REPORT

ON

RUPTURE PROPERTIES AT 1100°F OF SIMULATED TURBINE WHEEL FORGINGS FROM "17-22-A"V, "17-22-A"S, AND REX 448 STEELS

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INTRODUCTION

The investigation covered by this report was undertaken to determine the rupture properties of "17-22-A"V steel in the form approximating the forged discs of the type used as rotors in the gas turbines in the jet aircraft industry.

In addition to the "17-22-A"V discs, comparison discs were supplied from "17-22-A"S and Rex 448 (12 Cr Mo V Cb) steels. Rex 448 barstock was also included for comparative purposes.

Previous work on barstock from small induction heats of "17-22-A"V and Rex 448 analysis indicated that the rupture strength and ductility of the "17-22-A"V steel at 1100°F was substantially higher than that of the "17-22-A"S steel. However, both the rupture strength and ductility values for "17-22-A"V steel were lower than those of the Rex 448 analysis.

This report presents the properties established for each of the forgings and in addition are compared with the properties previously established for "17-22-A"V and "17-22-A"S barstock.

SUMMARY AND CONCLUSIONS

Appraisal of the data from this investigation led to the following conclusions:

1. The rupture strength and ductility of the disc material were equal to those obtained previously for barstock from "17-22-A"V steel.

2. The rupture strength and ductility at 1100°F obtained for the disc made from "17-22-A"V steel were substantially higher than those for the disc from "17-22-A"S. The "17-22-A"V material had 1000-hour rupture strengths of 30,000 to 36,500 at 1100°F as compared to the 22,000 to 24,000 psi for "17-22-A"S.

3. The "17-22-A"V steel disc data indicated equal and possibly higher rupture strength than for the Rex 448 steel forging for time periods of up to about 300 hours. The steeper stress - rupture time curves for the "17-22-A"V material resulted in lower 1000-hour strengths.

4. The Rex 448 barstock oil quenched from 2115°F was approximately equal instrength and ductility at 1100°F to the Rex 448 disc, whereas that of the 1850°F normalized barstock was lower than either.

5. The ductility of the specimens from barstock and disc of "17-22-A"V steel was in all cases substantially lower than that of the Rex 448 steel.

6. The 1000-hour rupture strength for the "17-22-A"V disc material varied from 30,000 psi to 32,500 psi for the tangential specimens and from 30,000 psi to 36,500 psi for the radial specimens. These variations in rupture strength obtained for the specimens from the "17-22-A"V disc are difficult to explain because it is uncertain whether the variations were

caused by differences in tempering conditions, location of the original specimens in the disc, or a combination of both.

7. The rupture strength of the disc from "17-22-A"S steel was higher than that of barstock from a commercial heat of similar analysis.

8. The discs from both steels -- "17-22-A"V and "17-22-A"S -- apparently had greater resistance to tempering than had been expected. Previous work done on these materials did not show the same resistance.

TEST MATERIALS

Machined 0.505-inch diameter tensile specimens were supplied from "17-22-A"S, "17-22-A"V, and Rex 448 steels reported to have the following analysis:

Heat No.	Chemical Composition (percent) C	Mn	Si	Cr	Ni	Mo	V	Cb	Al	N_2
				"17-22-A"V Steel						
02359	0.25	0.56	0.66	1.24	0.27	0.55	0.73	--	--	--
				"17-22-A"S Steel						
02358	0.29	0.50	0.68	1.29	0.25	0.50	0.25	--	--	--
				Rex 448 Steel						
02336	0.084	0.90	0.10	10.64	0.28	0.80	0.18	0.32	--	--
(1)	0.102	1.08	0.49	10.73	0.84	0.70	0.23	0.50	0.013	0.045

(1) English made disc having in addition the following: Zr - 0.16, Al_2O_3 - 0.006, Cu - 0.16, SiO_2 - 0.006.

The V/C ratio of Heat 02359 was somewhat lower than the approximate values of four which was originally considered desirable for "17-22-A"V steel. The composition of Heat 02358 was typical of "17-22-A"S steel.

The tensile specimens were prepared from discs and/or barstock heat treated as indicated in Table I. It will be noted that retempering was required in the case of the "17-22-A" type steels to obtain the desired hardness level of about 300 BHN.

Metallographic specimens were cut from the end of tensile specimens without knowledge as to the position of the specimen in the disc itself.

Where the stress for rupture was 40,000 psi or more, the diameter of the specimen was reduced to 0.400 inches in order to maintain load requirements within the capacity of the stress-rupture units.

