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**STRESS-RUPTURE AND CREEP BEHAVIOR OF
HAYNES ALLOY NO. 25
AT 1400°, 1700°, and 2000°F IN AIR**

**P. N. Flagella
W. L. McCullough**

August 18, 1967

**NUCLEAR TECHNOLOGY DEPARTMENT
NUCLEAR ENERGY DIVISION**

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Work described in this report was performed in support of the SNAP-27 Program, AEC prime contract AT(30-1)-3535 with General Electric's Missile and Space Division, Valley Forge, Pa.

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STRESS-RUPTURE AND CREEP BEHAVIOR OF
HAYNES ALLOY NO. 25
AT 1400°, 1700°, and 2000°F
IN AIR

INTRODUCTION

This report presents the results of the stress-rupture and creep tests of Haynes Alloy No. 25¹ (HS-25) performed by GE-NMPO at 1400°, 1700°, and 2000°F in air. All samples were supplied by GE-MSD completely fabricated and ready for testing per Purchase Order No. 028-E22002.

The objective of this program was to determine the stress-rupture and creep characteristics of the material in the as-fabricated condition. Specimens containing circumferential butt-weld joints were also to be evaluated. Additionally, the effect of a coating (on one surface) on both welded and unwelded samples was to be determined.

MATERIAL

According to specifications provided by GE-MSD, the material used in this evaluation was prepared by the consumable electrode vacuum melting process as compared to the air melting process normally employed in the production of the commercial forms of this alloy.

Material, in rod form (2-3/4 inch diameter), was machined into a tubular shape per the drawing shown in Figure 1. Part number P-3 was used to fabricate the base metal test samples and part number G-1 was used to fabricate welded samples. Samples after being cut from the tubular shapes and machined to final dimensions are shown in Figure 2. Samples used for coating evaluations were coated with 2 mil of Fe₂TiO₅ on the outside (i. e., side having larger radius of curvature) surface only, using the flame spraying technique. This coating was applied after complete sample fabrication. Attempts to coat the entire tubular shape prior to cutting into samples were not satisfactory since small parts of the coating chipped off during the final machining operations.

TEST EQUIPMENT

Six creep-rupture test stands, with 9:1 overhead lever arms, were modified to accommodate the special pull-rod hardware required in the testing of these slightly curved samples. Hydraulic pumps and jacks were also installed to allow for a gradual lowering of the lever arms in order to prevent shock loading of the specimens. Each stand consisted of a lever arm, hydraulic system for lowering the lever arm, a high-temperature platinum-wound furnace, a recorder-controller to monitor and control the test temperature, a test-time hour meter and an optical extensometer for the measurement of creep.

Special pull-rods were fabricated to accommodate the curved sample design. Figure 3 is a drawing of the pull-rod used at the upper and lower ends of the samples. Two different alloys were selected as pull-rod material, Hastelloy X for oxidation resistance at 1400°F and 1700°F and HS-25 for strength at 2000°F. Because of the sample curvature and the resulting shift of the centroidal (neutral) axis, the slot in the pull-rods was offset so that the load would be applied along the neutral axis. Both the Hastelloy X and HS-25 pull-rods

¹Union Carbide Corporation, Stellite Division, Kokomo, Indiana.

Dimensions in inches

Fig. 1 - Tubular shape from which test specimens were cut

Dimensions in inches

Fig. 2—Creep-rupture test specimens

Fig. 3 – Pull-rod design for curved specimens (Dwg. 119C1934C)

were rough machined and then finished to size by grinding. The threads were also ground on both materials. Due to the complex nature of the slot in the pull-rods and the toughness of the HS-25 alloy, electro-discharge-machining (EDM) was used. Figure 4 shows the set-up used to machine the slot in four pull-rods simultaneously.

Three thermocouples were used to determine the temperature of the sample during test as shown in Figure 5. Two were fastened with Ni-Cr wire to the ends of the sample gage section and the third was fastened to the center of the gage section with a Ni-Cr strip spot welded to the edges. Chromel-alumel thermocouples were used to measure temperature for the samples tested at 1400°F and 1700°F and Pt/Pt-10% Rh thermocouples were used to measure temperature at 2000°F.

Tongue and groove type platinum extensometer strips were used to determine the amount of creep that was occurring during test. As shown in Figure 6, the strips were spot welded at each end of the gage section on the inside surface of the curved samples.

