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Ann Arbor, Michigan

RUPTURE-TEST PROPERTIES OF 18Cr-15Ni-3Mo ALLOY WITH Ti, N AND Al ADDED

by

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Project 04603-64-T
Report 249

March 10, 1965.

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STEEL AND TUBE DIVISION
CANTON, OHIO

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The rupture properties of three heats of modified 18Cr-15Ni-3Mo steel were studied at 1350°F. The modifications took the form of additions of titanium, aluminum and nitrogen. The level of added elements ranged from 0.09 to 0.17 percent titanium, 0.49 to 1.90 percent aluminum and 0.13 to 0.18 percent nitrogen.

The principal objective of the study was to determine whether promising properties could be obtained in an austenitic steel at 1350°F through the precipitation of the γ' phase, Ni_3 (Al Ti). Other γ' strengthened austenitic alloys have been shown to possess excellent properties at temperatures from about 1200°F to 1600°F or higher.

CONCLUSIONS

Simultaneous additions of titanium, aluminum and nitrogen to an 18Cr-15Ni-3Mo austenitic steel resulted in rupture strengths at 1350°F and 1500°F below those typical of Type 316 (18Cr-10Ni-Mo) stainless steel.

The rupture strength of the modified alloy decreased with increasing aluminum content. The weakening was associated with the development of sigma phase, which apparently restricted any benefit of γ' precipitation. The amount of titanium was apparently limited due to its interaction with nitrogen forming TiN.

TEST MATERIALS

Machined tensile specimens from three experimental heats of 18Cr-15Ni steel were supplied by The Timken Roller Bearing Company Inc. These heats had the following reported analyses:

Heat No.	C	Mn	P	S	Si	Cr	Ni	Mo	Ti	N	Al
Z2803	.074	1.66	.014	.012	.70	18.64	14.61	2.82	.09	.174	.49
Z2804	.042	1.74	.013	.013	.67	18.25	15.17	2.82	.17	.178	1.90
Z2805	.039	1.78	.012	.012	.67	18.28	15.10	2.82	.17	.13	.91

Specimen blanks from these three heats were oil quenched after 30 minutes at 1950°F. This heat treatment resulted in the following hardness values:

Heat No.	Brinell Hardness Number
Z2803	163
Z2804	197
Z2805	152

RESULTS AND DISCUSSION

Rupture tests were conducted at 1350°F on specimens from all three heats. In addition, one heat was tested at 1500°F. The rupture data obtained from these heats are reported in Table 1 and the stress-rupture time curves are plotted in Figure 1.

The following results were derived from the data:

1. All three heats had considerably lower rupture strengths (Table 2) than is typical for Type 316 steel. The difference in strength was greater at 1000 hours than at 100 hours, indicating that the modified alloys would not improve in relative strength at prolonged time periods.
2. The rupture strengths at 1350°F decreased with increasing aluminum content (Fig. 1).
3. The specimens from all three heats had high rupture elongations at 1350°F. Considerably lower elongations occurred in specimens from the 0.5 percent aluminum heat (Z2803) when tested at 1500°F. The rupture specimen tested at 3000 psi at 1500°F ruptured in 480 hours. This specimen was both severely oxidized and very brittle, breaking in three places.

The microstructures of the alloys are shown in Plates 1, 2 and 3. These microstructures indicate:

a. The 0.5 percent aluminum alloy (Heat Z2803) contained no appreciable amount of ferrite (Plate 1).

b. The 1 percent aluminum material (Heat Z2805) and the 1.9 percent aluminum alloy (Heat Z2804) contained significant amounts of ferrite, the amount of this phase increasing with increasing aluminum content. This is readily evident in Plates 2 and 3.

c. Titanium carbonitride particles were present in each of the three alloys. The number of these particles, however, decreased with increasing aluminum content. These particles may have helped suppress the grain size of the 0.5 percent aluminum alloy.

Experience with these types of alloys indicates that the low aluminum alloy (Heat Z2803) should develop extensive sigma phase during testing. Sigma phase is associated with low strength and high ductility during rupture testing. Such behavior is evident at 1350°F. The low ductility of this heat at 1500°F is probably due to the excessive oxidation which occurred at this temperature.

The ferrite present in Heats Z2804 and Z2805 would be expected to transform to sigma phase during testing. The rupture strength of these two alloys varied inversely with the amount of ferrite in the initial microstructure, indicating that sigma phase did indeed form during testing. This is confirmed by direct relation between rupture ductility and ferrite which existed for these two alloys as is shown in Figure 1.

It appears that the high aluminum contents of these alloys caused the formation of sigma phase, which in turn resulted in low strength properties. The sigma phase apparently formed from ferrite in two of the alloys.

Nitrogen presumably removed titanium from solution in the alloy by the formation of TiN. The decreasing number of TiN particles with increasing ferrite level suggests that some titanium may have been absorbed in the ferrite. This could occur in much the same manner as columbium is absorbed by ferrite present in Type 347 steel. If the titanium segregated to the ferrite then it is very doubtful that it could participate in a strengthening reaction.

In order to obtain high strengths in a titanium and aluminum modified stainless steel it will probably be necessary to have a completely austenitic matrix. There is more than a littl e doubt that high rupture strengths can be obtained, however. It is questionable whether a strengthening reaction active in nickel-base austenitic al loys can be successfully applied to iron-base austenitic materials. Certainly the successful application of the γ' strengthening reaction to iron base austenitic alloys would require mugh higher nickel contents in order to (1) insure a completely austenitic matrix and (2) provide sufficient nickel to participate in the precipitation reaction.

TABLE 1

Stress-Rupture Time Data for three heats of
18Cr-15Ni-3Mo Alloy with Ti, N and Al added

Heat No.	Aluminum (%)	Stress (psi)	Rupture Time (hrs.)	Elong. (% in 2 ins)	Red. of Area (%)
		Rupture Tests at 1350°F			
Z2803	0.49	25,000	19.9	55.5	61.0
		17,500	101.5	22.0	33.0
Z2805	0.91	21,000	16.8	52.5	53.0
		12,000	273	25.0	25.0
Z2804	1.90	21,000	15.5	47.0 (1)	60.5
		12,000	108	38.0	43.5
		Rupture Tests at 1500°F			
Z2803	0.49	6,000	82	3.5 (2)	-
		3,000	480	9.0 (3)	-

(1) - Broke in gage mark

(2) - Broke in fillet

(3) - Broke in several places - considerable amount of oxidation occurred

TABLE 2

Rupture Test Properties at 1350° and 1500°F for 18Cr-15Ni-3Mo Alloy with Ti, N and Al added

Heat No.	Aluminum (%)	100 hour Rupture Strength (psi)	100 hour Elongation (%)	Extrapolated 1000 hour Rupture Strength (psi)
		1350°F		
Z2803	0.49	17,500	22	(10,500)
Z2805	0.91	14,700	30	(9,200)
Z2804	1.90	12,300	38	(6,500
Typical Type 316 steel		18,000		12,000
		1500°F		
Z2803	0.49	5,500	3.5	(2,250)
Typical Type 316 steel		10,000		6,000