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EFFECT OF HEAT TREATMENT AT 1150°C ON CREEP RUPTURE PROPERTIES OF A Fe₃Al-BASED ALLOY

C. G. McKamey, Y. Marrero-Santos,* and P. J. Maziasz
Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831
*Emilio R. Delgado High School, Corozal, PR 00783

ABSTRACT

The effects of heat treatment at 1150°C on the creep-rupture properties of a Fe₃Al-based alloy were studied. Tests were conducted in air using various test temperatures and stresses. By plotting the data to a power-law equation, the activation energy for creep was determined to be approximately 150 kcal/mole and the creep exponent to be about 8. Optical metallography and scanning electron microscopy of ruptured specimens indicated that failure was in a ductile manner by microvoid coalescence at grain boundaries and triple points. Analytical electron microscopy was used to study characteristics of the microstructure and to identify Zr-rich precipitates that formed during heat treatment or creep testing. These precipitates were found to provide strengthening by pinning dislocations and grain boundaries.

INTRODUCTION

Past studies have shown that binary Fe₃Al possesses low creep-rupture strength compared to many other alloys, with creep-rupture lives of less than 5 h being reported for tests conducted at 593°C and 207 MPa (ref. 1). The combination of poor creep resistance and low room-temperature tensile ductility due to a susceptibility to environmentally-induced dynamic hydrogen embrittlement^{2,3} has limited use of these alloys for structural applications, despite their excellent corrosion properties.⁴ Improvements in room temperature tensile ductility have been realized mainly through alloying effects, changes in thermomechanical processing to control microstructure, and by control of the specimen's surface condition.^{3,5} Ductilities of 10-20% and tensile yield strengths as high as 500 MPa have been reported.^{6,7} In terms of creep-rupture strength, small additions of Mo, Nb, and Zr have produced significant improvements, but at the expense of weldability and room-temperature tensile ductility.^{1,8-11} Recently an alloy containing these additions, designated FA-180, was shown to exhibit a creep-rupture life of over 2000 h after a heat treatment of 1 h at 1150°C.¹² This study presents the results of creep-rupture tests at various test temperatures and stresses and discusses the results as part of our effort to understand the strengthening mechanisms involved with heat treatment at 1150°C.

EXPERIMENTAL PROCEDURES

The alloy composition used in this study was designated FA-180 and has a nominal composition of Fe-28Al-5Cr (at.%) with 0.5% Nb, 0.8% Mo, 0.025% Zr, 0.05%

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C, and 0.005% B. It was prepared by arc-melting and drop-casting into a chilled copper mold. Fabrication to 0.8-mm-thick sheet was accomplished by hot-rolling, beginning at 1000°C and finishing at 600-650°C. After a stress relief heat treatment of 1 h at 700°C, flat tensile specimens (0.8 x 3.18 x 12.7 mm) were mechanically punched from the rolled sheet. Before testing, the tensile specimens were further annealed in air for 1 h at 1150°C and air cooled. Creep-rupture tests were performed in air at temperatures between 500 and 775°C and at stresses of 69 to 379 MPa (10-55 ksi). Minimum creep rates (MCR) were measured as the slope of the linear portion of the test curve. The data was plotted to a power-law equation in order to obtain the creep exponent and activation energy. Optical metallography and scanning electron microscopy (SEM) were used to study the microstructures and fracture modes. Analytical electron microscopy (AEM) using either a Philips CM30 (300 kV) or CM12 [120 kV, with ultra-thin-window x-ray energy dispersive spectrometry (XEDS) detector] electron microscope was performed on samples cut from the gage portion of selected test specimens.

RESULTS AND DISCUSSION

Optical metallography of alloy FA-180 heat treated at 1150°C for 1 h showed the starting microstructure to be composed of 150-250 μm diameter grains containing a dispersion of coarse ($\approx 2-4 \mu\text{m}$ diameter) precipitates that were earlier determined to be Mo, Nb, and/or Zr-rich carbides.^{1,12,13} Larger grains of up to 400 μm diameter were also observed in some areas, as was reported earlier for this same alloy and heat treatment.¹² AEM of specimens before creep-rupture testing also showed the presence of much finer Zr-rich precipitates (shown in Fig. 1) within the grains.¹²

