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SOME CREEP-RUPTURE DATA FOR NEWER HEATS OF HAYNES ALLOY NO. 25 (L-605)

R. W. Swindeman

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METALS AND CERAMICS DIVISION

SOME CREEP-RUPTURE DATA FOR NEWER HEATS OF HAYNES ALLOY NO. 25 (L-605)

R. W. Swindeman

AUGUST 1970

OAK RIDGE NATIONAL LABORATORY
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R. W. Swindeman

ABSTRACT

A number of exploratory creep- and stress-rupture tests were performed on four newer heats of Haynes alloy No. 25, over the range 649 to 1316°C. Melting practice included air, vacuum, and electroslag processes. The results confirmed that existing literature data were adequate. The rupture strengths of weldments produced in three of the heats fell within the scatter band for the base metal.

INTRODUCTION

Superalloys have been considered as canning materials for radioisotopes.[1] One promising alloy for service in the temperature range 600 to 900°C has been the cobalt-base alloy Haynes alloy No. 25. This material is attractive because it is readily fabricated, has fair oxidation and corrosion resistance, seems to be compatible with many of the potential isotope fuel forms, and possesses excellent high-temperature strength. One drawback, which has not been unique to this alloy, is the tendency to embrittle during long-time service at elevated temperatures.

Strength becomes a factor in designing for the containment of alpha-emitting isotopes. Although some devices allow the use of a vent to permit the helium escaping from the fuel to leave the capsule, others require complete and positive containment of all gaseous species generated within the capsule. Further, in some devices helium does not escape from the fuel except in event of a rapid thermal excursion, which

[1] D. E. Thomas, W. O. Harms, and R. T. Huntoon, eds., Symposium on Materials for Radio-Isotope Heat Sources, Nucl. Met. 14, American Institute of Mining, Metallurgical and Petroleum Engineers, New York, 1969.

accompanies certain accident situations. A pressure surge could follow if the vent release rate is low.

Data on the strength of Haynes alloy No. 25 are available from many sources. Slunder,[2] for example, has compiled tensile property data obtained from 44 references. Included was a wide range of material and testing variables, with temperatures ranging from cryogenic to 1200°C. Most of these data pertained to short-time exposure before testing, whereas the aging effect could be an important consideration for isotope capsules. The work of Wlodek[3] and Sandrock et al.[4] sheds some light on the aging embrittlement problem. Further information is provided by Bourgette.[5] We have a number of sources of creep- and stress-rupture behavior, also. Ten sets of data collected before 1954 were compiled by Simmons and Cross.[6] Since then Baughman,[7] Greene,[8] Sandrock et al.,[4] Conrad et al.,[9] Flagella and McCullough,[10] Yukawa and Satô,[11] and and Widmer et al.[12,13] have made further contributions. The work of Widmer et al. was particularly important since it extended testing times to beyond 30,000 hr. With this much information available one might question the need for further testing. The answer is that in recent years the melting practice used to produce Haynes alloy No. 25 has been expanded to include consumable arc melting and electroslag melting.

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[2]C. J. Slunder, Short-Time Tensile Properties of the Co–20Cr–15W–10Ni Cobalt-Base Alloy (L-605), DMIC-Memo-179 (Sept. 27, 1963).

[3]S. T. Wlodek, "Embrittlement of a Co–Cr–W (L-605) Alloy," Trans. ASM (Am. Soc. Metals) 56, 287–303 (1963).

[4]G. D. Sandrock, R. L. Ashbrook, and J. C. Freche, Effect of Variations in Silicon and Iron Content on Embrittlement of a Cobalt-Base Alloy (L-605), NASA-TN-D-2989 (September 1965).

[5]D. T. Bourgette, Effect of Aging Time and Temperature on the Impact and Tensile Behavior of L-605 – A Cobalt Base Alloy, report in preparation.

[6]W. F. Simmons and H. C. Cross, The Elevated Temperature Properties of Selected Super-Strength Alloys, Spec. Tech. Publ. No. 160, American Society for Testing and Materials, Philadelphia, 1954.

[7]B. A. Baughman, Gas Atmosphere Effects on Materials, WADC-TR-59-511 (PB-161980) (May 1960).

[8]A. Greene, Research Investigation on Mechanical Properties of Nickel and Cobalt-Base Alloys for Inclusion in Military Handbook-5, AD-418639 (March 1963).

These practices have altered the composition somewhat, particularly by reducing the silicon level. It was of interest to know whether melting practice significantly influences the strength and ductility. The performance of weldments was of particular interest in this regard. To this end we performed a number of tests that were designed to supplement existing creep-rupture data.

The testing program consisted of short-time tests at 982°C and above to provide data applicable to certain isotope capsule accident situations, and longer time tests at 871°C and below to provide data applicable to some service conditions.

