FOR FIGURES 1 THRU 38 SEE FILE COPY.

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REPORT

ON

THE RUPTURE AND TOTAL DEFORMATION PROPERTIES OF FOUR SHEET MATERIALS AT 1800° AND 2000°F

by

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SUMMARY

The properties of Hastelloy X, N-155, HS-25 and vacuum melted Jetalloy 1570 in sheet form were evaluated at 1800° and 2000°F. The evaluation covered rupture strengths and total-deformation strengths for 2.0, 1.0, 0.5, 0.2 and 0.1 percent in time periods from 5 to 300 hours. Due to the few test specimens supplied, some of the total-deformation strengths were not established for all alloys.

Data from previous investigations of the alloys in sheet form were incorporated into the report. These data were used to extend the range of data down to 1200°F for Hastelloy X, and to 1600°F for N-155 and HS-25 alloys.

One heat of HS-25 alloy had the highest strengths at 1800° and 2000°F. The other two heats of HS-25 alloy had intermediate properties. The Jetalloy 1570 had the lowest strengths, except for equal or slightly lower rupture strengths for Hastelloy X. The limited deformation strengths for Jetalloy 1570 were a smaller fraction of the rupture strengths than for the other three alloys. Aluminum coating of Jetalloy 1570 by two methods did not improve strength appreciably.

The variation in properties of HS-25 alloy between heats illustrates the influence of such variables as heat treatment and melting practice on properties of the alloys considered. It could not be determined from the available information to what degree the observed variations between alloys was due to nominal chemical composition and the heat treatment and melting practice variables.

INTRODUCTION

The creep-rupture properties of Hastelloy X, N-155, HS-25 and vacuum melted Jetalloy 1570 sheet were evaluated at 1800° and 2000°F. The properties reported include rupture strengths and stresses for total deformations of 0.1, 0.2, 0.5, 1.0 and 2.0 percent for time periods up to 300 hours. The materials examined were all approximately 0.060-inch thick except samples from two heats of HS-25 alloy which were about 0.085-inch thick. All specimens were taken transverse to the rolling direction of the sheets except for longitudinal specimens from one heat of HS-25 alloy. All materials were annealed in accordance with applicable AMS Specifications except for aluminum coated Jetalloy 1570 specimens.

The Jetalloy 1570 material was tested in the as-produced condition and after coating by the Solar Alcote process and with aluminum by Whitfield and Sheshanoff.

The properties of all the alloys except Jetalloy 1570 had previously been established at lower or overlapping temperatures. These properties have been incorporated into the present report in order to have all the data in one report.

TEST MATERIALS

were submitted from three different heats with the actual analysis given for only one heat. An analysis was not supplied for the Hastelloy X material. The Jetalloy 1570 sheet had been made from a vacuum melted heat.

Machined specimens ready for testing were supplied by the Wright Aeronautical Division. These were 1-inch wide by 22-inches long with a 0.500-inch wide by 2.25-inch long gage section at the center. All specimens had been taken transverse to the sheet direction except longitudinal specimens of HS-25 alloy from Heat BO-336. All sheets were approximately 0.060-inch thick except those from two heats of HS-25 alloy which were approximately 0.085-inch thick. (See Table I)

Specimens were submitted from three heats of HS-25 alloy due to lack of sufficient material for the required number of specimens from any one heat. It was not done to compare heats.

The sheets had been heat treated as follows:

Hastelloy X - Annealed to AMS 5536

N-155 - Annealed to AMS 5532

HS-25 - Annealed to AMS 5537

Jetalloy 1570 uncoated -- not reported.

One group of specimens of Jetalloy 1570 were supplied with a coating produced by the Solar Alcote process. The type of coating was designated as S10-33A and it was reported that this involved a firing cycle of 1/2 hour at 1400°F plus a diffusion cycle of 1 hour at 1900°F. The specimens were finally cleaned by the Hydrohone process using 240 grit alumina.

Another group of Jetalloy 1570 specimens coated with aluminum by Whitfield and Sheshanoff were also supplied for testing. Details of the thermal treatments involved were not reported.

PROCEDURE

Rupture tests at three or four stresses were used to establish stress-rupture time curves between 5 and 300 hours. Creep was measured during the rupture tests and creep curves plotted. Creep tests at stresses below the rupture strengths for 300 hours were run to obtain necessary total deformation data. The time periods for total deformations of 0.1, 0.2, 0.5, 1.0 and 2.0 percent were taken from the creep curves and used to plot stress versus time for total deformation curves. Elongations were measured from gage marks for the fractured rupture-test specimens. There were not sufficient specimens of HS-25 and Jetalloy 1570 alloys to obtain all the desired total deformation data. Tests were limited to rupture tests in these cases.

When additional data of the same type were available from prior studies of the alloys it was incorporated into the report.

The total deformation values reported include the deformation during loading of the specimens as well as the subsequent creep.

The stresses for the tests on coated specimens of Jetalloy 1570 were based on the dimensions before coating, not on the dimensions after coating.

The stress-rupture tests were conducted in single units of the dead weight-beam loaded type, except when low stresses required the use of a direct load.

The following procedure was used to bring the specimens to temperature:

1. The specimens were set up in the units and the heat turned on at 4:00 p.m. to bring the temperature within 50°F of the desired temperature by 5:00 p.m.

2. The specimens were allowed to stand overnight, the temperature raised to test temperature between 8:00 and 9:00 a.m. the next day.

3. Final adjustments to test temperature and for temperature distribution along the length of the specimen were made so that stress could be applied by 1:00 p.m.

4. Time-elongation data were secured by means of extensometers. Collars were fixed on the upper and lower shoulders of the specimens by means of pins inserted through holes drilled in the specimen shoulder. Extension rods were attached to the collars and extended out of the furnace. Rollers carrying a mirror were inserted between each pair of upper and lower extension rods. As the specimen elongated, the mirrors rotated and the rotation was measured by a scale reflected in the mirrors to a telescope.