TESTING PROCEDURE

Before testing, the cross sectional area of the sample was determined by measuring the thickness and width of the sample gage section. The curvature effect on the area was neglected since it corresponds to less than 1%. Thickness measurements for coated samples were based on the gage section thickness less the coating thickness, with the actual coating thickness based on measurements at the edge of the coated region, with and without coating. No measurements were made of welded samples but a thickness of 0.053 inch (lap joint) and gage length of 0.080 inch (nominal weld width) were assumed based on the design drawing specifications (see Figure 1).

An optical comparator was used to determine the precise gage length of the sample by measuring the distance between spot welds fastening the platinum extensometer strip to the sample. Creep was assumed to occur uniformly over this distance for the unwelded samples and over the 0.080 inch length for the welded samples.

After placing the instrumented sample and pull-rods in the creep stand, the platinum strip was aligned with the furnace window to allow creep measurements to be made optically. The furnace was then brought to temperature using a separate thermocouple for furnace control. When the desired test temperature was reached, as determined by the center thermocouple of the sample, the top and bottom temperatures of the sample were recorded. If necessary, a portion of the furnace windings were shunted to obtain a temperature uniformity for the gage length of the sample within $\pm 3^\circ\text{F}$ of the center thermocouple in the tests at 1400°F and 1700°F and $\pm 5^\circ\text{F}$ for the 2000°F tests (per ASTM Designation E139-58T). When this was accomplished and thermal equilibrium of the system was attained (generally overnight), the load was applied to the sample.

Creep strain was determined by sighting through the furnace window onto the platinum extensometer strip with a 20 power optical extensometer. The optical unit was mounted on a track so that samples in all six stands could be read with the same instrument. The eyepiece of the optical extensometer had a total range of 0.2 inch with each minor division being 50 micro-inches. It would appear that the total range of measured strain would be only 0.2 inch; however, when used in conjunction with the platinum extensometer strip, several inches can be measured in much the same manner as five or six feet can be measured with a 6-inch rule. One end of the tongue and groove strip is spot welded to the bottom of the sample, and the other end spot welded to the top. During creep, the sample elongates and the extensometer extends much the same as a slide rule. Initially, the distance between two identifiable subdivisions, on adjacent scales of the platinum strip, was determined prior to loading. Upon loading, the distance was determined again and at regular intervals of time during the test. When the two original reference marks approached the range

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Fig. 4—EDM set-up for machining curved slots in pull rods (4 at a time)
(Neg. P66-6-3A)

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Fig. 5 - Thermocouple attachment used for temperature measurement during creep-rupture tests (Neg. P66-8-32D)

Fig. 6 - Platinum tongue and groove extensometer spot welded to creep specimen (Neg. P66-8-32C)

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of the eyepiece, a new set of reference marks was selected. This was continued throughout the test to allow fairly large strains to be measured.

STRESS-RUPTURE AND CREEP

In this portion of the test program 81 samples were creep-rupture tested in air at temperatures of 1400°, 1700°, and 2000°F with test times ranging from 0.15 to 2053.8 hours. Three of the tests were not analyzed due to equipment malfunction or, in one case, a faulty sample. The test results are given in Tables 1, 2, and 3 for temperatures of 1400°, 1700°, and 2000°F, respectively. Figures 7, 8, and 9 show typical creep curves based on strain measurements obtained during test. The curves for the coated and uncoated base metal samples are essentially the same. A similar conclusion was reached in the case of the welded samples, indicating the coating effect to be negligible for these tests. The welded samples show a shorter time to rupture than the base metal samples for the same temperature and stress.

All of the creep curves were analyzed to determine the secondary (linear) creep rate. The results are shown in Figure 10 as a function of stress. Reasonably good correlation was obtained for the different forms of the material except for the data at 2000°F. The welded samples had a significantly higher creep rate than the base metal samples at 2000°F.

Stress-rupture data for the various forms of the material are given in Figure 11. It can be seen that the data for the base metal and coated base metal samples give essentially the same results; this is also true for the welded samples coated and uncoated. The base metal shows a somewhat greater rupture life than the welded samples for the same temperature and stress. Also shown for comparison are curves based on data reported by Union Carbide² for HS-25 alloy bar material. For temperatures of 1400°F and 1700°F, the experimental data of this report exceed that predicted by the curves from the Union Carbide data. At 2000°F the Union Carbide data exceed the experimental data of this report for the lower stresses.