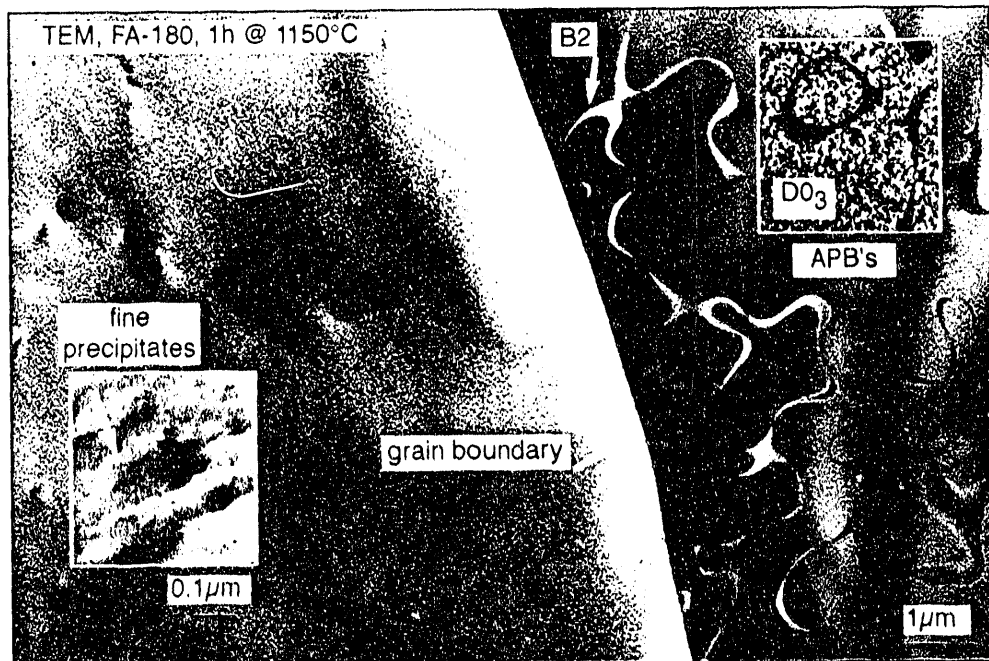


Fig. 1. Electron micrographs showing microstructural features of FA-180 as-heat-treated at 1150°C: (a) clean grain boundaries, (b) fine matrix precipitates, (c) fine D0₃ structure within coarse B2.

Tables I and II list the results of creep-rupture tests conducted as a function of test temperature and stress, respectively. The results of tests at temperatures between 593 and 700°C showed that under a stress of 207 MPa this alloy had good creep resistance to a temperature of 650°C, but the creep-rupture life decreased dramatically at 675°C. Other data in Tables I and II indicate that with a lower stress the use temperature can be pushed to temperatures higher than 650°C. For example, using a stress of 69 MPa, a creep-rupture life of over 500 h was attained at 675°C and almost 200 h at 700°C (Table I). All of the fractured specimens showed a ductile failure mode in which creep voids were observed to have coalesced at grain boundaries and triple points (see Fig. 2).

Table I. Creep test results for tests conducted at constant stress

Test #	Stress (MPa)	Temperature (°C)	Rupture Life (h)	Elongation (%)	MCR ^a (%/h)
404/405	207	700	0.6	26.2	13.6
407/431		675	0.8	27.0	20.8
410		650	1059.0	11.0	0.002
411		593	1959.2	9.7	0.003
418/420	69	775	5.1	72.6	4.0
417/419		750	12.5	72.2	1.6
421/422		725	54.5	52.2	0.4
415/416		700	192.1	60.4	0.03
412		675	591.0	45.0	0.002

^aMCR = minimum creep rate measured in the linear portion of the creep curve.

Table II. Creep test results for tests conducted at constant temperature

Test #	Temperature (°C)	Stress (MPa)	Rupture Life (h)	Elongation (%)	MCR ^a (%/h)
407/431	675	207	0.8	27.0	20.8
425/430		172	14.2	27.0	1.4
408/413/414		138	52.2	29.0	0.1
427		103	252.4	24.8	0.01
412		69	591.0	45.0	0.002
429	500	379	28.2		0.2
426		345	54.0	25.1	0.3
428		310	27.9		0.05

^aMCR = minimum creep rate measured in the linear portion of the creep curve.