The readings on both sides of the specimens were taken and averaged. The sensitivity of the extensometer system was 0.000003 inches per inch in the 2-inch gage length.

Inasmuch as the extensometers were attached to the shoulders, the observed deformation included elongation in the fillets and a portion of the shoulders of the specimen as well as the reduced section. A system of correcting the deformation through a calculated "effective gage length" was used.

RESULTS

The properties of each alloy are presented in the following sections. The incorporation of data previously obtained for some of the alloys extends the property data to temperatures lower than 1800°F and, in some cases, provided comparative properties between heats for 1800°F. The properties of the four alloys are compared in a final section.

The basic objective was to obtain rupture-and total-deformation strengths for time periods between 5 and 300 hours. The practice of measuring creep during the rupture tests permitted establishment of total deformation strengths back to less than one hour in many cases. In a number of cases insufficient specimens were supplied for establishment of total-deformation strengths to 300 hours.

The primary test data for all alloys are the rupture times and elongations, the deformations during loading and the time periods to attain the total deformations of interest. Elongations at fracture are indicated at all rupture data points shown in the figures.

Hastelloy X Sheet

The test data are summarized in Table II. This table includes data at 1600°F which had previously been reported by letter for P. O. FX60962 (Project 2317) under date of August 23, 1955.

The stress-rupture time curves are shown as Figure 1. This figure includes curves at 1200°, 1350°, 1500°, 1650 and 1800°F for Heat X1037 from Report 2540-5-P, "The Properties of Hastelloy X Sheet at 1200° to 1800°F" submitted under date of November 2, 1956 under P. O. FX27866-1. The rupture strengths defined by the curves of Figure 1 for time periods from 5 to 300 hours are summarized in Table III.

The curves of stress versus time for total deformation for 1800° and 2000°F are shown as Figures 2a and 2b. Figure 2a includes curves at 1600°F from the August 23, 1955 letter report. The stresses for total deformations in specific time periods as defined by these curves are summarized in Table III. The stress-time for total-deformation curves from Report 2540-5-P are not repeated in this report. The deformation strengths are, however, included in Table III.

The rupture- and total-deformation strengths are shown graphically as a function of temperature in Figure 3 through 8. The strengths of Heat X107 used for this investigation were slightly higher than those for Heat X1037 used for Report 2540-5-P. It should be noted that Heat X107 apparently had higher yield strengths than Heat X1037 at the lower temperatures. The smaller deformations were largely introduced during loading for Heat X1037 while they were more dependent on creep for Heat X107 because of its higher yield strength.

Elongations of the rupture specimens were somewhat higher in the tests at 2000°F than at 1800° or 1600°F. Comparison of the values from this investigation with those in Report 2540-5-P for Heat X1037 indicate that Heat X1037 had somewhat higher elongations in rupture tests.

N-155 Sheet

The primary test data for N-155 sheet are summarized in Table IV. The data at 1800° and 2000°F are supplemented by the data at 1600°F from a letter report submitted under P. O. FX60962 (Project 2317) under date of February 15, 1955.

The stress-rupture time curves are shown as Figure 9 and the stress-time for total deformation curves as Figure 10. The rupture- and total-deformation strengths defined by these curves are summarized in Table V and shown graphically as a function of temperature by Figures 11 through 16.

The elongations in the rupture tests fell to as low as 5 percent for time periods longer than 100 hours at 1800° and 2000°F. At 1600°F the elongations stayed above 10 percent.

HS-32 Sheet

The primary test data are summarized in Table VI. The data obtained at 1800° and 2000°F is supplemented by data for 1600°F as submitted in a letter report under P. O. FX60962 (Project 2317) under date of August 23, 1955.

Specimens from three heats were used for the tests at 1800° and 2000°F. The specimens supplied from any one heat were insufficient to establish both the rupture- and total-deformation properties. There was a large difference in properties between Heat L1061 and the other two heats. The latter two also differed sufficiently in total-deformation characteristics so that they could not be used jointly to establish single curves. In addition, there was considerable question because originally two setsof specimens were taken transverse and the other longitudinal to the sheet. Consequently, the total-deformation curves are not well established at the longer time periods.

The stress-rupture time curves, Figure 17, show the superior rupture strength of Heat L1061 for time periods longer than about 30 hours at 1800° and about 3 hours at 2000°F. There was no appreciable difference at 1600°F. Heat L1061 had much lower elongation in the rupture tests than the other two heats. The other two heats increased in elongation with test temperature whereas there was little change for Heat L1061. These differences may be a reflection of the thinner gage for the specimens from Heat L1061.

The specimens from Heat BO-336 were taken longitudinal to the original sheet while the specimens from the other two heats were transverse. It is not known to what degree this influenced relative properties.

Stress time for total-deformation curves are shown as Figures 18 through 20. It will be noted that the curves for Heat L1061 tended to show breaks causing steep curves at 1600° and 1800°F. The curves for the other two heats did not develop this tendency until the temperatures were raised to 1800° and 2000°F.

The rupture- and total-deformation strengths defined by Figures 18 through 20 are summarized in Table VII and shown graphically as a function of temperature by Figures 21 through 26.

Vacuum Melted Jetalloy 1570 Sheet

The primary test data are summarized in Table VIII. Three types of material were tested: (1) as-produced uncoated sheet, (2) specimens coated with Solar Alcote, and (3) specimens coated by an aluminum coating process of Whitfield and Sheshanoff. No data were available from prior work on Jetalloy 1570 sheet.

The stress-rupture time curves, Figure 27, show that the coated specimens had higher rupture strength at 1800°F than the uncoated specimens but that there was no significant difference in strengths at 2000°F. The properties of the specimens coated by the two processes were similar.