LARSON-MILLER ANALYSIS

All of the stress-rupture data were analyzed in terms of the Larson-Miller parameter, $P = T (C + \log t_R)$, where T is temperature in °R, t_R is the time to rupture in hours and C is a constant. A special computer program, developed at GE-NMPO, involving a third degree polynomial was least squares fitted to the data. This program also yields the optimum C value for the data involved.

The data reported by Union Carbide were analyzed first and the optimum C value was determined to be 20.0. The test data of this investigation were then analyzed using 20.0 as the C value in order to make a direct comparison. The results are shown in Figure 12 for the base metal samples and Figure 13 for the welded samples. As observed in the stress-rupture plot (Figure 11), the base metal is stronger than the welded samples and no difference exists between the coated and uncoated samples. Also apparent is the crossover of the two parameter curves at the higher parameter numbers corresponding to the high-temperature (2000°F), low-stress, tests.

In order to more accurately use the experimental data of this report for interpolation and extrapolation, the optimum C value in the Larson-Miller equation was determined for the base metal (coated and uncoated) and the welded (coated and uncoated) samples. The results are shown in Figures 14 and 15 with C values of 23.276 and 25.378 for the base metal and welded samples, respectively.

²Union Carbide Corp., Stellite Division, Kokomo, Indiana, F-30, 041D, page 14.

TABLE 1
CREEP-RUPTURE RESULTS FOR HS-25 ALLOY
TESTED IN AIR AT 1400°F

Sample No.	Stress, psi	Sample Type ^a	Rupture Time, hr	Linear Creep Rate, hr ⁻¹	Elongation, %
M-6	32,000	A	180.2 ^b	1.24 x 10 ⁻⁴	4.7
L-5	34,000	A	2053.8	6.6 x 10 ⁻⁶	11.5
L-3	34,000	A	1584.3	1.43 x 10 ⁻⁵	10.2
M-1	40,000	A	184.1	1.40 x 10 ⁻⁴	7.7
B-O-3	42,000	A	103.5	2.95 x 10 ⁻⁴	6.8
L-6	45,000	A	83.1	3.44 x 10 ⁻⁴	6.4
J-2-5	50,000	A	29.2	1.27 x 10 ⁻³	4.0
L-1	55,000	A	16.9	2.57 x 10 ⁻³	7.4
N-2	35,000	B	1289.4	2.53 x 10 ⁻⁵	12.6
H-1-4	35,000	B	1002.2	2.61 x 10 ⁻⁵	6.9
N-3	42,000	B	194.0	1.61 x 10 ⁻⁴	6.5
H-1-5	42,000	B	152.5	2.34 x 10 ⁻⁴	5.1
H-1-6	55,000	B	9.1	2.93 x 10 ⁻³	4.3
13-1-C-1	35,000	C	532.9	3.5 x 10 ⁻⁵	22.5
7-C-1	35,000	C	315.7	1.69 x 10 ⁻⁴	8.8
13-1-C-2	42,000	C	150.1	4.7 x 10 ⁻⁴	11.3
7-0-C-8	42,000	C	24.1	7.38 x 10 ⁻⁴	6.3
2-0-C-6	55,000	C	1.9	1.51 x 10 ⁻³	37.5
8-1-C-4	55,000	C	.15	—	21.0
9-1-C-5	34,000	D	555.0	—	36.3
4-0-C-1	35,000	D	300.5	4.34 x 10 ⁻⁵	13.8
4-0-C-2	42,000	D	16.8	—	22.5
9-1-C-6	42,000	D	11.0	1.25 x 10 ⁻³	32.5
4-0-C-3	55,000	D	5.0	9.7 x 10 ⁻³	21.3
14-8	55,000	D	1.6	1.34 x 10 ⁻²	16.3
15-5	55,000	D	1.4	6.25 x 10 ⁻³	8.8

^aA Base metal specimen, % elongation based on a 2-inch gage length.

B Base metal, Fe₂TiO₅ on one side, % elongation based on a 2-inch gage length.

C Welded specimen, % elongation based on a 0.080 inch gage length.

D Welded specimen, Fe₂TiO₅ on welded side, % elongation based on a 0.080 inch gage length.

^bDefective sample.