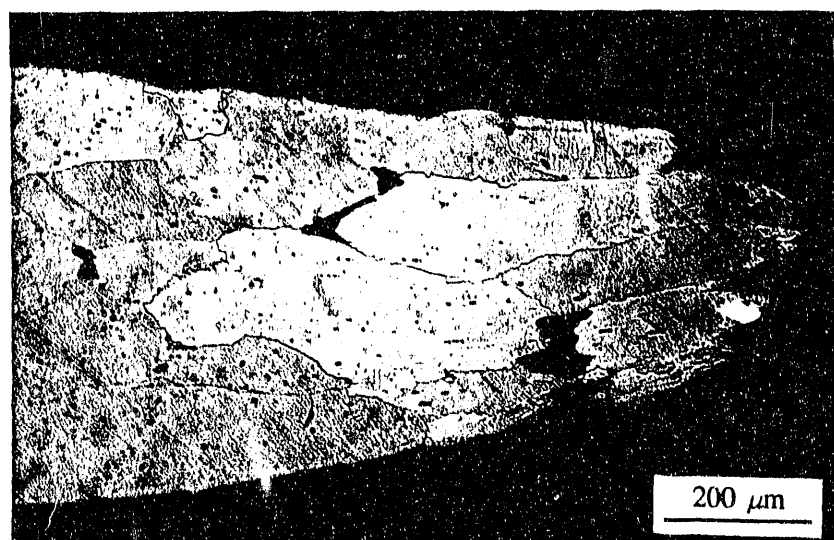


Fig. 2. Optical micrograph showing the presence of creep voids on grain boundaries and triple points of a creep-ruptured specimen.

If one can assume that the mechanisms of dislocation creep in intermetallic alloys do not differ from those in conventional alloys (as has been done by other researchers in the past¹⁵⁻¹⁸), then the creep data can be fitted to a power-law creep equation of the form

$$\dot{\epsilon} = A\sigma^n(e^{-Q/RT}) ,$$

where $\dot{\epsilon}$ is the minimum creep rate (MCR), A is a constant, σ is the test stress, n is the creep exponent, Q is the activation energy for creep, T is the temperature in Kelvin (K) and R is the universal gas constant with a value of 1.987 cal/mol/°C. By rearranging this equation and inserting the data for constant stress or constant temperature tests, the activation energy for creep (Q) and the creep exponent (n) were obtained (see Figs. 3 and 4). The results are accumulated in Table III. The average activation energy was determined to be approximately 150 kcal/mol which indicates a much stronger alloy than binary Fe-28Al or the ternary alloys containing additions of only Mo or Nb/Zr (~80 kcal/mol).^{1,19} [Note the binary alloy has been shown to have very poor creep resistance under the test conditions used in the current study¹ and a heat treatment at 1150°C produced absolutely no improvement,¹⁴ as was expected for a binary alloy with no precipitate formers.] A creep exponent of almost 8 suggests that the increased creep strength with the 1150°C heat treatment probably involved particle strengthening,¹⁵⁻¹⁷ and this was substantiated by the AEM results reported earlier.¹² Due to the fewer number of tests in this study, any dependence of the creep exponent on the test stress, as was reported earlier for binary and ternary alloys,¹ was not observed. An investigation of that possibility would need to be part of any further study.

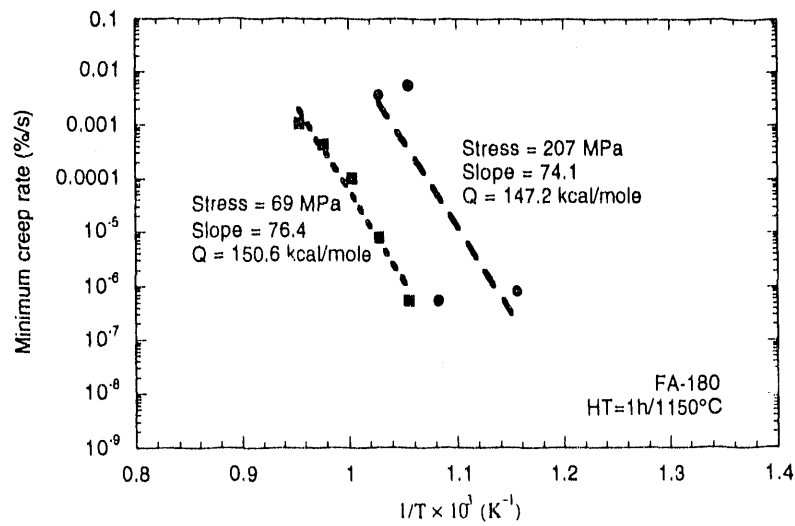


Fig. 3. Minimum creep rate versus temperature for FA-180. The slope represents the activation energy for creep.