The elongation at rupture for the uncoated material appeared to first decrease and then increase with rupture time at 1800°F, and was considerably higher at 2000° than at 1800°F. The coated specimens may have had slightly higher elongation at 1800°F although there was little effect at either temperature.

The stress time for total-deformation curves are shown as Figures 28 and 29. It will be noted that there were insufficient specimens to establish the total-deformation curves to 300 hours. The coated specimens had superior deformation strengths at 1800°F similar to the superiority shown in rupture strengths. The limited deformation superiority for coated specimens also occurred at 2000°F, even though no significant difference was indicated by the rupture tests. The limited deformation strengths of the Jetalloy 1570 material were a smaller fraction of the rupture strengths, particularly at 1800°F, than for the other alloys reported here.

The rupture- and total-deformation strengths defined by the curves of Figures 28 through 29 are summarized in Table IX and shown graphically as a function of temperature in Figures 30 through 35.

DISCUSSION

The relative strengths of the four alloys in sheet form are summarized by Table X and Figures 36, 37 and 38. The properties compared in the table and figures are the 10, 100 and 300-hour strengths so as to cover the range comparatively. Consideration of the data show that:

1. The highest strengths were exhibited by Heat L1061 of HS-25 alloy at 1800° and 2000°F. At 1600°F, Heat E30801 of HS-25 and the N-155 alloys tended to be stronger.

2. While Heat L1061 of HS-25 was the strongest material considered, the other two heats of HS-25 alloy gave intermediate strengths.

3. The weakest material considered at 1800° and 2000°F was the Jetalloy 1570. It seems evident that this would be true even where comparative data were not established. The only exception to this was rupture strengths where the Hastelloy X tended to be the weakest.

It is common experience to find more variation between heats of one alloy than there are differences between alloys when the materials have been developed for equivalent types of service. The data for HS-25 alloy illustrate this point quite well. It is, however, not possible from the data to estimate whether or not Jetalloy 1570 would have compared better if more heats had been tested. The two heats of Hastelloy X tested had quite similar properties, although again data on more heats would be needed to be sure that this agreement would be maintained.

So far as is known there are two major reasons for variations of properties within a given alloy. The conditions used for heat treatment can vary between producers under the applicable specifications. When properties are fairly sensitive to conditions of heat treatment, the normal variation in conditions of control during heat treatment can be expected to influence properties. In addition, the response to a given heat treatment is sometimes quite sensitive to prior conditions of working. This is especially true for sheet where the heat treatment times are usually quite short and often kept to lower temperatures.

The other source of variation is the heat-to-heat variation for a given producer and between producers. It is now known that such elements as oxygen and nitrogen in combination with elements commonly added for "deoxidation," such as B, Zr, Mg, Al, Ti, etc. can have a profound effect on properties. There is no information available to the authors on the effects of these elements for temperatures as high as 1800° and 2000°F; or on the particular alloys considered at any temperature. It is presumed, however, that such variations are probably the major reason for the differences between the HS-25 alloy heats. It is not known to what degree the vacuum melting of the Jetalloy 1570 might have been involved.

Test temperatures of 1800° and 2000°F are sufficiently high so that one might anticipate that oxidation during testing could influence results. The factor is not clear from the data. Any of the variations encountered between alloys could just as well be due to the first two factors. Certainly aluminum coating the Jetalloy 1570 did not improve properties beyond what might be anticipated from the differences in thermal history involved. The thinnest HS-25 alloy sheet had the highest strengths. This could reflect absorption of oxygen and nitrogen from the atmosphere although it is more likely that it reflected a difference in heat treatment.

TABLE I

SHEET THICKNESS AND AVAILABLE CHEMICAL COMPOSITION FOR THE FOUR ALLOYS

	Hastelloy X	N-155	HS-25			Jetalloy 1570*
Heat No.	X-107	M-1048	L-1061,	E-30801,	BO-336	1044*
Thickness (inch)	0.064	0.063	0.062,	0.087,	0.085	0.059
Chemical Composition (%)	not available			not available	not available	
C		0.10	0.06			0.20
Cr		20.99	20.53			20.32
W		2.35	14.95			7.5
Fe		Bal.	2.85			2.2
Si		0.62	0.50			--
Co		19.77	Bal.			39.64
Ni		20.22	9.75			25.39
Mn		1.46	1.53			--
Mo		3.20	--			--
N_2		0.10	--			--
Cb + Ta		0.91	--			--
P		0.017	0.009			--
S		0.011	0.009			--
Ti		--	--			4.6

* Vacuum melted.

Note: All specimens taken to transverse direction of sheet except for longitudinal specimens from Heat BO-336 of HS-25 alloy.

TABLE II

STRESS-RUPTURE AND STRESS-TOTAL DEFORMATION DATA FOR SHEET SPECIMENS OF HASTELLOY X ALLOY AT 1600°, 1800° AND 2000°F (0.064-INCH THICK SHEET FROM HEAT X-107 TO AMS SPECIFICATION 5536)