TABLE 2
CREEP-RUPTURE RESULTS FOR HS-25 ALLOY
TESTED IN AIR AT 1700°F

Sample No.	Stress, psi	Sample Type ^a	Rupture Time, hr	Linear Creep Rate, hr ⁻¹	Elongation, %
A-0-4	11,000	A	1057.6	1.76×10^{-5}	15.9
L-2	12,000	A	729.4	2.3×10^{-5}	21.3
H-2-3	12,000	A	652.6	3.8×10^{-5}	26.6
F-2-5	17,000	A	92.7	1.74×10^{-4}	22.3
M-2	17,000	A	81.3	4.35×10^{-4}	21.0
A-0-5	17,000	A	79.2	1.46×10^{-4}	28.0
L-4	20,000	A	24.1	2.53×10^{-3}	33.3
B-0-1	20,000	A	23.6	1.89×10^{-3}	22.9
H-1-1	20,000	A	17.0	5.87×10^{-3}	23.5
C-1-3	12,000	B	554.7	2.67×10^{-5}	23.8
H-1-2	17,000	B	74.9	5.77×10^{-4}	20.0
N-1	20,000	B	13.6	3.76×10^{-3}	25.2
12-1-C-3	12,000	C	392.9	3.3×10^{-4}	31.3
1-0-C-7	12,000	C	320.9	1.55×10^{-5}	10.0
1-0-C-8	17,000	C	27.4	9.37×10^{-4}	2.5
12-1-C-4	17,000	C	15.6	—	21.3
2-0-C-3	20,000	C	26.9	2.91×10^{-3}	7.1
7-6	20,000	C	17.9	4.48×10^{-3}	17.5
14-2	12,000	D	364.9	3.27×10^{-4}	35.0
8-1-C-8	12,000	D	81.2	—	16.3
14-6	17,000	D	66.1	1.28×10^{-3}	42.5
9-1-B-1	17,000	D	31.5	1.57×10^{-3}	27.5
3-C-5	17,000	D	5.8	—	27.5
9-1-C-3	17,000 (Lower pin sheared on loading sample)				
14-7	20,000	D	21.4	4.07×10^{-3}	61.3
3-0-C-6	24,000	D	4.3	1.66×10^{-2}	21.0

^aA Base metal specimen, % elongation based on a 2-inch gage length.

B Base metal, Fe_2TiO_5 on one side, % elongation based on a 2-inch gage length.

C Welded specimen, % elongation based on a 0.080 inch gage length.

D Welded specimen, Fe_2TiO_5 on welded side, % elongation based on a 0.080 inch gage length.

TABLE 3
CREEP-RUPTURE RESULTS FOR HS-25 ALLOY
TESTED IN AIR AT 2000°F

Sample No.	Stress, psi	Sample Type ^a	Rupture Time, hr	Linear Creep Rate, hr ⁻¹	Elongation, %
K-5	2,000	A	424.6	5.67×10^{-6}	4.1
A-0-1	2,000	A	329.7	5.88×10^{-6}	3.7
B-0-4	2,600	A	223.3	1.25×10^{-5}	0.9 ^b
C-1-8	3,300	A	150.8	8.0×10^{-5}	6.2
K-6	3,500	A	170.4	2.1×10^{-5}	3.8
A-0-2 ^c	3,500	A	39.6	4.0×10^{-5}	0.3
F-2-3	6,000	A	13.6	1.28×10^{-3}	12.1
A-0-3	6,000	A	9.8	2.59×10^{-3}	10.6
C-1-4	6,000	A	0.4 ^d	—	9.0
M-5	1,500	B	595.2	7.0×10^{-6}	—
B-0-5	2,000	B	219.8	6.55×10^{-6}	4.0
C-1-1	3,500	B	132.4	5.21×10^{-5}	7.0
M-3	3,600	B	64.0	3.8×10^{-5}	0.9 ^b
C-1-5	6,000	B	5.4	9.12×10^{-3}	—
C-1-2	6,100	B	14.5	7.78×10^{-4}	10.5
1-0-C-8	1,500	C	1614.2	5.77×10^{-6}	—
1-0-C-5	1,500	C	874.4	8.75×10^{-5}	—
6-0-C-7	3,500	C	74.6	1.99×10^{-4}	7.5
12-1-C-1	3,500	C	38.3	—	—
1-0-C-6	6,000	C	7.2	8.2×10^{-3}	38.8
12-1-C-2	6,000	C	1.0	—	34.0
8-1-C-5	1,500	D	424.3	6.91×10^{-5}	—
2-0-C-7	1,900	D	129.8	—	20.0
13-1-C-8	3,500	D	75.05	8.0×10^{-4}	22.5
8-1-C-6	3,500	D	17.6	—	18.8
3-2	3,500	D	17.0	—	23.8
14-1	6,000	D	6.1	9.11×10^{-3}	25.0
8-1-C-7	6,000	D	2.8	1.44×10^{-2}	—
9-1-C-7	6,000	D	2.1	2.21×10^{-2}	21.3

^aA Base metal specimen, % elongation based on a 2-inch gage length.