RESULTS AND DISCUSSION

Tests were carried out to establish the rupture characteristics of both the tangential and the radial specimens from the forgings made of "17-22-A"V, "17-22-A"S, and Rex 448 steels. The results of the stress-rupture tests at 1100°F are presented in Table II and Figures 1 through 4. In each case, comparative stress-rupture time curves from barstock were included. The following sections present and discuss the results of the data obtained.

"17-22-A"V Forgings

As will be discussed later, there were complications in the data due to tempering difficulties. The data appear to indicate that the radial specimens had higher strength and elongation at 1100°F than the tangential specimens for time periods longer than about 350 hours. (See Figure 1.) The radial specimens were also somewhat higher than the original experimental heat of barstock (Heat A80). Comparative rupture strengths for 200 and 1000 hours were as follows:

Type Specimen	Heat Treatment	BHN	Rupture Strength (psi) 200-hr	1000-hr	Elongation at Fracture (%) 200-hr	1000-hr
Heat 02359						
Tang-ential	N. 1800°F + 6 hrs 1225°F + 6 hrs 1200°F + 6 hrs 1225°F	302/323	--	(32,500)	--	6
Tang-ential	N. 1800°F + 6 hrs 1225°F + 6 hrs 1200°F + 6 hrs 1225°F	311/321	53,000	30,000	~5	<3
Radial	N. 1800°F + 6 hrs 1225°F + 6 hrs 1225°F	323/337	45,500	36,500	~8.5	~4.5
Radial	N. 1800°F + 6 hrs 1225°F + 6 hrs 1200°F + 6 hrs 1225°F	311/321	--	(30,000)	--	--
Heat A80						
Barstock	N. 1800°F + 6 hrs 1200°F	302/311	(50,000)	34,500	~7	<5

Values for rupture in 200 hours were used, rather than the more common 100-hour values because it is doubtful that the data could be reliably extrapolated to 100 hours. It will also be noted that the number of tests was so limited as to constitute a survey, rather than to exactly establish values.

As originally heat treated, the disc had a higher hardness than was desired, 352 - 375 BHN. Retempering was carried out under the several conditions listed in Table I to bring the hardness down closer to a 330 maximum. Examination of Figure 1 suggests the possibility that the retempering of finished specimens at Michigan led to higher strengths than these materials retempered by Timken. It appears very possible that this was more important than the difference between radial and tangential specimens. It appears that the forging structures were more resistant to tempering than barstock normalized from the same temperature.

The microstructures of the "17-22-A"V disc shown by Plates 1 through 3 indicate considerable variation in structure between specimens. The structures of the radial specimens varied from a banded type structure of ferrite and a finer grained tempered bainite, Plate 1A, to a mainly coarser accicular, tempered bainite structure, Plates 2A and 3A.

The tangential specimens, on the other hand, showed a more uniform structure of fine grained ferrite and bainite, Plates 1B and 2B. Plate 3B shows a number of larger ferrite patches.

No significant difference in structure was observed between the specimens with the various retempering procedures. Variations between specimens, probably due to variation in location in the forging, obscured any conclusion regarding tempering conditions.

Since the photomicrographs were made from metallographic samples taken from ends of tensile specimens, the photomicrographs therefore may not be representative of the structure in the gage section, particularly in view of the fact that the exact position of the samples in the disc is unknown.

It is uncertain whether the differences observed between the radial and tangential specimens from the "17-22-A"V steel were entirely due to the location of the specimens, to the differences in microstructure, to the tempering conditions, or to a combination of any of these factors in the original disc.

"17-22-A"S Steel

The rupture test data obtained at 1100°F are given in Table II and plotted in Figure 2 as stress - rupture time curves. The limited number of tests indicated a higher rupture strength and lower ductility than is charactereistic of barstock. Comparative rupture strengths and elongation values were as follows:

Type Specimen	Heat Treatment	BHN	Rupture Strength (psi) 200-hr	Rupture Strength (psi) 1000-hr	Elongation at Fracture (%) 200-hr	Elongation at Fracture (%) 1000-hr
Heat 02358						
Tangential	N. 1725°F + 6 hrs 1200°F + 6 hrs 1200°F	321/331	39,500	22,000	<1	~1
Radial	N. 1725°F + 6 hrs 1200°F + 6 hrs 1225°F	306/331	40,000	24,000	<1	~1
Heat 16030						
Barstock	N. 1725°F + 6 hrs 1200°F	311/331	35,000	20,500	~3	5

There was no significant difference between tangential and radial specimens, although the indications again were that tangential specimens were somewhat lower in strength at the longer time periods. Again there was a difference in tempering conditions to complicate the comparison between types of specimens. There was also some indication of increased resistance to tempering for the disc forgings.