Spec. No.	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Deformation on loading (%)	Time for Specified Total Deformation (hours)				
					0.1%	0.2%	0.5%	1.0%	2.0%
				1600°F					
2	12,000	24.6	15.0 (a)	0.0787	0.07	0.3	1.2	2.9	6.3
1	9,000	110.1	7.5 (a)	0.0524	0.65	3.15	14.0	30.0	---
4	7,500	256.5	5.0 (a)	0.0410	2.5	16.0	42.0	100.0	191.
				1800°F					
21	8,000	6.5	16.5	0.069	0.015	0.06	0.225	0.52	1.15
20	5,600	32.6	10.5	0.044	0.29	1.08	4.0	7.5	13.7
19	4,000	96.8	6.0	0.028	2.55	9.5	24.0	38.2	56.
33	3,300	278.5	7.5	0.020	10.	30.	74.	125.	204.
24	3,000	429.1	6.5	0.017					
22	2,750	518.	7.0	0.0133	27.	94.	212.	324.	428.
23	2,232	317. (d)	-----	0.011	155.	233.	---	---	---
				2000°F					
29	4,000	7.4	14.5	0.045	0.04	0.11	0.33	0.67	1.22
28	3,000	13.4	20.5	0.0255	0.08	0.20	0.62	1.31	2.65
27	2,143	69.3	13.0	0.015	1.05	3.13	8.8	15.7	25.9
30	1,400	366.2	11.8	0.008	5.2	15.6	45.0	82.0	132.5
31	1,100	243.3 (d)	-----	0.0065	11.5	31.5	78.0	136.0	232.
32	800	270.4 (d)	-----	0.0045	41.6	86.8	191.	338.	---

(a) in gage mark
(d) discontinued

Note: Data for 1600°F taken from letter report under P.O. FX60962 (Project 2317) dated August 23, 1955.

TABLE III

RUPTURE AND TOTAL DEFORMATION STRENGTHS FOR HASTELLOY X SHEET AT 1200°, 1350°, 1500°, 1600°, 1650°, 1800° AND 2000°F

Heat No.	Test Temp (°F)	Rupture or Total Deformation Strengths (psi) for Indicated Time Periods (hours)						
		1-hr	5-hr	10-hr	25-hr	50-hr	100-hr	300-hr
					Rupture Strength			
X1037	1200		65,000	60,000	54,000	48,500	44,000	37,000
X1037	1350		42,000	37,500	32,000	28,500	25,500	21,000
X1037	1500		24,750	21,500	18,500	16,500	14,500	12,000
X107	1600		--	(14,200)	12,000	10,600	9,200	7,400
X1037	1650		13,000	11,500	9,900	8,800	7,800	6,500
X1037	1800		8,200	7,000	5,700	4,750	4,000	3,200
X107	1800		8,500	7,200	5,800	4,900	4,200	3,250
X107	2000		4,200	3,500	2,300	2,350	1,950	1,480
					2.0 Percent Total Deformation Strength			
X1037	1200	45,000	43,900	43,200	40,000	36,600	33,200	
X1037	1350	38,500	30,700	27,300	23,000	21,300	19,500	
X1037	1500	22,500	18,300	16,500	14,250	13,400	12,500	
X107	1600	--	12,500	11,300	10,000	9,000	8,200	7,100
X1037	1650	13,200	10,600	9,600	8,350	7,500	6,700	
X1037	1800	8,300	6,100	5,200	4,500	4,000	3,500	
X107	1800	8,200	6,500	5,900	5,000	4,300	3,750	3,000
X107	2000	3,850	2,900	2,500	2,150	1,850	1,450	1,000
					1.0 Percent Total Deformation Strength			
X1037	1200	42,000	39,200	38,000	36,500	33,600	29,800	
X1037	1350	34,700	27,000	23,700	21,700	18,800	17,000	
X1037	1500	20,500	16,600	15,000	13,600	12,600	11,750	
X107	1600	--	11,300	10,200	9,100	8,200	7,400	
X1037	1650	12,000	9,700	8,700	7,500	6,900	6,200	
X1037	1800	7,300	5,600	4,800	4,200	3,700	3,200	
X107	1800	7,300	5,900	5,300	4,400	3,900	3,400	2,750
X107	2000	3,500	2,600	2,300	1,950	1,550	1,200	830

TABLE III (con d.)

Heat No.	Test Temp (°F)	1-hr	5-hr	10-hr	25-hr	50-hr	100-hr	300-hr
		Rupture or Total Deformation Strengths (psi) for Indicated Time Periods (hours)						
		0.5 Percent Total Deformation Strength						
X1037	1200	38,000	36,000	35,000	33,500	29,200	25,000	
X1037	1350	30,750	24,000	21,000	18,000	16,500	14,800	
X1037	1500	18,500	14,800	13,300	11,800	11,200	10,250	
X107	1600	12,500	10,000	9,300	8,100	7,500	(6,800)	
X1037	1650	11,000	9,000	8,000	7,000	6,500	5,800	
X1037	1800	6,300	4,900	4,300	3,750	3,300	2,800	
X107	1800	6,600	5,400	4,700	4,000	3,500	3,100	2,550
X107	2000	3,000	2,350	2,100	1,580	1,250	1,000	700
		0.2 Percent Total Deformation Strength						
X1037	1200	31,500	29,500	28,800	26,500	21,700	17,000	
X1037	1350	24,200	17,200	15,000	12,300	10,000	8,000	
X1037	1500	15,000	11,500	10,200	9,000	8,000	7,200	
X107	1600	10,200	8,500	7,900	7,100	--	--	
X1037	1650	9,200	7,250	6,800	6,100	5,600	5,100	
X1037	1800	5,300	4,100	3,600	3,000	2,800	2,500	
X107	1800	5,600	4,450	3,900	3,400	3,000	2,650	2,200
X107	2000	2,550	1,900	1,550	1,180	960	770	
		0.1 Percent Total Deformation Strength						
X1037	1200							
X1037	1350	14,000	8,200	(6,100)				
X1037	1500	10,400	7,500	(6,100)				
X107	1600	8,600	7,100	--				
X1037	1650	(8,200)	6,100	5,600	(5,000)			
X1037	1800	(4,600)	3,600	3,200	2,700	2,500	(2,200)	
X107	1800	4,600	3,650	3,300	2,900	2,600	2,400	2,050
X107	2000	2,200	1,400	1,170	920	770	640	