B Base metal, Fe_2TiO_5 on one side, % elongation based on a 2-inch gage length.

C Welded specimen, % elongation based on a 0.080 inch gage length.

D Welded specimen, Fe_2TiO_5 on welded side, % elongation based on a 0.080 inch gage length.

^bRuptured outside gage length.

^cFailed outside reduced section.

^dOver temperature $\approx 100^\circ\text{F}$.

Fig. 7 - Creep curves for HS-25 alloy at 1400°F tested in air

Fig. 8 - Creep curves for HS-25 alloy at 1700°F and 12,000 psi tested in air

Fig. 9 – Creep curves for HS-25 alloy at 2000°F and 3500 psi tested in air

Fig. 10 - Creep rate versus stress results for HS-25 alloy tested in air

Fig. 11 – Stress-rupture results for HS-25 alloy tested in air

Fig. 12 - Larson-Miller parameter plot for HS-25 alloy at 1400°, 1700°, and 2000°F based on $C = 20.0$

Fig. 13—Larson-Miller parameter plot for welded HS-25 alloy at 1400°, 1700°, and 2000°F based on $C = 20.0$

Fig. 14 – Larson-Miller parameter plot for HS-25 alloy at 1400°, 1700°, and 2000°F based on $C = 23.276$

Fig. 15—Larson-Miller parameter plot for welded HS-25 alloy at 1400°, 1700°, and 2000°F based on $C = 25.378$

SAMPLES AFTER TEST

Figures 16, 17, and 18 show typical test samples after test at 1400°, 1700°, and 2000°F, respectively. At 1400°F and 1700°F there appears to be very little difference in the oxide buildup for the samples tested for approximately the same amount of time. The coating remained intact on the welded samples tested at 1400°F and in the fillet area of the base metal samples. However, the coating was lost in the region of the reduced section (high strain area) of the base metal samples. The coating was lost on both the welded and base metal samples tested at 1700°F but the oxidation was less than the uncoated areas. Samples tested at 2000°F were oxidized from a moderate degree for short-time tests to severe oxidation for the long-time tests with little or no coating remaining after several hours at temperature.

CONCLUSIONS

1. The stress-rupture and creep test results obtained for the special heat of Haynes Alloy No. 25 at 1400°F and 1700°F show the material strength to exceed the average rupture data quoted by Union Carbide. At 2000°F the test data, for low stresses, fall below the rupture life indicated by the Union Carbide data.
2. Welded samples gave a rupture life which was less than that obtained for base metal samples at all three temperatures investigated. The data scatter was considerably greater for the welded samples and was probably due to the variation in actual weld penetration and width which was assumed to be constant.
3. The results of testing samples coated on one side and uncoated samples (base metal and welded) gave essentially the same results within the experimental scatter.
4. For the material and samples evaluated, the Larson-Miller parameter constant C was determined to be 23.276 for the base metal and 25.378 for the welded samples.

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The authors wish to thank Mr. N. B. Lauck for his conscientious effort in performing the experimental work of this program.

Fig. 16A – HS-25 alloy samples after creep-rupture testing in air at 1400°F for short time. (Left – inside surface; right – outside surface.) (Neg. P67-4-34A)

Fig. 16B – HS-25 alloy samples after creep-rupture testing in air at 1400°F for long time. (Left – inside surface, right – outside surface.) (Neg. P67 4-34E)

Fig. 17A – HS-25 alloy samples after creep-rupture testing in air at 1700°F for short time. (Left – inside surface, right – outside surface.)
(Neg. P67 4-34C)

Fig 17B – HS-25 alloy samples after creep-rupture testing in air at 1700°F for long time. (Left – inside surface, right – outside surface.)
(Neg P67 4 34F)

Fig. 18A – HS-25 alloy samples after creep-rupture testing in air at 2000°F for short time. (Left – inside surface; right – outside surface.) (Neg. P67-4-34B)

Fig. 18B – HS-25 alloy samples after creep-rupture testing in air at 2000°F for long time. (Left – inside surface; right – outside surface.) (Neg. P67-4-34D)