Representative microstructures of the "17-22-A"S disc are presented in Plate 4. The structure shown, typical of both the radial and tangential "17-22-A"S specimens obtained from discs, consisted of a relatively coarse-grained tempered, accicular bainite. This structure is somewhat more accicular and coarser in nature than those observed in the past in the "17-22-A"S barstock with the same heat treatment. Again, no difference due to tempering conditions was observed.

Rex 448 Steel

Barstock and disc material from a Timken heat and a disc from a British heat were tested. The heat treatments and rupture data are presented in Tables I and II respectively.

There appeared to be very little variation in rupture strength or ductility between specimens from barstock or disc or from Timken or British made heats when air cooled or oil quenched from 2115°F, as may be seen from the stress-rupture time curves of Figure 3 and the following tabulation:

Type Specimen	Heat Treatment	BHN	Rupture Strength (psi) 200-hr	Rupture Strength (psi) 1000-hr	Elongation at Fracture (%) 200-hr	Elongation at Fracture (%) 1000-hr
Timken -- Heat 02336						
Tangential	A.C. 2115°F + 6 hrs 1200°F	294	49,500	41,000	11	15
Radial	A.C. 2115°F + 6 hrs 1200°F	277	48,000	41,000	14	24
Barstock	O.Q. 2115°F + Tempered at 1200°F	285	48,000	(40,000)	10	--
Barstock	N. 1850°F + Tempered at 1200°F	277	40,000	(31,500)	14	--
British Heat						
Tangential	O.Q. 2115°F + Tempered at 1200°F	285	--	(41,000)	--	11
Radial	O.Q. 2115°F + Tempered at 1200°F	285	46,000	40,000	~15	12.5

Normalizing the barstock from 1850°F appeared to cause a decrease in rupture strength of approximately 8,000 psi, though the ductility remained the same.

Microstructures typical of Rex 448 steels are shown in Plates 5 and 6. In all cases, the main structure was tempered martensite. Variable amounts of delta ferrite were present in all samples. It is impossible to say whether the ferrite variation was due to heat treatment, source of material, or to normal variation between specimens. Normalizing from 1850°F gave a finer structure than heat treating at 2115°F. The specimens from the british heat were definitely coarser grained. There appeared to be no significant difference in structure between oil quenching and normalizing or between radial and tangential specimens from the discs.

Comparison of Properties of "17-22-A"V, "17-22-A"S, and Rex 448 Steel Forgings

The rupture properties of the "17-22-A"V disc forgings are compared to the forgings made from the other type materials in the stress - rupture time curves of Figure 4 and the following tabulation:

Type Specimen	Heat Treatment	Stress for Rupture (psi) 200-hr	1000-hr	Elongation (% in 2 in.) 200-hr	1000-hr
"17-22-A"V Steel - Heat 02359					
Tang-ential	N. 1800°F and Tempered	--/ 53,000	30,000/ 32,500	--/5	3 / 6
Radial	N. 1800°F and Tempered	45,000/ --	30,000/ 36,500	8.5/--	4.5/--
"17-22-A"S Steel - Heat 02358					
Tang-ential	N. 1725°F and Tempered	39,500	22,000	< 1	~1
Radial	N. 1725°F and Tempered	40,000	24,000	1	1
Rex 448 Steel - Heat 02336					
Tang-ential	A.C. 2115°F and Tempered	49,500	41,000	11	15
Radial	A.C. 2115°F and Tempered	48,000	41,000	14	24
Rex 448 Steel - British Heat					
Tang-ential	O.Q. 2115°F and Tempered	--	41,000	--	11
Radial	O.Q. 2115°F and Tempered	46,000	40,000	15	12.5

The data at 1100°F show that the "17-22-A"V disc has substantially higher rupture strength and ductility than the "17-22-A"S disc.

The steep slope of the stress - rupture time curves for the "17-22-A"V disc material results in lower rupture strength beyond about 300 hours than that of the Rex 448 disc.

The ductility of the "17-22-A"V disc is considerably lower than that of the Rex 448 steel.

The "17-22-A"V disc material showed more variation in structure between specimens than did the "17-22-A"S or Rex 448 disc material.