( ) Extraplated Value

Note: Data for Heat X1037 were taken from Report 2540-5-P submitted under P. O. FX27866.
Data at 1600°F for Heat X107 were taken from letter report dated August 23, 1955 submitted under P. O. FX 0962

TABLE IV

STRESS-RUPTURE AND STRESS-TOTAL DEFORMATION DATA FOR SHEET SPECIMENS OF N-155 ALLOY AT 1600°, 1800° AND 2000°F (0.063-INCH THICK SHEET FROM HEAT M-1048 TO AMS SPECIFICATION 5532)

Spec. No.	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Deformation on loading (%)	Time for Specified Total Deformation (hours) 0.1%	0.2%	0.5%	1.0%	2.0%
				1600°F					
2	14,500	21.0	25.0	0.096	0.02	0.25	1.0	2.2	4.4
1	13,000	40.3	16.5	0.082	0.15	1.0	4.4	11.2	17.6
3	11,500	119.0	16.5	0.081	0.5	2.8	15.0	28.4	46.2
4	10,200	253.1	11.0	0.063	2.0	11.0	46.5	83.0	131.0
				1800°F					
106	9,000	4.7	22.5	0.078	0.013	0.027	0.137	0.34	0.74
103	8,000	8.7	30.5	0.069	0.02	0.09	0.28	0.67	1.49
105	6,500	39.7	14.5	0.057	0.09	0.58	2.55	5.95	12.10
102	5,000	137.2	6.0	0.036	1.0	6.9	28.4	59.6	91.2
104	4,000	428.1	5.5	0.029	14.0	63.0	132.0	225.0	329.0
107	3,500	381.4 (d)	----	0.026	47.0	230.0	--	--	--
108	3,000	1149.0 (c)	----	0.021	244	316	454	606	804
				2000°F					
113	4,200	5.8	23.5	0.0620	0.02	0.07	0.25	0.54	1.05
110	3,150	24.6	12.5	0.0375	0.13	0.70	2.55	4.80	8.25
112	2,400	99.1	12.5	0.026	0.40	1.60	7.3	14.6	29.4
111	1,750	335.0	5.4	0.019	10.0	27.0	63.0	110.0	184.0
114	1,400	432.9 (d)	----	0.015	24.0	67.2	156.0	300.0	--

(d) discontinued

Note: Data for 1600°F taken from letter report under P.O. FX60962 (Project 2317) dated February 15, 1955.

TABLE V

RUPTURE AND TOTAL DEFORMATION STRENGTHS FOR N-155 SHEET AT

1600°, 1800° AND 2000°F

	Rupture and Total Deformation Strengths (psi)						
	1-hr	5-hr	10-hr	25-hr	50-hr	100-hr	300-hr
				1600°F			
Rupture	--	(17,500)	(16,000)	14,000	13,000	11,800	10,000
2%	--	14,500	13,500	12,200	11,400	10,500	(9,500)
1%	(16,300)	13,800	12,800	11,700	10,900	10,000	(8,900)
0.5%	14,800	12,700	12,000	11,000	10,100	9,500	--
0.2%	12,900	11,000	10,200	9,500			
0.1%	11,000	9,400	(8,900)				
				1800°F			
Rupture	--	8,800	8,000	7,000	6,200	5,400	4,300
2%	8,600	7,200	6,600	6,000	5,600	4,900	3,900
1%	7,900	6,600	6,100	5,500	5,100	4,500	3,650
0.5%	7,100	6,000	5,600	5,100	4,600	4,000	3,400
0.2%	6,200	5,200	4,800	4,400	4,100	3,750	3,200
0.1%	5,250	4,400	4,100	3,800	3,500	3,300	2,950
				2000°F			
Rupture	--	4,400	3,800	3,100	2,700	2,350	1,900
2%	4,250	3,400	3,000	2,550	2,250	2,000	1,650
1%	3,850	3,050	2,700	2,250	2,000	1,750	1,430
0.5%	3,500	2,700	2,350	2,000	1,750	1,550	1,270
0.2%	2,850	2,200	2,000	1,700	1,550	1,400	1,160
0.1%	2,300	1,800	1,600	1,400	1,250	(1140)	

Note: Data for 1600°F taken from letter report dated February 15, 1955, submitted under P. O. FX 60962.

( ) Extrapolated value.

TABLE VI

STRESS-RUPTURE AND STRESS-TOTAL DEFORMATION DATA FOR SHEET SPECIMENS OF HS-25 ALLOY AT 1600°, 1800° AND 2000°F (0.064 AND 0.085-INCH THICK SHEET FROM HEATS L1061, E30801 AND BO336 TO AMS SPECIFICATION 5537)

Spec. No.	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Deformation on loading (%)	Time for Specified Total Deformation (hours) 0.1%	0.2%	0.5%	1.0%	2.0%
				1600°F					
				Heat L1061					
1	20,500	22.3	19.0	0.092		0.2	0.5	0.8	1.5
3	16,500	74.1	19.0	0.087		1.5	4.2	9.0	19.0
4	16,500	101.4	15.0	0.073		0.5	1.5	4.2	10.3
2	12,500	596.0	4.0	0.068		1.0	5.0	20.0	81.0
				Heat E30801					
32	20,500	26.3	30.5	0.110					
34	18,000	59.9	27.5	0.096		0.35	1.4	3.0	5.4
31	16,500	112.2	23.5	0.089		0.8	2.3	6.2	15
33	14,500	221.4	23.5	0.078		3.0	10.9	30.5	71
				1800°F					
				Heat L1061					
33	12,000	7.5	19.0	0.120	a	0.03	0.285	0.7	1.35
32	9,200	30.8	10.5	0.063	0.08	0.7	6.0	10.8	20.3
31	7,000	129.0	3.5	0.045	0.8	8.0	53.5	90	115.5
34	5,500	237.5	5.5	0.035	2.4	10.7	97	163.0	206
				Heat E30801					
40	12,000	6.0	21.0	0.140	a	0.02	0.17	0.46	0.975
41	8,000	41.0	23.0	0.070	0.1	0.5	1.93	4.68	(9.35)
39	5,500	119.5	29.0	0.0485	0.8	4.7	14.0	26.5	40.0
42	5,000	126.5	25.5	0.044	0.93	4.6	13.0	22.3	35.5
43	4,000	213.7	22.5	0.035	4.0	14.0	32.5	46.5	73.9

TABLE VI (con'd.)

