TENTH PROGRESS REPORT

TO

MATERIALS LABORATORY, WRIGHT AIR DEVELOPMENT CENTER

DEPARTMENT OF THE AIR FORCE

ON

FOUR LOW-ALLOY STEELS FOR ROTOR DISKS OF GAS TURBINES IN JET ENGINES

by

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PROJECT M903

AIR FORCE CONTRACT NUMBER: AF33(038)-13496
SUPPLEMENTAL AGREEMENT NUMBER: S4(53-534)
EXPENDITURE ORDER NUMBERS: 605-227 SR-7 and
R615-13 SR-3a

June 30, 1953

SUMMARY

The original investigation began as a study of the high temperature properties of four low-alloy steels: 4340, "17-22A"S, H-40 and C-422, in the form of forged J-33 jet engine disks. A concurrent investigation of the high temperature properties of the products of isothermal transformation of each steel was carried out utilizing bar stock. The investigation was then extended to include a more complete investigation of the products of isothermal transformation, as well as the normalized and oil quenched structures. The original investigation of the jet engine disks and the concurrent study of the products of isothermal transformation have been completed and reports are now being prepared.

This progress report covers the period between April 1, 1953 and June 30, 1953. Survey type testing has been started and data obtained at 700°, 900°, 1100° and 1200°F for the "17-22A"S steel. Data has been accumulated at 700°, 900°, 1000° and 1100°F for the 4340 steel. Tests are now in progress at 700°, 900°, 1100° and 1200°F for the H-40 steel, but no additional data have been obtained during this period. The data have been organized to include data previously obtained, as well as those from current tests at the new temperature and on the new structures.

The tests conducted to date are not conclusive. The trends being obtained, however, are interesting and are as follows:

4340 Steel

At 700°F and a stress of 90,000 psi the normalized structure had the best strength, whereas at 900°F and a stress of 55,000 psi, the lower bainitic structure had the best properties. At 1000°F and 13,000

psi, the upper bainitic structure is the strongest, but at 1100°F and 4,500 psi there was little difference between the upper and middle bainitic structures, both being somewhat stronger than the next strongest, the normalized structure.

"17-22A"S Steel

At 700°F and 115,000 psi the oil-quenched structure was strongest. However, the stress was too high for a good evaluation. At 900°F and 70,000 psi, the normalized structure appears to be slightly stronger, but the bainitic structures had good ductility. At 1100°F and 19,000 psi the lower bainitic structure had the best strength, but at 1200°F and 7,500 psi the middle pearlitic structure appears to be strongest.

H-40 Steel

No additional data have been accumulated for the H-40 steel during this period.

INTRODUCTION

The Materials Laboratory, Wright Air Development Center, is sponsoring an investigation of the high temperature properties of low alloy steels for use as forged wheels for the gas turbines of jet engines. This progress report covers the period between April 1, 1953 and June 30, 1953. The work is being carried out under Contract Number: AF 33(038)-13496 (Expenditure Order Number 605-227 SR-7) and Supplemental Agreement Number: S4 (53-534) (Expenditure Order Number: R615-13 SR-3a).

A final report presenting the properties of forged wheels of 4340, "17-22A"S, H-40 and C-422 alloys is in the process of reproduction. It will be submitted early in the next period. For purposes of simplicity and usefulness, it has been decided to submit two final reports. A second report is being prepared to present the original results from studies of the products of isothermal transformation, as related to the properties at high temperatures. In addition, this report will present an analysis of the microstructures of the wheels and attempt a correlation, as far as possible, of the structure studies of the bar structures.

This present progress report also presents the results of considerable progress on the survey tests of the current program.

RESULTS

During the period covered by this report, the work was nearly completed on a final report presenting the properties obtained in the investigation of forged turbine wheels. The correlation work in structures of the wheels and bar stock studies is continuing and is nearly ready for reporting.

Structures to Be Investigated

The structures and treatments to be investigated are outlined in Tables I through III. Certain idealized structures were selected to cover the range of structures possible from the transformation diagrams. These idealized structures have been given simple names in order to provide a convenient means of referring to the treatments and structures in the text. It is important to realize, as is outlined in the tables, that the actual structures deviated from the idealized structures in some cases. It should also be realized, for example, that the "upper pearlite" of the 4340 steel is a different structure from the "upper pearlite" of the "17-22A"S steel, and in turn these two structures are different from the "pearlite" formed in the H-40 steel. A more complete discussion of the nomenclature used will be found in Progress Report Number 9.