MATERIALS

Four heats of Haynes alloy No. 25 were investigated. Heat 1716 was produced by melting in air and fabricated by the vendor to nominal 0.06-in. sheet conforming to the AMS-5537B specification. The grain size was approximately ASTM 4.

Heat 1931 was vacuum melted by the consumable arc process and fabricated by the vendor to a nominal 0.06-in. sheet conforming to the AMS-5537B specification. The grain size was ASTM 5.

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[9]H. Conrad, E. Bernett, and J. White, "Correlation and Interpretation of High Temperature Mechanical Properties of Certain Superalloys," pp. 1-9–1-29 in Joint International Conference on Creep, The Institution of Mechanical Engineers, London, 1963.

[10]P. N. Flagella and W. L. McCullough, Stress-Rupture and Creep Behavior of Haynes Alloy No. 25 at 1440°, 1700°, and 2000°F in Air, TID-24045 (GE-NMP-67-528) (August 1967).

[11]N. Yukawa and K. Satô, "The Correlation between Microstructure and Stress Rupture Properties of a Co-Cr-Ni-W (HS-25) Alloy," pp. 680–686 in Proceedings of the International Conference on the Strength of Metals and Alloys, The Japan Institute of Metals, Omachi, Sendai, Japan, 1968.

[12]R. Widmer et al., Mechanisms Associated with Long-Time Creep Phenomena, Part I, AFML-TR-65-181 (AD-468683) (June 1965) (Limited distribution).

[13]R. Widmer, J. M. Dhosi, and N. J. Grant, Mechanisms Associated with Long-Time Creep Phenomena, Part II, AFML-TR-65-181 (AD-815679) (March 1967) (Limited distribution).

Heat 1843 was also vacuum melted and was received as 3/16-in. plate conforming to AMS-5537B. The plate was then rolled with intermediate anneals to a nominal 0.06 in. and given a final anneal at 1215°C for 1 hr. This resulted in a grain size of approximately ASTM 3. Part of the annealed sheet was cold rolled 10% in addition.[5]

Heat 1335 was electroslag melted and received as nominal 0.06-in. sheet conforming to AMS-5537C with an ASTM grain size 4.

The chemical compositions of the four heats, provided by the vendor, are given in Table 1. Where indicated, a check was made on certain elements. The variation in silicon analysis is considerable, especially for heat 1843.

Table 1. Chemical Composition of Heats Tested[a]

Element	Content (wt %) for Various Heats			
	1716	1843	1931	1335
Cr	20.01	20.24	20.03	19.39 18.9[b]
W	14.85	15.02	14.93	14.96 15.0[b]
Fe	2.17	2.00	2.20	2.82
C	0.11 0.074[b]	0.09 0.057[b]	0.11	0.11 0.086[b]
Si	0.51 0.62[b] 0.36[c]	0.03 0.35[b] 0.16[c]	0.18 0.16[c]	0.11 0.25[b] 0.20[c]
Ni	10.31	10.24	10.38	10.19 9.13[b]
Mn	1.36	1.35	1.37	1.28
P	0.011	0.007	0.025	0.013
S	0.013	0.005	0.010	0.002

[a]Vendor analysis except where indicated. Balance: cobalt.

[b]Analysis by ORNL Analytical Chemistry Division.

[c]Analysis by Oak Ridge Y-12 Plant.

TESTING

Specimen Design

Base metal specimens were machined transverse to the rolling direction. Specimens tested at 982°C and above had a 0.25 × 2.0 in. gage section. Specimens tested below 982°C had a 0.25 × 1.0 in. section.

Gas tungsten-arc (GTA) welds were made in sheets of heats 1931, 1843, and 1335. These welds[14] were approximately 1/4 in. wide, parallel to the rolling direction, and located at the center of the specimen transverse to the testing direction. The specimens were surface ground after welding to produce a uniform thickness. Some weldments were etched and inspected for flaws by ultraviolet dye penetrant. All appeared sound.

Creep Testing

Creep tests at 982°C and above were performed in a dead-load creep machine in argon-filled chambers. Molybdenum pins and grips were employed. Specimens were heated as rapidly as possible to the test temperature, held for approximately 0.5 hr, and loaded. Deformation-time curves were obtained from a transducer attached to the active pull rod.

Stress-rupture tests between 760 and 871°C were performed in air with superalloy pins and grips and dead-load creep machines. Tests at 649 and 704°C were performed in a machine with a 12:1 lever arm. Pull rod extensions were measured, but pin bending contributed substantially, especially for tests at 871°C. One test at 760°C in which an extensometer was placed on the specimen indicated a creep rate about 80% of that calculated from pull-rod movement. However, post-test elongation measurement at 871°C indicated about half the strain indicated by the pull-rod movement. For this reason data pertaining to creep rates below 982°C represent only an approximation.

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[14]The welding conditions were 105 amp at 10 in./min and a 0.06-in. arc.