Spec. No.	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Deformation on loading (%)	Time for Specified Total Deformation (hours) 0.1%	0.2%	0.5%	1.0%	2.0%
				1800°F					
				Heat BO336					
3	11,000	11.0	27.5	0.116	a	0.08	0.40	1.0	2.13
1	7,000	67.1	20.0	0.0635	0.3	1.5	7.0	14.6	22.3
2	4,000	299.1	29.0	0.0360	4.5	14.5	34.5	63.0	95.0
				2000°F					
				Heat L1061					
38	6,500	3.6	15.5	0.078	0.008	0.045	0.172	0.365	0.7
36	4,000	47.1	7.0	0.038	0.62	2.4	6.0	10.5	17.3
35	3,000	73.1	5.5	0.0285	0.50	3.4	17.0	39.5	58.0
37	2,000	321.6 (1)	7.5	0.019	53.0	70.0	123.0	188.0	265.0
				Heat E30801					
44	3,500	20.4	27.0	0.0475	0.05	0.245	0.9	1.85	3.55
45	2,000	97.3	36.0	0.027	0.60	1.7	4.9	10.2	18.25
46	1,350	596.7	40.0	0.018	2.0	4.8	7.8	17.2	27.7
				Heat BO336					
6	4,500	11.1	27.5	0.0575	0.030	0.118	0.46	0.98	1.86
5	3,000	39.0	35.5	0.0380	0.24	0.62	1.67	3.38	5.97
7	1,500	224.8	58.5	0.0190	1.5	3.0	6.7	11.3	18.3
8	800	(d)	----	0.0100	4.5	12.5	28.	45.7	72.5

(a) deformation reached on loading
(d) discontinued
(1) overheated during test

Note: Data for 1600°F taken from letter report under P.O. FX60962 (Project 2317) dated May 10, 1955. The HS-25 sheet from Heat L1061 was 0.062-inch thick; those from the other two heats were 0.085-inch thick. Specimens from Heat BO336 were taken longitudinal to the sheet. All other specimens were transverse.

TABLE VII

RUPTURE AND TOTAL DEFORMATION STRENGTHS OBTAINED AT 1600°, 1800° AND 2000°F FOR SHEET SPECIMENS OF HS-25 ALLOY

	Rupture and Total Deformation Strengths (psi)						
	1-hr	5-hr	10-hr	25-hr	50-hr	100-hr	300-hr
			1600°F, Heat L1061				
Rupture	--	(26,000)	23,500	20,000	18,000	16,500	13,800
2%	--	18,500	17,000	15,000	13,500	12,000	--
1%	--	17,000	14,500	12,500	--	--	--
0.5%	--	12,600	10,000	--	--	--	--
0.2%	--	--	--	--	--	--	--
0.1%	--	--	--	--	--	--	--
			1600°F, Heat E30801				
Rupture	--	(26,500)	24,000	20,500	18,500	16,500	14,000
2%	--	18,000	17,000	16,000	15,000	14,000	--
1%	--	17,000	16,000	14,600	13,800	12,900	--
0.5%	18,500	15,500	14,500	13,300	--	--	--
0.2%	16,000	14,000	13,000	--	--	--	--
0.1%	--	--	--	--	--	--	--
			1800°F, Heat L1061				
Rupture	--	13,000	11,400	9,600	8,400	7,400	5,000
2%	(13,000)	10,500	9,700	8,600	7,800	7,100	4,600
1%	11,900	9,800	9,200	8,100	7,500	6,700	4,200
0.5%	10,900	9,100	8,400	7,600	7,000	5,500	--
0.2%	8,700	7,400	6,200	--	--	--	--
0.1%	6,900	4,000	--	--	--	--	--
			1800°F, Heat E30801				
Rupture	--	12,500	10,800	8,900	7,700	5,800	3,400
2%	12,000	9,000	7,900	6,500	4,700	3,500	--
1%	10,400	7,900	7,000	5,200	3,850	--	--
0.5%	8,900	6,800	6,000	4,400	3,400	--	--
0.2%	6,900	5,200	4,300	3,600	--	--	--
0.1%	5,200	3,850	3,400	--	--	--	--
			1800°F, Heat BO336				
Rupture	--	13,300	11,200	9,000	7,500	6,000	4,000
2%	(12,800)	9,300	8,200	6,600	5,100	3,900	2,600
1%	11,000	8,400	7,500	5,700	4,400	3,400	2,250
0.5%	9,600	7,400	6,200	4,600	3,650	2,900	2,000
0.2%	7,500	5,000	4,000	3,150	2,600	(2,100)	--
0.1%	5,000	3,300	2,750	(2,150)	--	--	--

TABLE VII (con'd.)