Heat Treatment Studies

The data obtained from the survey tests for the isothermally transformed structures and the oil quenched and normalized structures are given in Tables IV and V. These tables have been organized to include data previously obtained, as well as those from current tests so as to completely present available data. The following general trends regarding relations between structures and properties at high temperatures appear to be shown by the data obtained to date:

4340 Steel

1. The test data are still considered too limited for definite conclusions regarding the relationships between structure and strength.

2. At 700°F, the normalized structure (65% bainites + 35% martensite) had the best strength of the structures tested on the basis of the time to reach one-per cent deformation or minimum creep rate under a stress of 90,000 psi. The "lower bainitic" structure (100% lower bainite) was next strongest. There are two major limitations to the available data. None of the "pearlitic" structures have yet been tested. Secondly, only one stress has been used to date. The stress of 90,000 psi is somewhat above the proportional limit of the specimens thus far tested.

3. At 900°F a stress of 55,000 psi was used. It resulted in fracture of all the specimens tested in time periods ranging from 4.5 hours to 1417 hours. "Middle" bainite (100% medium acicular bainite) had the longest time for fracture and the lowest minimum creep rate. There was a considerable decrease in strength to the next two strongest structures, "lower" bainite and normalized material. "Upper" and "lower" pearlite were both very weak comparatively. The stress level was such that the time to reach one-per cent deformation was rather short and largely controlled by the initial deformation. "Upper" bainite ought to be tested before too definite conclusions are drawn. Also at 900°F a lower stress throwing the comparison mainly on total deformation and creep rates ought to be used for evaluation.

It will be noted that the "middle" bainite had rather low elongation and reduction of area. Even though the time for fracture was considerably longer than for the other tests (such values generally tend to decrease with time for fracture), it appears quite certain that the medium acicular bainitic structure is associated with low ductility in the rupture test at 900°F for this alloy.

4. At 1000°F, "upper" bainite (70% upper bainite + 30% martensite) is the strongest on the basis of total deformation and minimum creep rates. The normalized and "middle" bainite ranks next. It is interesting to note that "lower" pearlite was stronger than the oil quenched structure. Rupture tests ought to be carried out on these structures before definite conclusions are reached regarding relative strengths of structures.

"17-22A"S Steel

1. The stress used at 700°F (115,000 psi) resulted in fracture of all the structures in rather short time periods. At this high stress the oil quenched material was strongest. These was very little difference in ductility for the different structures, all being quite high.

It is considered that the stress used was too high for a good evaluation and tests should be made under a stress causing about one-per cent total deformation in 1000 hours for the stronger structures.

2. The stress used at 900°F (70,000 psi) also caused fracture of all but the normalized structure, which appears to be the strongest structure at 900°F. The oil quenched structure appears to be slightly stronger than "upper bainite," but not as strong as "lower bainite." The bainitic structures had good ductility.

3. At 1100°F, all except the "lower bainite" specimen fractured in less than 1000 hours. This specimen, however, was not as creep

resistant as the normalized specimen, even though it apparently had higher rupture strength. The spread in rupture times for the other structures was surprisingly small. Also, all of the structures had rather low elongation, except for "lower pearlite." The spread in times for one-per cent total deformation and minimum creep rates was also rather small for all the structures.

4. At 1200°F "middle" pearlite has the best strength on the basis of rupture time, total deformation or minimum creep rate. As at 1100°F, however, there was a surprisingly small range in relative strengths. Ductility to fracture was considerably higher at 1200°F than at 1100°F.

H-40 Steel

No additional data have been accumulated. The specimens have been heat treated and tests are now in progress.

DISCUSSION

The tests conducted to date are not conclusive. The trends being obtained are, however, interesting and should prove useful. One finding which seems to be contrary to generally accepted concepts of the past is the comparatively low creep resistance of tempered martensite (oil quenched specimens) at temperatures as low as 700°F.