RESULTS

Tensile Properties

The room-temperature tensile properties of the materials are given in Table 2. The material annealed at 1215°C is somewhat weaker than that received from the vendor. The apparent yield strengths of weldments, however, are equivalent or higher than those of base metal specimens in all cases except for the 10% cold-rolled condition. Ultimate

Table 2. Summary of Room-Temperature Tensile Properties

Heat	Condition	Yield Stress (psi)	Ultimate Tensile Strength (psi)	Elongation (%)
1716	AMS-5537B 0.065-in. sheet	71,400	126,300	43
1931	AMS-5537B 0.065-in. sheet	67,350[a] 66,500	146,500[a] 143,500	61[a] 67
	AMS-5537B 0.065-in. sheet GTA welded and ground to 0.060 in.	69,700	132,000	35
1843	AMS-5537B 3/16-in. plate	65,600[a]	137,100[a]	60[a]
	3/16-in. plate, cold rolled and annealed in steps to 0.062-in. sheet. Final anneal 0.5 hr at 1215°C	55,300 55,800	124,000 126,800	75 77
	As above for 0.062-in. sheet. GTA welded and ground to 0.060 in.	62,600 62,600	124,000 125,300	34 34
	As above for 0.062-in. sheet. Cold rolled 10% to 0.056 in.	83,700	140,000	50
	As above for 0.056-in. sheet. GTA welded and ground to 0.054 in.	69,500 69,400	123,600 120,300	22 20
	AMS-5537B 0.056-in. sheet.	64,750[a]	136,650[a]	56[a]
1335	AMS-5537C 0.065-in. sheet	66,050[a] 69,000	141,150[a] 150,000	62[a] 65
	AMS-5537C, GTA welded and ground to 0.060 in.	71,000	141,000	40

[a]Measurement by vendor.

strengths and elongations are reduced and all weldments broke at the weld center line.

Creep-Rupture Tests at 982°C and Above

The results of creep-rupture tests at 982°C and above are summarized in Table 3. Only heats 1716 and 1931 were tested. At 982 and 1204°C both heats and weldments of heat 1931 showed similar creep rates and rupture lives. However, at 1093 and 1149°C a significant difference between the two heats was observed. This difference is illustrated in Fig. 1, which shows the creep curves at 1149°C and 6000 psi. Heat 1716 exhibited a lower creep rate, longer life, and lower ductility. One specimen of this heat was annealed at 1215°C and tested. This specimen more closely matched the creep curve of heat 1931.

Except in one test at 982°C and 20,000 psi, all weldment specimens failed in the base metal away from the weld area. Post-test measurements indicated less strain in the weldment region except at 1204°C, at which the deformation was about the same as in the base metal.

Metallography revealed the presence of a precipitate, both on the grain boundaries and in the matrix, which persisted up to 1149°C for heat 1716. This structure, shown in Fig. 2, was identified by x-ray diffraction to be Laves phase. At and above 1204°C precipitation was not observed, but grain-boundary migration and grain growth were quite evident, as illustrated in Fig. 3. The structure of heat 1931 revealed grain-boundary migration at 1149°C.

Stress Rupture at 871°C and Below

Data collected in the range 649 to 871°C are summarized in Table 4. The only condition at which all heats were tested was 17,500 psi and 816°C. Base metal specimens from different heats showed fair agreement in rupture life at this temperature. The exception was the 10% cold-rolled material of heat 1843, which was considerably stronger.

No clear trend was found in the life of weldments relative to base metal specimens except for heat 1843, for which all three weldments

Table 3. Summary of Creep Results at 982°C and Above

Condition	Temperature (°C)	Stress (psi)	Life (hr)	Elongation (%)	Creep Rate[a] (hr^{-1})	Failure Location
			Heat 1716			
AMS-5537B	982	20,000	0.26	16	0.4	
AMS-5537B	982	15,000	1.0	9	0.05	
AMS-5537B	1093	15,000	0.03	13	4.0	
AMS-5537B	1093	10,000	0.31	12	0.22	
AMS-5537B	1093	7,000	2.4	6	0.12	
AMS-5537B	1149	10,000	0.03	7.5	1.8	
AMS-5537B	1149	6,000	0.5	5	0.045	
AMS-5537B	1149	4,000	3.0	4	0.003	
Annealed at 1215°C	1149	6,000	0.21	15	0.6	
AMS-5537B	1177	6,000	0.16	15	0.55	
AMS-5537B	1177	4,000	0.83	7	0.065	
AMS-5537B	1204	6,000	0.11	16	1.3	
AMS-5537B	1204	4,000	0.36	11	0.27	
AMS-5537B	1204	3,000	1.26	10	0.058	
AMS-5537B	1260	4,000	0.15	15	0.9	
AMS-5537B	1316	2,000	0.62	12.5	0.15	
			Heat 1931			
AMS-5537B	982	15,000	1.45	15	0.079	
Welded	982	20,000	0.22	9	(0.33)	HAZ[b]
Welded	982	15,000	1.16	15	(0.084)	Base
AMS-5537B	1093	10,000	0.15	14	0.33	
AMS-5537B	1093	7,000	0.78	9	0.10	
Welded	1093	10,000	0.05	17		Base
Welded	1093	10,000	0.06	15		Base
Welded	1093	7,000	0.85	7	(0.05)	Base
AMS-5537B	1149	6,000	0.25	17	0.42	
Welded	1149	6,000	0.29	10	(0.22)	Base
AMS-5537B	1204	4,000	0.57	22	0.26	
Welded	1204	4,000	0.53	30	(0.30)	Base