TABLE I

Section Size, Heat Treatment, and Hardness Data

for "17-22-A"V, "17-22-A"S, and Rex 448 Steels

Type Stock	Heat Treatment	BHN
	"17-22-A"V Steel	
Heat 02359		
(1)	N. 1800°F + 6 hrs at 1225°F	352/375
(2)	N. 1800°F + Tempered at 1200° + 1225°F	311/321
(3)	N. 1800°F + Tempered at 1200° + 1225°F	302/323
(4)	N. 1800°F + 12 hrs at 1225°F	323/337
	"17-22-A"S Steel	
Heat 02358		
(1)	N. 1725°F + 6 hrs at 1200°F	352/363
(5)	N. 1725°F + 12 hrs at 1200°F	321/331
(6)	N. 1725°F + 6 hrs at 1200°F + 6 hrs at 1225°F	306/331
	Rex 448 Steel	
Heat 02336		
Barstock	N. 1850°F + Tempered at 1200°F	277
Barstock	O.Q. 2115°F + Tempered at 1200°F	285
Forging	A.C. 2115°F + 6 hrs at 1200°F	277/294
British Made Heat		
Forging	O.Q. 2115°F + Tempered at 1200°F (presumably)	285

(1) 2" x 22" forging.
(2) 2" x 22" forging tempered for 6 hours at 1225°F. Half the forging tempered an additional 6 hours at 1200°F. 1"-square by 7"-sections were cut and retempered 6 hours at 1225°F.
(3) 2" x 22" forging tempered for 6 hours at 1225°F. 0.505" diameter specimens retempered for 6 hours at 1200°F + 6 hours at 1225°F.
(4) 2" x 22" forging tempered for 6 hours at 1225°F. The 0.505" diameter specimens retempered for 6 hours at 1225°F.
(5) 2" x 22" forging tempered for 6 hours at 1200°F. Half of disc retempered 6 hours at 1200°F.
(6) 2" x 22" forging tempered for 6 hours at 1200°F. 0.505" diameter specimens retempered 6 hours at 1225°F.

TABLE II

Rupture Data for "17-22-A"V, "17-22-A"S, and Rex 448 Steels at 1100°F

Heat Treatment	Code No.	Brinell Hardness Number	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Reduction of Area (%)
		"17-22-A"V Disc				
Heat 02359						
N. 1800°F + Temper (2)	Tang	352/375	44,000	353	10.0	17.8
N. 1800°F + Temper (3)	Tang	311/321	50,000	235	4.5	5.9
			45,000	323	4.6	6.6
			35,000	660	3.0 (1)	11.0
N. 1800°F + Temper (4)	Tang	302/323	30,000	1421	6.1	12.1
N. 1800°F + Temper (3)	Rad	311/321	38,000	533	12.5	15.6
N. 1800°F + Temper (5)	Rad	323/337	45,000	219	8.5	15.3
			38,000	876	5.5	10.0
			35,000	1199	4.3	12.0
		"17-22-A"S Disc				
Heat 02358						
N. 1725°F + Temper (6)	Tang	321/331	40,000	195	1.5	2.0
			25,000	699	1.5	1.5
N. 1725°F + Temper (7)	Rad	306/331	40,000	198	1.0	0.5
			25,000	869	2.0	0.5
		Rex 448 Disc and Barstock				
"Timken" Heat 02336 (Disc)						
A.C. from 2115°F + 6 hrs at 1200°F	Tang	294	50,000	171	11.0	49.2
			40,000	1111	16.5	67.6
	Rad	277	50,000	137	9.2	52.3
			40,000	1149	24.5	70.5
"Timken" Heat 02336 (Barstock)						
N. 1850°F + Tempered at 1200°F	N	277	45,000	65	18.0	73.0
			40,000	188	14.1	72.4
			35,000	483	16.0	71.6
O.Q. 2115°F + Tempered at 1200°F	Q	285	50,000	134	14.0	62.0
			45,000	348	12.0	65.0
British Made Disc						
O.Q. 2115°F + Temperd at 1200°F	Tang	285	40,000	1212	11.0	37.1
	Rad	285	50,000	65	15.1	62.8
			40,000	1073	12.5	44.8

(1) Broke in fillet.
(2) 2" x 22" forging tempered for 6 hours at 1225°F.
(3) 2" x 22" forging tempered for 6 hours at 1225°F. Half the forging retempered 6 hours at 1200°F. 1"-square by 7"-sections were cut and retempered 6 hours at 1225°F.
(4) 2" x 22" forging tempered for 6 hours at 1225°F. 0.505" diameter specimens were retempered for 6 hours at 1200°F and 6 hours at 1225°F.
(5) 2" x 22" forging tempered for 6 hours at 1225°F. The 0.505" diameter specimens were then given an additional 6 hours at 1225°F
(6) 2" x 22" forging tempered for 6 hours at 1200°F. Half of disc then retempered for 6 hours at 1200°F.
(7) 2" x 22" forging tempered for 6 hours at 1200°F. The 0.505" diameter specimens were then retempered an additional 6 hours at 1225°F.