REPORT

ON

RELAXATION PROPERTIES OF "17-22-A"V AND "17-22-A"S STEELS BETWEEN 1000° AND 1100°F

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RELAXATION PROPERTIES OF "17-22-A"V and "17-22-A"S STEELS BETWEEN 1000° and 1100°F

The relaxation properties of "17-22-A"V steel were examined to establish its performance as a high-temperature bolting material. The temperatures covered were 1000°, 1050° and 1100°F. The superior rupture properties at 1100°F of the "17-22-A"V steel over the original "17-22-A"S steel indicated that the relaxation properties might well be considerably better.

Initial studies were made on specimens obtained from a forging. To check these initial results, barstock from a commercial heat was examined at 1000° and 1100°F.

"17-22-A"S steel was included at 1050°F both for comparison and to extend the data for this alloy.

SUMMARY AND CONCLUSIONS

The investigation showed that:

1. The relaxation resistance of "17-22-A"V steel is high in accordance with its high strength at high temperatures when the proper response to heat treatment to give high strength is obtained.

Samples from a high strength forging had high relaxation resistance for the longer time periods at 1000°F and for all time periods at 1050° and 1100°F. Barstock, normalized from too low a temperature to develop high strength in the heat, had low strength.

2. The usable temperature range for long time relaxation resistance for properly heat treated "17-22-A"V steel may be as high as 1050°F. Relaxation apparently occurs too rapidly at 1100°F for prolonged service. Estimated 10,000 hour residual stress values were:

1000°F - 18,000 psi
1050°F - 15,000 psi
1100°F - 6,000 psi

3. High strength "17-22-A"V material does not have much higher relaxation strength than "17-22-A"S steel at 1000°F until the time periods exceed 1000 hours. It is much stronger at 1050°F for all time periods.

4. There is some uncertainty about the extrapolation to 10,000 hours in all cases considered except the forged "17-22-A"V material at 1000°F. Structural instability complicates extrapolation.

TEST MATERIALS

Tensile specimens from both "17-22-A"V and "17-22-A"S steel were supplied for this investigation. The compositions of the test materials were reported to be as follows:

Type Steel	Heat No.	C	Mn	Si	P	S	Cr	Mo	V	Ni
"17-22-A"V	02359	.25	.66	.56	-	-	1.24	.55	.73	.27
	11833	.29	.70	.71	.019	.017	1.43	.51	.81	.31
"17-22-A"S	16030	.32	.60	.74	.013	.017	1.23	.49	.21	.28

Both radial and tangential specimens were supplied from a 2 x 22-inch upset pancake forging of "17-22-A"V steel from Heat 02359. The forging was normalized at 1800°F and tempered for 6 hours at 1225°F to 352/375 Brinell. In addition, the section from which the radial specimens were taken (1/2 of the original disc) was retempered for 6 hours at 1200°F, cut up into 1 x 1 x 7-inch sections and retempered an additional 6 hours at 1225°F to 311/331 Brinell. Machined tangential specimens with the 352/375 Brinell Hardness were retempered for 6 hours at 1200°F and 6 hours at 1225°F to a hardness of 302/323 Brinell.

The specimens from Heat 11833 of "17-22-A"V steel had been machined from 3-inch round barstock, normalized from 1800°F and followed by a 6 hour temper at 1200°F to 337 Brinell.

The "17-22-A"S specimen had been machined from 1-inch round barstock normalized from 1725°F and tempered at 1200°F to 311/331 Brinell.

PROCEDURE

The relaxation characteristics of the materials investigated were measured by a step-down relaxation test. A generalized outline of the procedure used is as follows:

1. - The test specimens were brought to temperature and distribution without stress in standard creep units.

2. - Sufficient load was applied to each specimen to bring the total strain on loading to slightly below the limiting deformation of the test.

3. - A small increment of load was removed each and every time that the creep strain reached the limiting deformation. This step was repeated until the test was discontinued.

The initial stresses required to obtain the desired deformations were chosen with the aid of stress-strain curves from short time tensile tests and/or from creep tests previously run at the test temperatures. The limiting deformations on the specimens of "17-22-A"V from Heat 11833 were 0.15 percent at 1000°F and 0.10 percent at 1100°F. For all other tests the limiting deformation was 0.16 percent. The minimum testing periods were 1000 hours.

RESULTS

The primary data are shown as the time-elongation curves of Figures 1 through 6. The derived log-residual stress-log time curves are shown in Figures 7, 9 and 11 and as semi-log residual stress-time curves in Figures 8, 10 and 12. Stress-creep rate curves, where the creep rates were those existing for each stress level, are shown in Figures 13, 14 and 15.

Both the log-log and semi-log curves show extrapolation to 10,000 hours. Both methods gave similar values, Table I, for 1000° and 1050°F for the "17-22-A"V tests. The semi-log curves gave lower values for the "17-22-A"V tests at 1100°F and for the "17-22-A"S test at 1050°F. In fact, the semi-log curve predicted zero stress in about 4,500 hours for the specimen of "17-22-A"V barstock at 1100°F, Figure 10, a result which cannot be correct.