[a]Values for welded material are uncertain because the strain was divided between the weld metal and the base metal.

[b]Heat-affected zone.

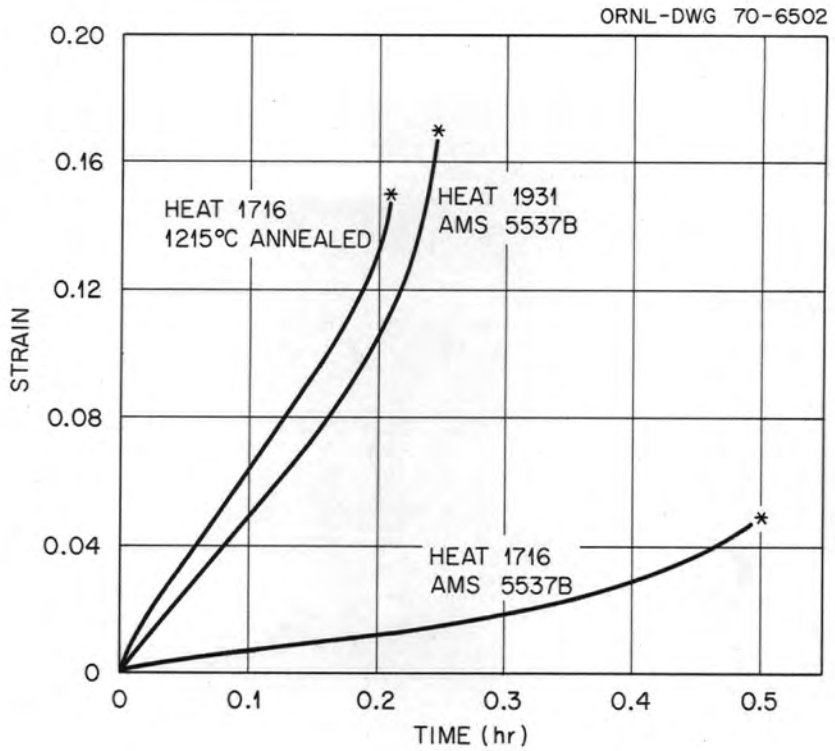

Fig. 1. Creep Curves for Haynes Alloy No. 25 at 6000 psi and 1149°C, Showing Variability of Creep Resistance.