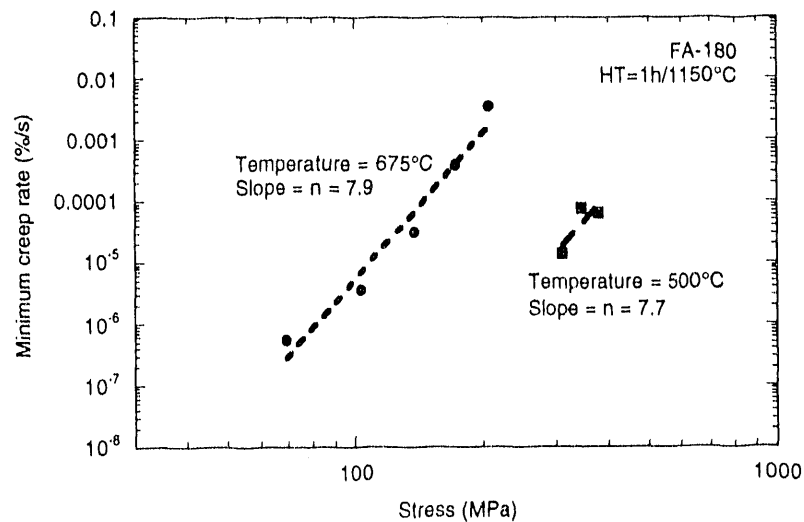


Fig. 4. Minimum creep rate versus stress for FA-180. The slope equals the creep exponent n .

Table III. Activation energies (Q) and creep exponents (n) for alloy FA-180 determined from the results of the present study

Alloy	Temperature (°C)	Stress (MPa)	Slope	Q (kcal/mole)	n
FA-180	675	69-206	7.9	151.8	7.9
	500	310-380	7.7		7.7
FA-180	675-775	69	76.4	147.2	
	593-700	207	74.1		

CONCLUSIONS

The creep-rupture strength of Fe₃Al-based alloy FA-180 (Fe-28Al-5Cr-0.5Nb-0.8Mo-0.025Zr-0.05C-0.005B, at.%) has been improved significantly by heat treating for 1 h at 1150°C. This strengthening was attributed to the presence of fine matrix and grain boundary Zr-rich MC precipitates. The activation energy for creep in alloy FA-180 was determined to be approx. 150 kcal/mole which is twice that determined earlier for binary Fe₃Al. A creep exponent of almost 8 was determined, consistent with a precipitation-strengthening mechanism.

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REFERENCES

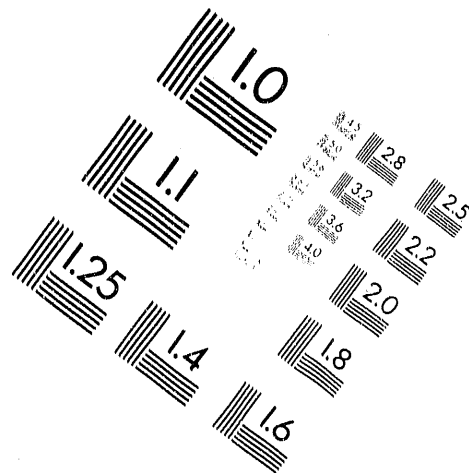
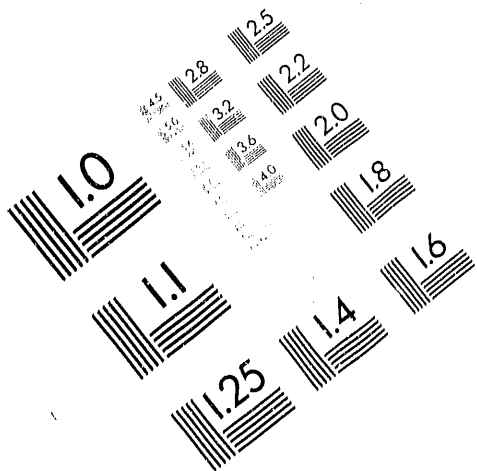
1. C. G. McKamey, P. J. Maziasz, and J. W. Jones, *J. Mater. Res.* **7**(8), 2089 (1992).
2. C. T. Liu, C. G. McKamey, and E. H. Lee, *Scripta Metall. Mater.* **24**(2), 385 (1990).
3. C. T. Liu and C. G. McKamey, in High Temperature Aluminides and Intermetallics, edited by S. H. Whang, C. T. Liu, D. P. Pope, and J. O. Stiegler (The Metallurgical Society, Warrendale, PA: 1990), pp. 133-151.
4. P. F. Tortorelli and J. H. DeVan, *Mater. Sci. & Eng.* **A153**, 573 (1992).
5. C. G. McKamey and C. T. Liu, in Proceedings of ADVMAT/91, First International Symposium on Environmental Effects on Advanced Materials, edited by R. D. Kane (NACE, Houston, TX, 1992), paper no. 17-1.
6. V. K. Sikka, *SAMPE Quart.* **22**(4), 2 (1991).
7. V. K. Sikka, S. Viswanathan, and C. G. McKamey, Structural Intermetallics, edited by R. Darolia, J. J. Lewandowski, C. T. Liu, P. L. Martin, D. B. Miracle, and M. V. Nathal (The Metallurgical Society, Warrendale, PA, 1993), pp. 483-91.
8. C. G. McKamey, J. H. DeVan, P. F. Tortorelli, and V. K. Sikka, *J. Mater. Res.* **6**(8), 1779 (1991).
9. P. J. Maziasz and C. G. McKamey, *Mater. Sci. & Eng.*, **A152**, 322 (1992).
10. D. M. Dimiduk, M. G. Mendiratta, D. Banerjee, and H. A. Lipsitt, *Acta Metall.* **36**, 2947 (1988).
11. D. G. Morris, M. Nazmy, and C. Nosedo, *Scripta Metall. Mater.* **31**, 173 (1994).
12. C. G. McKamey and P. J. Maziasz, in Processing, Properties, and Applications of Iron Aluminides, edited by J. H. Schneibel, M. A. Crimp, and R. Mason (TMS, Warrendale, PA, 1994), pp. 147-58.
13. C. G. McKamey, P. J. Maziasz, G. M. Goodwin, and T. Zacharia, *Mater. Sci. & Eng.* **A174**, 59 (1994).
14. C. G. McKamey, unpublished results, 1994.
15. F. Garofalo, Fundamentals of Creep and Creep-Rupture in Metals (The Macmillan Co., New York, 1965).
16. O. D. Sherby and P. M. Burke, *Prog. Mater. Sci.* **13**, 325 (1968).
17. N. S. Stoloff and R. G. Davies, *Prog. Mater. Sci.* **13**, 1 (1966).
18. I. Jung, M. Rudy, and G. Sauthoff, in High Temperature Ordered Intermetallic Alloys II, edited by N. S. Stoloff, C. C. Koch, C. T. Liu, and O. Izumi (*Mater. Res. Soc. Symp. Proc.* **81**, Pittsburgh, PA, 1987), pp. 263-274.
19. A. Lawley, J. A. Coll, and R. W. Cahn, *TMS AIME* **218**, 166 (1960).