	1-hr	5-hr	10-hr	25-hr	50-hr	100-hr	300-hr
			2000°F, Heat L1061				
Rupture	--	6,000	5,200	4,300	3,700	2,950	2,050
2%	6,100	4,800	4,300	3,750	3,100	2,600	1,930
1%	5,600	4,450	4,000	3,250	2,750	2,300	1,800
0.5%	5,100	4,100	3,500	2,850	2,450	2,100	1,650
0.2%	4,200	3,250	2,850	2,400	2,150	1,900	--
0.1%	3,400	2,750	2,500	2,200	2,000	1,800	--
			2000°F, Heat E30801				
Rupture	--	(5,400)	4,350	3,300	2,650	2,150	1,550
2%	--	3,100	2,450	1,750	--	--	--
1%	--	2,500	1,950	--	--	--	--
0.5%	3,350	1,850	1,450	--	--	--	--
0.2%	2,300	1,400	1,130	--	--	--	--
0.1%	1,750	1,200	1,000	--	--	--	--
			2000°F, Heat BO336				
Rupture	--	5,700	4,600	3,450	2,700	2,050	1,330
2%	--	3,200	2,260	1,400	950	650	--
1%	4,500	2,450	1,700	1,040	720	500	--
0.5%	3,500	1,800	1,300	840	590	--	--
0.2%	2,450	1,200	880	590	--	--	--
0.1%	1,700	890	670	--	--	--	--

( ) Extrapolated value.

Note: The HS-25 sheet from Heat L1061 was 0.062-inch thick; those from the other two heats were 0.085-inch thick. Specimens from Heat BO336 were taken longitudinal to the sheet. All other specimens were transverse.

TABLE VIII

STRESS-RUPTURE PROPERTIES OBTAINED AT 1800° AND 2000°F FOR COATED AND UNCOATED SHEET

SPECIMENS OF J1570 ALLOY

Spec. No.	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Deformation on loading (%)	Time for Specified Total Deformation (hours)				
					0.1%	0.2%	0.5%	1.0%	2.0%
1800°F									
Uncoated Condition									
17	9,149	6.0	23.5	0.147	a	0.007	0.078	0.233	0.64
13	7,400	9.4	17.5	0.091	0.005	0.035	0.155	0.40	1.015
16	5,000	45.4	22.0	0.051	0.06	0.23	0.88	2.18	5.42
15	4,000	84.6	17.0	0.040	0.15	0.51	1.80	4.99	10.33
14	3,100	177.3	34.5	0.029	0.40	1.40	5.0	11.3	23.5
18	2,650	683.8	49.0	0.025	0.5	1.48	5.7	13.2	27.9
Solar Alcote Condition									
29	6,000	44.0	24.5	0.055	0.04	0.14	0.62	1.70	4.48
30	4,000	485.3	----(b)	0.014	0.66	1.73	6.3	16.1	38.1
Al coated by Whitfield and Sheshunoff									
27	7,600	19.6	23.5	0.079	0.01	0.06	0.27	0.75	(1.9)
25	5,000	82.7	27	0.0528	0.1	0.35	1.5	3.85	9.5
2000°F									
Uncoated Condition									
20	4,150	3.7	46.0	0.126	a	0.006	0.031	0.070	0.154
19	2,650	29.5	55.0	0.078	0.01	0.048	0.165	0.375	0.83
21	2,050	45.5	55.5	0.066	0.015	0.078	0.29	0.670	1.53
22	1,550	187.5	50.6	0.037	0.07	0.2	0.67	1.46	3.22
24	1,150	709.8	45.0	0.025	0.2	0.45	1.35	3.05	6.5
Solar Alcote Condition									
31	2,500	28.0	48.5	0.055	0.03	0.09	0.29	0.68	1.57
32	1,400	384.4	58 on 2.3 G.L.	0.0301	0.165	0.478	1.5	3.85	8.95

TABLE VIII (con'd.)

Spec. No.	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Deformation on loading (%)	Time for Specified Total Deformation (hours)				
					0.1%	0.2%	0.5%	1.0%	2.0%
2000°F									
Al coated by Whitfield and Sheshunoff									
28	2,500	26.3	40.0	0.068	0.03	0.11	0.355	0.765	1.69
26	1,500	167.9	50.0	0.036	0.12	0.33	1.08	2.53	(5.4)

(a) deformation reached on loading.
(b) Broken outside gage length.
( ) Extrapolated value.

TABLE IX

RUPTURE AND TOTAL DEFORMATION STRENGTHS FOR JETALLOY 1570 SHEET, UNCOATED AND COATED, AT 1800° AND 2000°F

	Rupture and Total Deformation Strengths (psi)						
	1-hr	5-hr	10-hr	25-hr	50-hr	100-hr	300-hr
				1800°F, Uncoated			
Rupture	--	9,200	7,600	5,850	4,800	4,000	2,950
2%	8,000	4,900	4,000	3,050	2,475	(2,000)	(1,450)
1%	6,200	3,800	3,200	2,350	(1,925)	(1,575)	--
0.5%	4,800	3,000	2,450	(1,900)	(1,550)	--	--
0.2%	3,300	(2,100)	(1,750)	--	--	--	--
0.1%	2,450	(1,625)	--	--	--	--	--
				1800°F, Coated			
Rupture	--	11,400	9,300	7,100	5,800	4,800	3,500
2%	9,400	5,800	4,700	3,600	2,900	2,350	(1,700)
1%	7,000	4,350	3,500	2,700	(2,200)	(1,800)	--
0.5%	5,300	3,150	2,750	(2,100)	(1,700)	--	--
0.2%	3,600	(2,300)	(1,900)	--	--	--	--
0.1%	2,700	(1,800)	--	--	--	--	--
				2000°F, Uncoated			
Rupture	--	3,850	3,250	2,600	2,200	1,850	1,400
2%	2,400	1,310	1,025	(730)	--	--	--
1%	1,800	1,000	(780)	--	--	--	--
0.5%	1,350	(760)	--	--	--	--	--
0.2%	900	--	--	--	--	--	--
0.1%	(650)	--	--	--	--	--	--
				2000°F, Coated			
Rupture	--	3,850	3,250	2,600	2,200	1,850	1,400
2%	3,000	1,640	1,280	(900)	--	--	--
1%	2,200	1,250	(970)	--	--	--	--
0.5%	1,600	(920)	--	--	--	--	--
0.2%	1,080	--	--	--	--	--	--
0.1%	(780)	--	--	--	--	--	--

(   ) Extrapolated value.