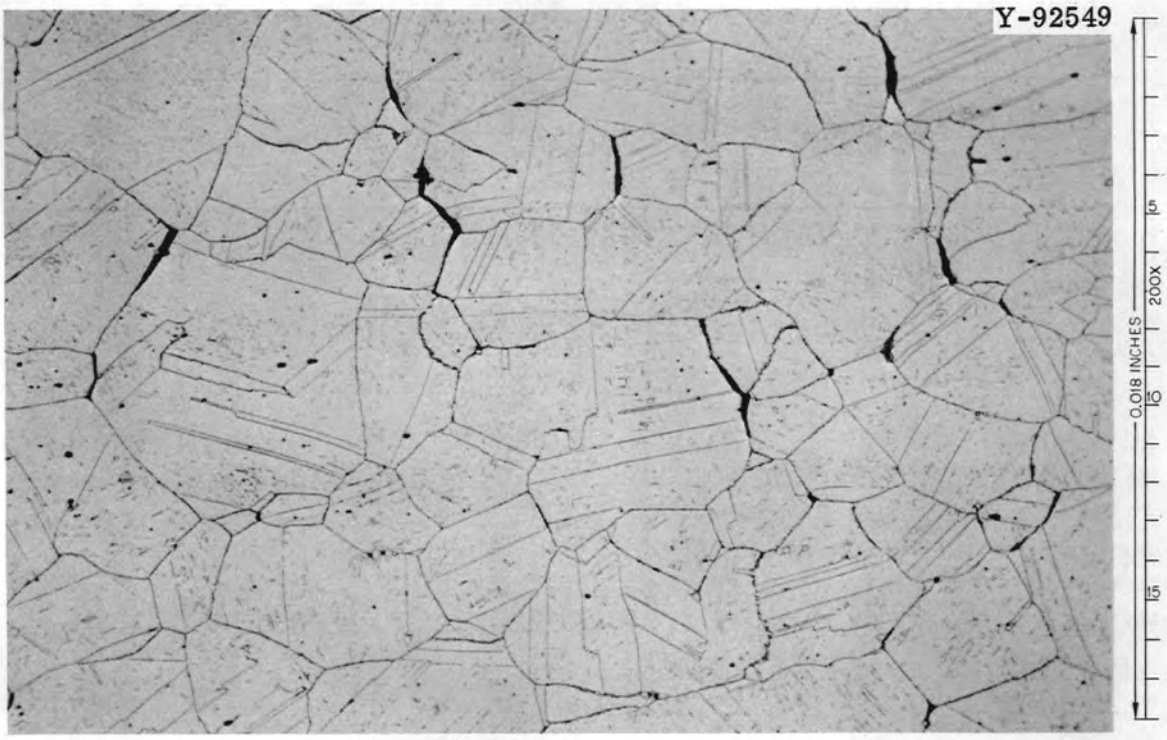

Fig. 2. Haynes Alloy No. 25 Creep Tested at 10,000 psi and 1093°C. Precipitate identified as Laves phase. Etchant: HCl, H_2O_2.

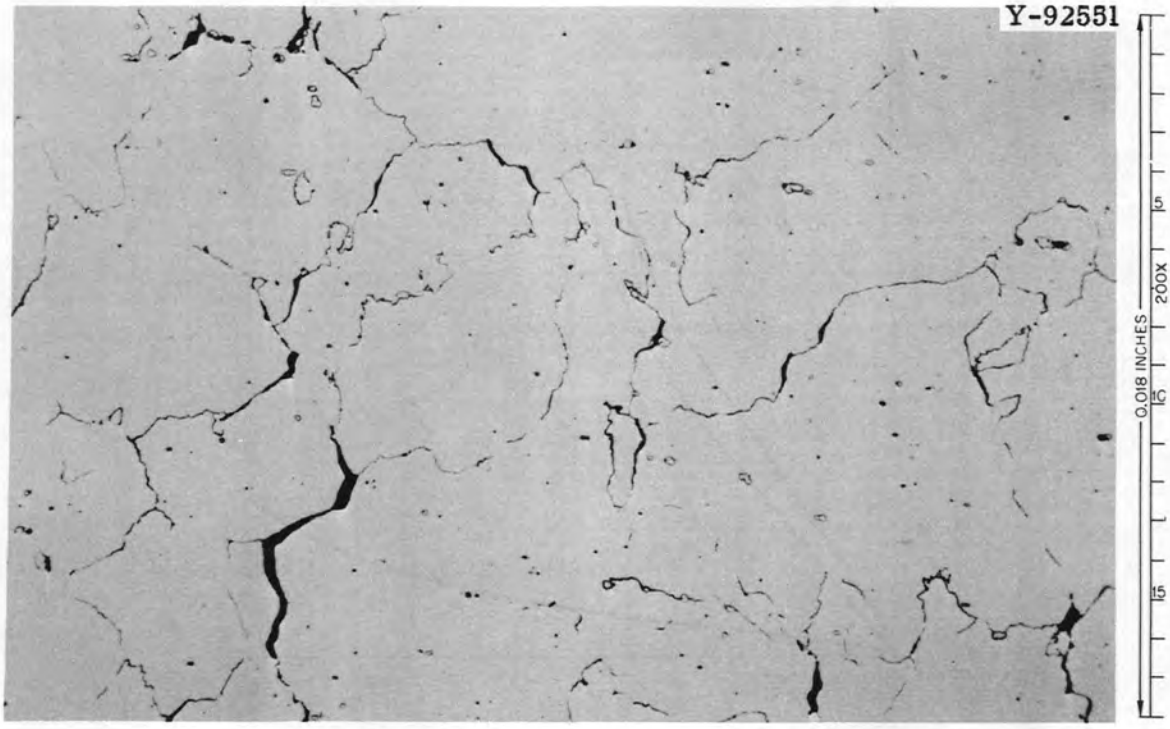

Fig. 3. Haynes Alloy No. 25 Creep Tested at 4000 psi and 1204°C. Etchant: HCl, H_2O_2.