The data obtained during the next period, together with more opportunity to analyze the data should lead to more definite conclusions regarding the realtions between structures and properties at high temperatures.

TABLE I

Type Structures, Heat Treatments and Actual Structures for 4340 Steel

(All 4340 bar stock austenitized at 1750°F for 1 hour.)

Aim Structure	Transformation Conditions		Approximate Structure Obtained	BHN	Tempering		BHN
	Temp-°F	Time-hrs			Temp-°F	Time-hrs	
Upper Pearlite	1240	10	65% medium pearlite + 35% ferrite	212/221	None	--	212/221
Middle Pearlite	1150	14	85% fine pearlite and fine carbide-ferrite aggregate + 15% ferrite	199/223	None	--	199/223
Lower Pearlite	1050	111	90% very fine carbide-ferrite aggregate + 10% ferrite	260/275	None	--	260/275
Upper Bainite	850	28	70% upper bainite + 30% martensite	319/324	None	--	319/324
Middle Bainite	750	24	100% medium acicular bainite	302/313	None	--	302/313
Lower Bainite	650	1-1/2	100% lower bainite	430	1100	1-1/4	277/301
Normalized	Air Cooled from 1750		35% martensite + 65% bainite	385	1100	1	300/311
Oil Quenched	Oil Quenched from 1750		100% martensite	585	1100	10	304/309

TABLE II

Type Structures, Heat Treatments and Actual Structures for 1.25 Cr-Mo-Si-V ("17-22A"S) Steel

(All "17-22A"S bar stock austenitized at 1750 for 1 hour)

Aim Structure	Transformation Conditions		Approximate Structure Obtained	BHN	Tempering		BHN
	Temp-°F	Time-hrs			Temp-°F	Time-hrs	
Upper Pearlite	1300	1-1/2	45% medium pearlite + 55% ferrite	309	None	--	309
Middle Pearlite	1225	1-1/2	40% medium fine pearlite + 60% ferrite	267/285	None	--	267/285
Lower Pearlite	1150	10	40% fine pearlite + 60% ferrite	375	1200	12	293/313
Upper Bainite	900	2	60% upper bainite and acicular ferrite + 40% martensite	465	1200	16	284/327
Middle Bainite	800	1/2	100% fine acicular bainite	360	1200	4	307/310
Lower Bainite	700	1/12	95% lower bainite + 5% ferrite	365	1200	12	273/302
Normalized	Air Cooled from 1750		15% martensite + 85% coarse bainite	355	1200	10	302/313
Oil Quenched	Oil Quenched from 1750		98% martensite + 2% ferrite	525	1300	1	272/310

TABLE III

Type Structures, Heat Treatments and Actual Structures for 3 Cr-Mo-W-V (H-40) Steel

(All H-40 bar stock austenitized at 1950°F for 1 hour.)

Aim Structure	Transformation Conditions		Approximate Structure Obtained	BHN	Tempering		BHN
	Temp-°F	Time-hrs			Temp-°F	Time-hrs	
Pearlite	1300	24	fine carbide precipitate	190/199	None	--	190/190
Bainite	750	10	40% bainite and acicular ferrite + 60% martensite	480	1300	1	293/312
Normalized	Air Cooled from 1950		30% martensite + 70% bainite	435	1200	18	312/320
Oil Quenched	Oil Quenched from 1950		98% martensite + 2% ferrite	523	1200	12	290/323

TABLE IV

Rupture, Total Deformation and Creep Data at 700°, 900°, 1000° and 1100°F for 4340 Steel

