EMITTANCE DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Conditions	Pressure	Spec. No.	Temp. (K)	ϵ_H
Polished (Cooling Curve) (i)	213.3 $\mu N/m^2$	12	1493.3	0.7229
" " "	"	"	1418.5	0.7035
" " "	"	"	1342.3	0.6839
" " "	"	"	1249.2	0.6635
" " "	"	"	1139.6	0.6384
" " "	"	"	1041.5	0.6162
" " "	"	"	932.7	0.5736
" " "	"	"	718.1	0.5328
Polished (First Heating) (i)	213.3 N/m^2	10	778.2	0.6161
" " "	"	"	906.7	0.6576
" " "	"	"	1018.2	0.6974
" " "	"	"	1132.7	0.7289
" " "	"	"	1236.0	0.7606
" " "	"	"	1354.2	0.7893
" " "	"	"	1449.2	0.8103
" " "	"	"	1576.0	0.8339
" " " (c)	"	"	1593.0	0.8014
Polished (Cooling Curve) (i)	213.3 N/m^2	10	1457.4	0.7716
" " "	"	"	1334.4	0.7472
" " "	"	"	1252.2	0.7431
" " "	"	"	1144.2	0.7080
" " "	"	"	1033.2	0.6852
" " "	"	"	919.7	0.6510
" " "	"	"	810.0	0.6197
" " "	"	"	699.2	0.5914

Notes:

(a) Temperature then raised to approximately 1460K and ϵ_H began to increase rapidly, temperature fell, and extensive coating formed on window and inside of bell jar.

(b) Sample was then heated to approximately 1360K and ϵ_H increased rapidly, temperature decreased and coating formed on window and bell jar.

(c) After 5 minutes at constant power

(d) At equilibrium

TABLE 74 (CONT.)

TOTAL HEMISPHERICAL EMITTANCE DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Notes: (continued)

(e) After 2 minutes at constant power input

(f) After 3 minutes at constant power

(g) After 1 minute at constant power

(h) Oxidized in air 1/2 hour at 1311K

(i) Oxidized in air 1/2 hour at 1311K and 213.3 N/m^2 at 1422K for 25 hours

APPENDIX M

ELECTRICAL RESISTIVITY DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

TABLE 75

ELECTRICAL RESISTIVITY DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Conditions	Pressure	Specimen No.	Temp. (K)	Resistance (Ohm cm x 10^6)
Polished (First Heat)	213.3 $\mu N/m^2$	7	697.1	112.228
" " "	"	"	818.9	113.540
" " "	"	"	920.5	112.310
" " "	"	"	1056.5	111.799
" " "	"	"	1184.1	112.374
" " "	"	"	1186.2	112.410
" " "	"	"	1251.0	112.885
" " "	"	"	1355.2	114.013
" " "	"	"	1354.4	113.999
Polished (Second Heat)	213.3 $\mu N/m^2$	7	1192.9	112.536
" " "	"	"	1322.6	113.774
" " "	"	"	1500.3	116.595
" " " (a)	"	"	1463.0	116.421
" " " (a)	"	"	1433.2	116.194
" " " (a)	"	"	1414.3	116.094
Polished (Cooling Curve)	213.3 $\mu N/m^2$	7	1154.9	112.938
" " "	"	"	883.6	112.468
" " "	"	"	703.9	111.948
Polished (First Heat)	213.3 N/m^2	8	707.0	112.715
" " "	"	"	803.5	113.866
" " "	"	"	920.5	112.643
" " " (b)	"	"	913.5	112.733
" " "	"	"	1026.6	112.245
" " " (b)	"	"	1010.3	112.257
" " "	"	"	1150.1	112.500
" " " (b)	"	"	1108.8	112.381
" " "	"	"	1253.7	113.654
" " " (c)	"	"	1249.7	113.550
" " "	"	"	1378.9	114.553

TABLE 75 (CONT.)

ELECTRICAL RESISTIVITY DATA FOR TD-NiCr FOR VARIOUS SURFACE CONDITIONS, TEMPERATURES, AND PRESSURES

Conditions	Pressure	Specimen No.	Temp. (K)	Resistance (Ohm cm x 10^6)
Polished (First Heat)	213.3 N/m^2	8	1365.4	114.364
" " "	"	"	1468.7	115.585
" " " (d)	"	"	1466.5	115.558
" " "	"	"	1592.0	117.265
Polished (Second Heat)	213.3 N/m^2	8	1036.1	112.220
" " "	"	"	922.2	112.613
As-Received (First Heat)	213.3 N/m^2	5	699.4	112.670
" " "	"	"	805.6	113.989
" " " (b)	"	"	798.6	114.170
" " "	"	"	923.6	112.730
" " " (b)	"	"	914.4	112.762
" " "	"	"	1018.8	112.332
" " " (b)	"	"	1005.0	112.333
" " "	"	"	1139.0	112.601
" " " (b)	"	"	1114.5	112.463
" " "	"	"	1233.3	113.264
" " " (e)	"	"	1361.4	114.406
" " " (e)	"	"	1479.0	115.828
" " " (e)	"	"	1585.0	117.182
As-Received (Second Heat)	213.3 N/m^2	5	920.4	112.834
" " "	"	"	1023.9	112.406

Notes:
(a) *After 2 minutes at constant power input*
(b) After 5 minutes at constant power
(c) After 3 minutes at constant power
(d) After 1 minute at constant power
(e) At equilibrium

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16. Abstract

Sheets of TD-NiCr processed using techniques developed to produce uniform material were tested to supply mechanical and physical property data. Two heats each of 0.025 and 0.051 cm thick sheet were tested.

Mechanical properties evaluated included tensile, modulus of elasticity, Poisson's Ratio, compression, creep-rupture, creep strength, bearing strength, shear strength, sharp notch and fatigue strength. Test temperatures covered the range from ambient to 1589K.

Physical properties were also studied as a function of temperature. The physical properties measured were thermal conductivity, linear thermal expansion, specific heat, total hemispherical emittance, thermal diffusivity, and electrical conductivity.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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