Table 4. Summary of Creep Results at 871°C and Below

Condition	Temperature (°C)	Stress (psi)	Life (hr)	Elongation (%)	Apparent Creep Rate[a] (hr^{-1})	Failure Location
			Heat 1716			
AMS-5537B	760	27,500	33	3		
AMS-5537B	816	17,500	386	6	0.00012	
AMS-5537B	871	11,500	164	3.5		
			Heat 1931			
AMS-5537B	649	35,000	>1457[b]	>1.3	0.000008	
Welded	649	50,000	105	5	0.00025	Base
Welded	649	42,500	> 600[b]	>2	0.00002	
AMS-5537B	704	40,000	248	5	0.00022	
Welded	704	40,000	173	2	(0.00015)	HAZ[c]
Welded	704	36,000	432	<2	(0.0001)	HAZ
AMS-5537B	760	27,500	155	8	0.0004	
Welded	760	27,500	226	10	(0.00035)	HAZ
Welded	760	22,500	547	8	(0.00009)	HAZ

Table 4 (continued)

Condition	Temperature (°C)	Stress (psi)	Life (hr)	Elongation (%)	Apparent Creep Rate (hr^{-1})	Failure Location
AMS-5537B	816	17,500	595	10	0.00013	
Welded	816	17,500	296	7.5	(0.00015)	HAZ
Welded	816	15,000	897	7	(0.00006)	HAZ
AMS-5537B	871	11,500	>495[b]	>7.5		
Welded	871	13,500	143	4		HAZ
Welded	871	11,500	558	7		HAZ
			Heat 1843			
Annealed at 1215°C	760	22,500	1296	20	0.00011	
Welded	760	22,500	1693	9	(0.0001)	Base
Annealed at 1215°C	816	17,500	382	23	0.0004	
Welded	816	17,500	1798	10	(0.00005)	Base
Annealed at 1215°C	871	11,500	515	20		
Welded	871	11,500	1194	10		Base
10% cold rolled	816	17,500	2367	15	0.00005	
Welded	816	17,500	1374	6	(0.00004)	HAZ
			Heat 1335			
Welded	649	50,000	372	6	(0.00004?)	Base
AMS-5537C	704	40,000	151	5	0.00008	
Welded	704	40,000	20	6		Base
Welded	704	40,000	86	3	(0.00025)	Weld
Welded	760	27,500	106	9	(0.0008)	Base
AMS-5537C	760	22,500	522	13	0.00017	
Welded	760	22,500	755	12	(0.0001)	Base
AMS-5537C	816	17,500	474	15	0.0002	
Welded	816	17,500	269	11	(0.0003)	Base
Welded	816	15,000	542	11		Base
Welded	871	11,300	410			Base

[a]Values for welded material are uncertain because the strain was divided between the weld metal and the base metal.

[b]Discontinued.

[c]Heat-affected zone.

showed greater lives, although the specimens failed in base metal. The cold rolled and welded heat 1843 failed in the heat-affected zone (HAZ). Eight out of nine failures in heat 1931 weldments occurred in the HAZ, while seven out of the eight failures in heat 1335 weldments occurred in the base metal. The remaining failure was at the weld center line. Failures in the HAZ were located within one or two grains of the fusion line, although some cracking was noticed along the weld center line, as shown in Fig. 4.

Fig. 4. Weldment in Haynes Alloy No. 25 Creep Tested at 15,000 psi and 816°C. Failure at right of photo is in the heat-affected zone of the base metal. Etchant: HCl, H_2O_2.

PARAMETRIC PLOTS FOR CREEP AND RUPTURE

Literature data for Haynes alloy No. 25 sheet[15–17] were used in conjunction with several time-temperature parameters to develop master curves for rupture. The modified Manson-Haferd parameter used by Widmer et al.[18] for Haynes alloy No. 25 rod worked quite well, and a plot of 82 data points taken from the literature and including five heats is shown in Fig. 5. All the data are covered by the scatter band, which

[15]W. F. Simmons and H. C. Cross, The Elevated Temperature Properties of Selected Super-Strength Alloys, Spec. Tech. Publ. No. 160, American Society for Testing and Materials, Philadelphia, 1954.

[16]B. A. Baughman, Gas Atmosphere Effects on Materials, WADC-TR-59-511 (PB-161980) (May 1960).

[17]A. Greene, Research Investigation on Mechanical Properties of Nickel and Cobalt-Base Alloys for Inclusion in Military Handbook-5, AD-418639 (March 1963).

[18]R. Widmer, J. M. Dhosi, and N. J. Grant, Mechanisms Associated with Long-Time Creep Phenomena, Part II, AFML-TR-65-181 (AD-815679) (March 1967) (Limited distribution).