There is some doubt regarding the accuracy of extrapolation in all cases. There is a large decrease in relaxation strength between 1000° or 1050° and 1100°F for the "17-22-A"V steel. This raises the possibility that the rate of relaxation would increase over the period of extrapolation. In fact, the curve for the "17-22-A"V barstock at 1000°F, Figure 10, shows downward curvature during the test period.

Because the curve at 1050°F for the "17-22-A"V forging, Figures 7 and 8, did not undergo a decrease in slope over the test period, it seems probable that the extrapolation at 1000°F is good to at least 10,000 hours. The large difference between 1050° and 1100°F, however, suggests that the extrapolation may be high at 1050°F, even for 10,000 hours. The log-log extrapolations at 1100°F for the "17-22-A"V forging and at 1000° and 1100°F for the "17-22-A"V barstock and for the "17-22-A"S at 1050°F are probably nearly correct at 10,000 hours, because they do include fairly drastic changes during the test periods.

The wide difference between the "17-22-A"V forging and the 3-inch barstock is shown by Figure 16. Figure 17 shows the influence of temperature on relaxation strength and compares available data for "17-22-A"V and "17-22-A"S.

The tensile properties obtained from the short time tensile tests at elevated temperatures are shown in Table II.

The hardness measurements made on the gage sections of the discontinued relaxation test specimens are compared with the original hardness in Table III. Little or no change in hardness was observed for both the barstock and forgings of both steels up to 1050°F even after nearly 3000 hours of testing. The "17-22-A"V material tested at 1100°F, however, showed a considerable decrease in hardness presumably due to tempering during testing.

Metallographic Examination

The microstructures of the specimens from the "17-22-A"V forging, Plate 1, indicated that some variation in structure existed between specimens. The radial specimen, Plate 1A, showed a structure consisting mainly of coarse acicular bainite. The specimen taken tangentially had essentially a fine grained bainitic structure with a number of patches of ferrite (Plate 1B).

The barstock from "17-22-A"V steel had a more uniform, finer grained structure of ferrite and bainite, Plate 2, than was observed in either of the forging specimens.

The structure of the "17-22-A"S barstock consisted of fairly well defined grains of acicular bainite, Plate 3.

Both the "17-22-A"S and "17-22-A"V barstock showed some evidence of banding.

DISCUSSION OF RESULTS

There are a number of features of the data which should be recognized:

Relaxation Resistance of "17-22-A"V Steel

The relaxation resistance of the specimens from the forging of "17-22-A"V steel was high and in accordance with the high strength of the alloy as established in previous studies of rupture and creep strength. This is shown by the values in Table I and by the comparison with "17-22-A"S steel in Figure 17. "17-22-A"V steel, however, has rather low relaxation strength at 1100°F for other than short time periods.

The "17-22-A"V barstock, however, was considerably weaker than the forging, Table I, and was at best only slightly more resistant to relaxation than "17-22-A"S steel, Figure 17. This figure also shows that the relaxation strength margin of the "17-22-A"V forged material over "17-22-A"S became significant only at the longer time periods.

It can be concluded that when "17-22-A"V responds to heat treatment as necessary to develop the high strength of the analysis, it does have a substantial strength advantage over "17-22-A"S at 1000° and 1050°F. At 1100°F, the relaxation resistance, however, is very low.

Relaxation Resistance of "17-22-A"S Steel

The test on "17-22-A"S at 1050°F gave very low strength. It seems certain that 1050°F is above the useful temperature range for "17-22-A"S steel where relaxation resistance at long time periods is required.

Extrapolated Relaxation Strengths

There is some doubt that the extrapolations of the residual stress curves are accurate. It is believed that the log-log curves are most reliable. At least there is no difference between them and the semi-log curves at 1000°F. The semi-log curves do show too low strength at very low stresses, even zero stress at finite time. Since all experimental and theoretical studies show that creep should slow down as the stress is reduced so as to cause the residual stress curve to approach zero stress asymptotically, it would appear that the semi-log relation breaks down at low stresses.

Actually, the reason for presenting both log-log and semi-log curves was the continued curvature for the "17-22-A"V barstock at 1000°F and the general uncertainty of extrapolation of all curves. Neither relationship gave a straight line for the "17-22-A"V curve. As noted both methods gave the same extrapolated values except where residual stresses became very low. Past experience had indicated that in some cases the semi-log relationship represented data as better straight line than log-log. In this case, both worked about equally well, except at low stresses.

The extrapolation of the "17-22-A"V forged material at 1100°F appears to be most in doubt since such low strength was found at the 50°F higher temperature. Extrapolations longer than 10,000 hours should be used with caution in any case. The stress-creep rate curves show the same deviations as the residual stress curves, as should be the case. Therefore, these creep data are no better for extrapolation purposes.