TABLE X (con'd.)

Alloy	Temp (°F)	Rupture or Total Deformation Strengths (psi) for Indicated Time Periods (hours) 10-hour	100-hour	300-hour
2.0-Percent Total Deformation Strengths (psi)				
Hastelloy X	1600	11,300	8,200	7,100
N-155	1600	(13,500)	10,500	(9,500)
HS-25				
Heat L1061	1600	17,000	12,000	--
Heat E30801	1600	17,000	14,000	--
Hastelloy X				
Heat X107	1800	5,900	3,750	3,000
Heat X1037	1800	5,200	3,500	--
N-155	1800	6,600	4,900	3,900
HS-25				
Heat L1061	1800	9,700	7,100	4,600
Heat E30801	1800	7,900	3,500	--
Heat BO336	1800	8,200	3,900	2,600
Jetalloy 1570				
Uncoated	1800	4,000	(2,000)	(1,450)
Al coated	1800	4,700	2,350	(1,700)
Hastelloy X	2000	2,500	1,450	1,000
N-155	2000	3,000	2,000	1,650
HS-25				
Heat L1061	2000	4,300	2,600	1,930
Heat E30801	2000	2,450	--	--
Heat BO336	2000	2,260	650	--
Jetalloy 1570				
Uncoated	2000	1,025	--	--
Al coated	2000	1,280	--	--
1.0-Percent Total Deformation Strengths (psi)				
Hastelloy X	1600	10,200	7,400	--
N-155	1600	12,800	10,000	(8,900)
HS-25				
Heat L1061	1600	14,500	--	--
Heat E30801	1600	16,000	12,900	--

TABLE X (con'd.)

Alloy	Temp (°F)	Rupture or Total Deformation Strengths (psi) for Indicated Time Periods (hours) 10-hour	100-hour	300-hour
		1.0-Percent Total Deformation Strengths (psi)		
Hastelloy X				
Heat X107	1800	5,300	3,400	2,750
Heat X1037	1800	4,800	3,200	--
N-155	1800	6,100	4,500	3,650
HS-25				
Heat L1061	1800	9,200	6,700	4,200
Heat E30801	1800	7,000	--	--
Heat BO336	1800	7,500	3,400	2,250
Jetalloy 1570				
Uncoated	1800	3,200	(1,575)	--
Al coated	1800	3,500	(1,800)	--
Hastelloy X	2000	2,300	1,200	830
N-155	2000	2,700	1,750	1,430
HS-25				
Heat L1061	2000	4,000	2,300	1,800
Heat E30801	2000	1,950	--	--
Heat BO336	2000	1,700	500	--
Jetalloy 1570				
Uncoated	2000	(780)	--	--
Al coated	2000	(970)	--	--
		0.5-Percent Total Deformation Strengths (psi)		
Hastelloy X	1600	9,300	(6,800)	--
N-155	1600	12,000	9,500	--
HS-25				
Heat L1061	1600	10,000	--	--
Heat E30801	1600	14,500	--	--
Hastelloy X				
Heat X107	1800	4,700	3,100	2,550
Heat X1037	1800	4,300	2,800	--
N-155	1800	5,600	4,000	3,400
HS-25				
Heat L1061	1800	8,400	5,500	--
Heat E30801	1800	6,000	--	--
Heat BO336	1800	6,200	2,900	2,000

TABLE X (con'd.)

Alloy	Temp (°F)	Rupture or Total Deformation Strengths (psi) for Indicated Time Periods (hours) 10-hour	100-hour	300-hour
		0.5-Percent Total Deformation Strengths (psi)		
Jetalloy 1570				
Uncoated	1800	2,450	--	--
Al coated	1800	2,750	--	--
Hastelloy X	2000	2,100	1,000	700
N-155	2000	2,350	1,550	1,270
HS-25				
Heat L1061	2000	3,500	2,100	1,650
Heat E30801	2000	1,450	--	--
Heat BO336	2000	1,300	--	--
		0.2-Percent Total Deformation Strengths (psi)		
Hastelloy X	1600	7,900	--	--
N-155	1600	10,200	--	--
HS-25	1600	13,000	--	--
Hastelloy X				
Heat X107	1800	3,900	2,650	2,200
Heat X1037	1800	3,600	2,500	--
N-155	1800	4,800	3,750	3,200
HS-25				
Heat L1061	1800	6,200	--	--
Heat E30801	1800	4,300	--	--
Heat BO336	1800	4,000	(2,100)	--
Jetalloy 1570				
Uncoated	1800	(1,750)	--	--
Al coated	1800	(1,900)	--	--
Hastelloy X	2000	1,550	700	--
N-155	2000	2,000	1,400	1,160
HS-25				
Heat L1061	2000	2,850	1,900	--
Heat E30801	2000	1,130	--	--
Heat BO336	2000	880	--	--

TABLE X (con'd.)

Alloy	Temp (°F)	Rupture or Total Deformation Strengths (psi) for Indicated Time Periods (hours) 10-hour	100-hour	300-hour
		0.1-Percent Total Deformation Strengths (psi)		
N-155	1600	(8,900)	--	--
Hastelloy X				
Heat X107	1800	3,300	2,400	2,050
Heat X1037	1800	3,200	(2,200)	--
N-155	1800	4,100	3,300	2,950
HS-25				
Heat E30801	1800	3,400	--	--
Heat BO336	1800	2,750	--	--
Hastelloy X	2000	1,170	640	--
N-155	2000	1,600	(1,140)	--
HS-25				
Heat L1061	2000	2,500	1,800	--
Heat E30801	2000	1,000	--	--
Heat BO336	2000	670	--	--