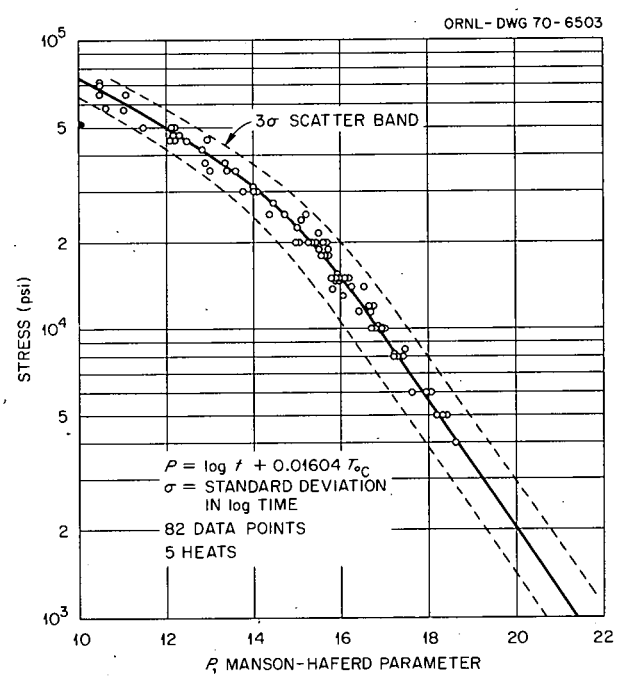

Fig. 5. Manson-Haferd Parameter for Rupture of Haynes Alloy No. 25 Sheet Calculated from Literature Data.

is based on three standard deviations in the logarithm of time. The rupture data reported in Tables 3 and 4 are compared to this master curve in Figs. 6 and 7.

We tried to correlate the creep rate data at 982°C and above on the basis of a time-temperature parameter. Literature data for sheet material in the range 649 to 1038°C were used to generate master curves for comparison. The Dorn parameter worked fairly well. The master curve is shown in Fig. 8, and data for the two heats tested at 982°C and above are shown in Fig. 9. Heat 1716 in the AMS-5537B condition follows the trend of the master curve for data up to 1149°C. At higher temperatures the parametric constant seems to be valid but the stress dependence changes and the data show higher creep rates than would be predicted. The annealed specimen of heat 1716 as well as both base metal and weldments of heat 1931 follow the trend of this lower strength curve.

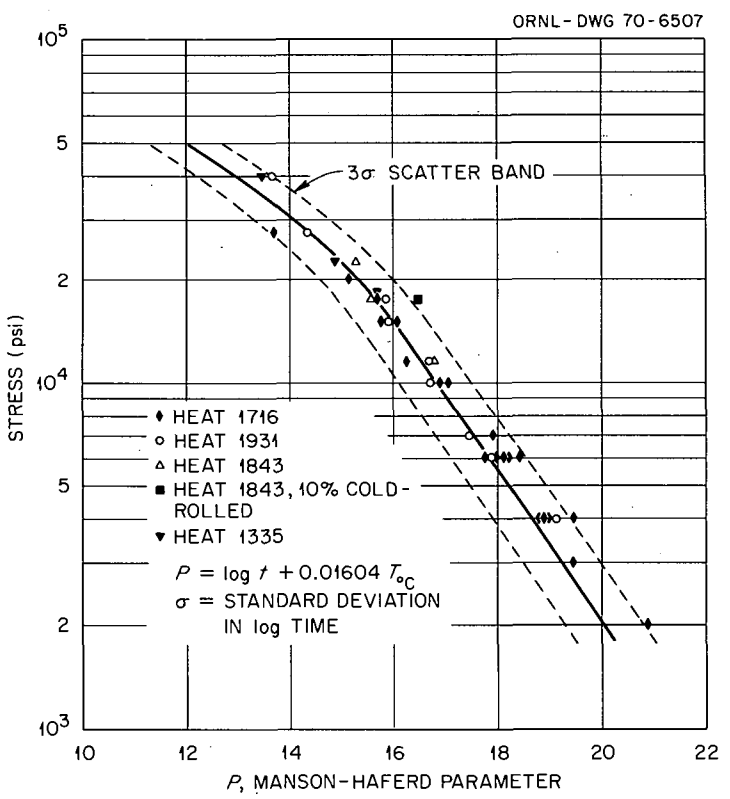

Fig. 6. Comparison of Base Metal Data from Tables 3 and 4 with Scatter Band Derived from Literature Data for Base Metal Sheet.

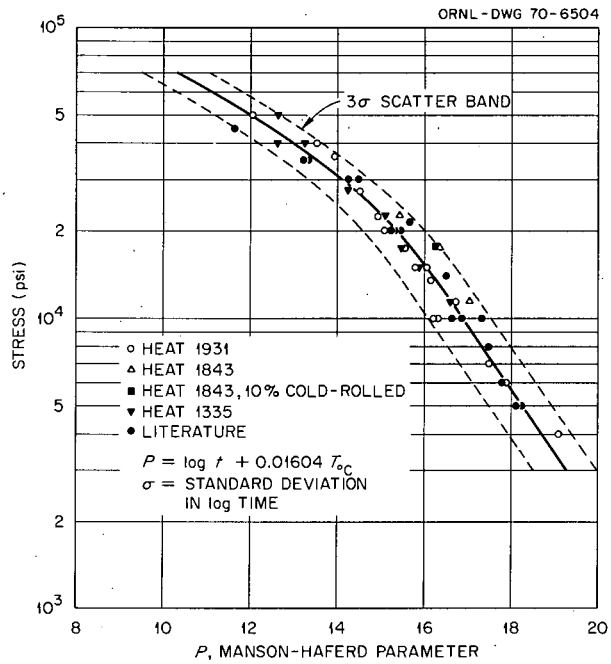

Fig. 7. Comparison of Weldment Data from Tables 3 and 4 with Scatter Band Derived from Literature Data for Base Metal Sheet.