Aim Structure	BHN	Temperature (°F)	Stress (psi)	Rupture Time (hours)	Elongation % in 2"	Reduction of Area (%)	Deformation on Loading (in./in.)	Time to Reach Specified Total Deformations 0.1%	0.2%	0.5%	1.0%	Minimum Creep Rate (%/hour)
Normalized 35% martensite + 65% bainites	300	700	90,000	1294(d)	--	--	0.00516	a	a	2	--	0.000112
Oil Quenched 100% martensite	304	700	90,000	1350(d)	--	--	0.00430	a	a	2	675	0.000272
Upper Bainite 70% upper bainite + 30% martensite	324	700	90,000	1316(d)	--	--	0.00465	a	a	1	198	0.000320
Middle Bainite 100% medium acicular bainite	309	700	90,000	1315(d)	--	--	0.00472	a	a	~1	1291	0.000190
Lower Bainite 100% lower bainite	277	700	90,000	1485(d)	--	--	0.00440	a	a	~1	2020(b)	0.000160
Normalized 35% matensite + 65% bainites	300	900	55,000	842	12.0	22.4	0.00260	a	a	8	64	0.00414
Oil Quenched 100% martensite	306	900	55,000	381	19.5	39.5	0.00269	a	a	2	13	0.0148
Upper Pearlite 65% medium pearlite + 35% ferrite	217	900	55,000	4.5	51.0	68.8	--	--	--	--	--	--
Lower Pearlite 90% very fine carbide-ferrite aggregate + 10% ferrite	260	900	55,000	20	34.5	37.9	0.00313	a	a	0.13	1	0.55
Middle Bainite 100% medium acicular bainite	313	900	55,000	1417	4.1(c)	2.4	0.00380	a	a	1	51	0.00064
Lower Bainite 100% lower bainite	277	900	55,000	897	18.5(c)	15.4	0.00250	a	a	8	51	0.0053
Normalized 35% martensite + 65% bainites	301	1000	12,000	1000(d)	--	--	0.00050	12	114	802	2150(b)	0.00037
Oil Quenched 100% martensite	306	1000	13,000	1025(d)	--	--	0.00060	3	27	248	628	0.00115
Upper Pearlite 65% medium pearlite + 35% ferrite	219	1000	13,000	1103(d)	--	--	0.00044	6	63	528	1400(b)	0.00057
Lower Pearlite 90% very fine carbide-ferrite aggregate + 10% ferrite	270	1000	13,000	848	21.4	24.8	0.00062	~2	6	46	141	0.00537

TABLE IV, Continued

Aim Structure	BHN	Temp-erature (°F)	Stress (psi)	Rupture Time (hours)	Elong-ation % in 2"	Reduction of Area (%)	Deformation on Loading (in./in.)	Time to Reach Specified Total Deformations 0.1%	0.2%	0.5%	1.0%	Minimum Creep Rate (%/hour)
Upper Bainite 70% upper bainite + 30% martensite	322	1000	13,000	1075(d)	--	--	0.00057	5	91	1130(b)	--	0.00023
Middle Bainite 100% medium acicular bainite	307	1000	12,470	1706(d)	--	--	0.00068	4	42	472	1920(b)	0.00030
Lower Bainite 100% lower bainite	294	1000	13,000	1035(d)	--	--	0.00055	~2	32	300	1104(b)	0.00053
Normalized 35% martensite + 65% bainites	311	1100	4,000	1056(d)	--	--	0.00017	18	96	484	1416(b)	0.00052
Oil Quenched 100% martensite	309	1100	4,500	1080(d)	--	--	0.00027	5	22	104	258	0.00316
Lower Pearlite 90% very fine carbide-ferrite aggregate + 10% ferrite	275	1100	4,250	1007(d)	--	--	0.00032	9	21	90	217	0.00390
Upper Bainite 70% upper bainite + 30% martensite	319	1100	4,500	990(d)	--	--	0.00026	17	78	552	1585(b)	0.00048
Middle Bainite 100% medium acicular bainite	302	1100	4,500	1343(d)	--	--	0.00025	13	55	432	1565(b)	0.000445
Lower Bainite 100% lower bainite	301	1100	4,500	1008(d)	--	--	0.00042	3	19	156	436	0.00172

(a) Specimen reached this deformation on loading.
(b) Extrapolated value.
(c) 0.250-inch diameter specimen, elongation % in 1-inch.
(d) Test discontinued at this time.