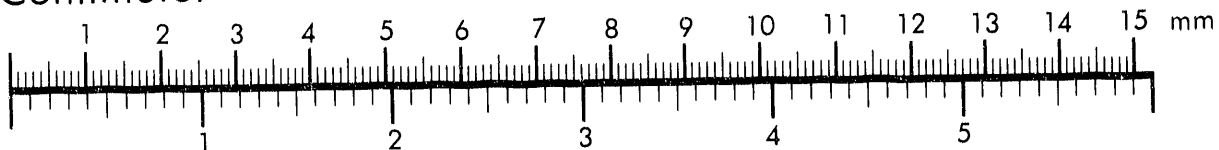
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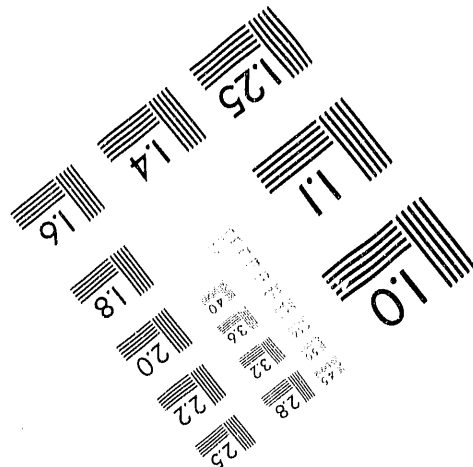
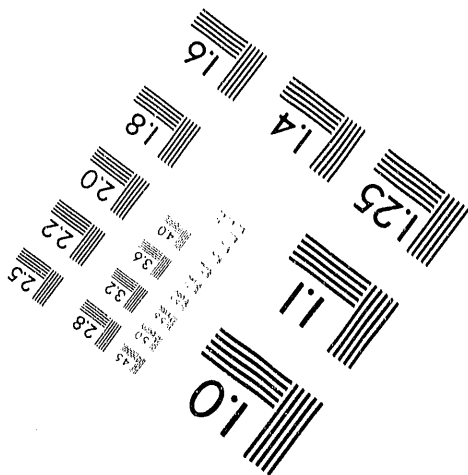
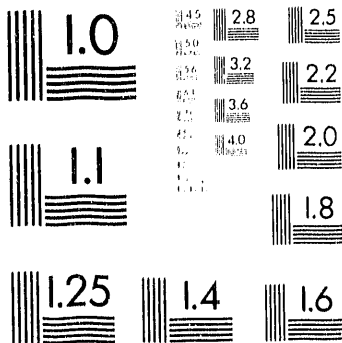
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