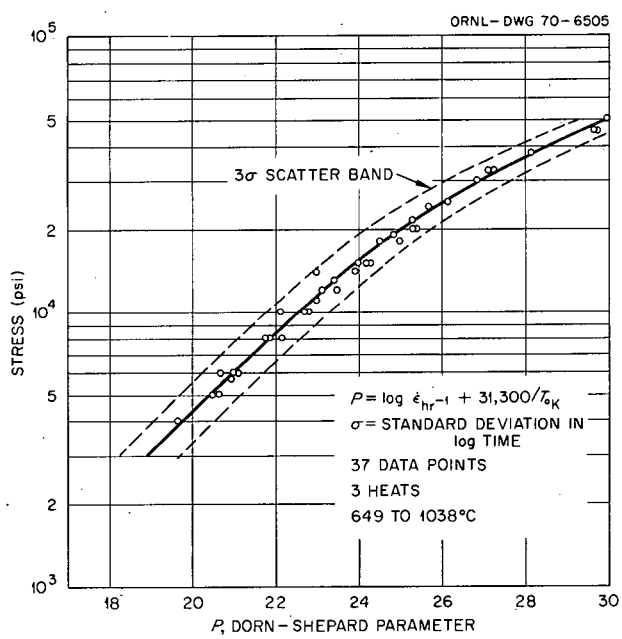

Fig. 8. Dorn-Shepard Parameter Calculated from Creep Rate Data for Haynes Alloy No. 25 Sheet Reported in the Literature.

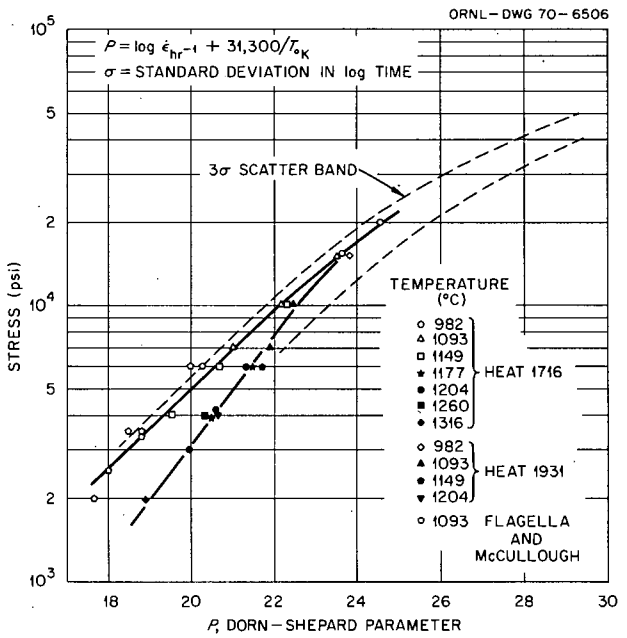

Fig. 9. Comparison of Very-High-Temperature Creep Rate Data with Scatter Band Derived for Haynes Alloy No. 25 from Literature Data at Lower Temperatures. Some data from Flagella and McCullough (TID-24045) are included. Data points for weld specimens are not shown but agree satisfactorily with the appropriate curves.

DISCUSSION

The data collected in this program show clearly that the rupture strength of Haynes alloy No. 25 has not been adversely affected by newer melting practices. This conclusion is clearly indicated in Figs. 6 and 7. This is not to say that the rupture life is independent of composition or thermal-mechanical treatment. For example, cold work probably improves the rupture life. A much more extensive program would be required to clarify the picture.

In regard to weldments we can see a fair degree of consistency when we consider a specific composition and thermal-mechanical treatment. However, the failure location is quite different for different heats. The performance of weldments in heat 1843 is particularly puzzling, for although failures occurred in the base metal, the rupture lives were quite a bit longer than those of comparable base metal specimens. We might surmise that thermal stresses developed during welding or post-weld grinding have in some way improved the strength of the weldment

specimens. From a practical viewpoint, however, weldment rupture data fall within the scatter band derived for base metal.

CONCLUSIONS

1. Recognizing the scatter typical of high-temperature stress rupture data, we conclude that changes in melting practice have not produced any appreciable loss in strength for Haynes Alloy No. 25.

2. Weldments appear to be comparable in strength to base metal.

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