Explanation of Relaxation Characteristics

It is known that "17-22-A"V steel requires a minimum normalizing temperature which varies between 1800° and 1850°F for high strength. The extensive rupture tests on the forging (Report 205) had demonstrated that the proper response to heat treatment had been obtained for the conditions used. The barstock evidently had been normalized from too low a temperature to develop the full potential of the alloy. Unreported data from barstock from the same heat indicate that the normalizing at lower temperatures resulted in rupture strengths no better than that of "17-22-A"S steel. Higher normalizing temperatures were required to bring the strength up to the level expected for the material. Allis Chalmers, in informal communications, showed rupture strengths which were very similar to those typical of "17-22-A"S steel thus confirming the results obtained at the University. The low strengths were, therefore, in accordance with the response to heat treatment. A somewhat higher normalizing temperature would undoubtedly increase the relaxation strength to a higher level. The relatively fine microstructure of the barstock was indicative of low creep resistance.

Structural instability, presumable continued tempering, was responsible for the low strength of the "17-22-A"V steel at 1100°F. Apparently, the forged material was considerably more stable than the barstock, since the latter material showed evidence of instability at 1000°F. Deviations from linearity in the residual stress curves at 1000°F for this material would only be expected in such a case. The rapid drop in strength between 1000° and 1100°F would also require structural instability since the decrease is more than would be expected from temperature alone. The low hardness exhibited by the material after testing at 1100°F appears to substantiate this.

The "17-22-A"S steel also would have to be unstable at 1050°F to account for the low strength. In fact, the relative strengths of "17-22-A"V and "17-22-A"S suggest that the "17-22-A"V is mainly more resistant to tempering. Otherwise, a larger difference would be expected at 1000°F.

The stress-creep rate curves reflect the differences in relaxation strength. This is only to be expected since creep causes relaxation.

There were variations in structure in the specimens from the "17-22-A"V forging. It seems probable that this was reflected in the relaxation characteristics. The residual stress-time curve at 1050°F appeared to be somewhat flatter than at 1000°F, probably due to differences in structure and between tangential and radial specimens.

Effect of Limiting Deformation and Initial Stress

Residual stresses, particularly at the shorter time periods, vary with the initial stress and limiting deformation. Generally, the higher the initial stress the higher the residual stress with the difference diminishing with increased time.

The difference between the forging and barstock of "17-22-A"V steel at 1000°F was, therefore, in part at least due to the lower stress and deformation used for the barstock. This, however, does not account for the fall-off in strength with time and the lower long time strength for the barstock. If some other factor had not been present the strength of the two materials should have become closer together at the longer time periods. A lower stress and limiting deformation was used on the bar stock to agree with certain check tests being made at Allis Chalmers.

The small limiting deformation used for the test on "17-22-A"V barstock at 1100°F also contributed to the strength being lower than for the forged material. The difference was so large that it may have contributed to the difference at 10,000 hours. However, instability was probably a major factor.

TABLE I

RELAXATION STRENGTH OF "17-22-A"V AND "17-22-A"S STEELS AT INDICATED TEMPERATURES

t ıp.)	Initial Stress (psi)	Limiting Deformation (%)	Test Duration (hrs)	Residual Stress (psi)			
						10,000 hours	
				100-hrs	1000-hrs	log-log curve	semi-log curve
				"17-22-A"V Forging - Heat 02359			
)	33,700	.16	2033	27,500	23,000	18,000	18,000
)	28,000	.16	1708	22,000	18,500	15,000	15,000
)	25,000	.16	1322	18,500	11,500	6,000	4,000
				"17-22-A"V - 3-inch Round Barstock - Heat 11833			
)	31,000	.15	2863	25,500	19,800	12,500	11,500
)	20,000	.10	1561	11,000	4,600	2,000	--
				"17-22-A"S - 1-inch Round Barstock - Heat 16030			
)	28,000	.16	1215	16,000	8,500	4,000	1,000

TABLE II

SHORT TIME TENSILE PROPERTIES OF "17-22-A"V and "17-22-A"S STEEL

Temperature (°F)	Tensile Strength (psi)	Offset Yield Strength (psi)		Elongation (% in 2 in.)	Reduction of Area (%)
		.1%	.2%		
		"17-22-A"V Barstock (Heat 11833)			
1000	105,800	91,000	(101,000)*	20.5	68.5
1100	92,500	72,500	(79,500)*	20.5	69.5
		"17-22-A"S Barstock (Heat 16030)			
1050	90,500	76,000	82,300	20.5	73.5

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* Extrapolated values from the stress-strain curves.

TABLE III

HARDNESS OF "17-22-A"V AND "17-22-A"S STEEL AFTER RELAXATION TESTING

Heat No.	Test Conditions Initial Stress (psi)	Limiting Deformation (%)	Temp. (°F)	Test Duration (hrs)	Brinell Hardness Initial	After Testing*
			"17-22-A"V Forging			
02359	33,700	.16	1000	2033	302/323	294
02359	28,000	.16	1050	1708	311/331	298
02359	25,000	.16	1100	1322	311/331	258
			"17-22-A"V Barstock			
11833	31,000	.15	1000	2863	337	327
11833	20,000	.10	1100	1561	337	253
			"17-22-A"S Barstock			
16030	28,000	.16	1050	1215	311/331	294

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* Converted from Rockwell C Hardness numbers.