TABLE V

Rupture, Total Deformation and Creep Data at 700°, 900°, 1100° and 1200°F for 1.25 Cr-Mo-Si-V ("17-22A"S) Steel

Aim Structure	BHN	Temperature (°F)	Stress (psi)	Rupture Time (hours)	Elongation % in 2"	Reduction of Area (%)	Deformation on Loading (in./in.)	Time to Reach Specified Total Deformations 0.1%	0.2%	0.5%	1.0%	Minimum Creep Rate (%/hour)
Normalized 15% martensite + 85% coarse bainite	302	700	115,000	132	21.0(c)	61.9	0.01580	a	a	a	a	0.0220
Oil Quenched 98% martensite + 2% ferrite	278	700	115,000	289	19.8(c)	63.3	0.01925	a	a	a	a	0.0095
Middle Pearlite 40% medium fine pearlite + 60% ferrite	267	700	115,000	265.2	20.0(c)	59.2	0.01950	a	a	a	a	0.0120
Upper Bainite 60% upper bainite and acicular ferrite + 40% martensite	284	700	115,000	147	20.2(c)	62.0	0.01570	a	a	a	a	0.0180
Lower Bainite 95% lower bainite + 5% ferrite	275	700	115,000	59.4	18.8(c)	66.7	--	--	--	--	--	--
Normalized 15% martensite + 85% coarse bainite	303	900	70,000	1482(d)	--	--	0.00335	a	a	24	1400	0.00030
Oil Quenched 98% martensite + 2% ferrite	272	900	70,000	756	30.3(c)	64.0	0.00378	a	a	3	50	0.00384
Upper Bainite 60% aupper bainite and acicular ferrite + 40% martensite	289	900	70,000	686	30.0(c)	59.5	0.00355	a	a	1	50	0.00504
Lower Bainite 95% lower bainite + 5% ferrite	283	900	70,000	1456	24.0(c)	56.2	0.00350	a	a	12	362	0.00326
Normalized 15% martensite + 85% coarse bainite	311	1100	20,000	773	2	--	0.00090	1	46	375	656	0.00086
Oil Quenched 98% martensite + 2% ferrite	306	1100	20,000	666	4.5	--	0.00101	1	13	139	345	0.00186
Upper Pearlite 45% medium pearlite + 55% ferrite	309	1100	19,000	565	4.4	--	0.00082	1	17	159	336	0.00204
Middle Pearlite 40% medium fine pearlite + 60% ferrite	285	1100	19,000	669(f)	3	1.6	0.00110	a	10	185	430	0.00145

TABLE V, Continued

Aim Structure	BHN	Temperature (°F)	Stress (psi)	Rupture Time (hours)	Elongation % in 2"	Reduction of Area (%)	Deformation on Loading (in./in.)	Time to Reach Specified Total Deformations 0.1%	0.2%	0.5%	1.0%	Minimum Creep Rate (%/hour)
Lower Pearlite 40% fine pearlite + 60% ferrite	313	1100	19,000	550	11.5	15.2	0.00093	a	10	79	194	0.00400
Upper Bainite 60% upper bainite and acicular ferrite + 40% martensite	327	1100	19,000	796	5.8(c)	6.6	0.00110	a	8	177	447	0.00140
Lower Bainite 95% lower bainite + 5% ferrite	302	1100	19,000	1040(d)	--	--	0.00127	a	18	104	281	0.00146
Normalized 15% martensite + 85% coarse bainite	313	1200	7,500	918	10.0	14.9	0.00046	6	46	176	333	0.00230
Oil Quenched 98% martensite + 2% ferrite	310	1200	7,500	575(f)	30.0	39.8	0.00058	6	17	69	144	0.00660
Middle Pearlite 40% medium fine pearlite + 60% ferrite	276	1200	7,500	1033	10(e)	--	0.00034	10	46	196	370	0.00198
Upper Bainite 60% upper bainite and acicular ferrite + 40% martensite	320	1200	7,500	456	22.5(c)	35.8	0.00054	1	8	45	104	0.00810
Middle Bainite 100% fine acicular bainite	310	1200	7,500	812	19.1(e)(c)	--	0.00050	10	26	115	228	0.00316
Lower Bainite 95% lower bainite + 5% ferrite	273	1200	7,500	709	22.9(c)	34.6	0.00048	6	30	112	229	0.00360

(a) Specimen reached this deformation on loading.
(b) Extrapolated value.
(c) 0.250-inch diameter specimen, elongation % in 1-inch.
(d) Test discontinued at this time.
(e) Very badly scaled.
(f) Broke in gage mark.