



Creep deformation and rupture behaviour of 9Cr–1W–0.2V–0.06Ta Reduced Activation Ferritic–Martensitic steel

J. Vanaja, K. Laha*, R. Mythili, K.S. Chandravathi, S. Saroja, M.D. Mathew

Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam 603102, India

ARTICLE INFO

Article history:

Received 16 March 2011
 Received in revised form 24 August 2011
 Accepted 26 October 2011
 Available online 11 November 2011

Keywords:

RAFM steel
 Creep damage
 TEM
 Microstructural degradation
 Rupture life

ABSTRACT

This paper presents the creep deformation and rupture behaviour of indigenously produced 9Cr–1W–0.2V–0.06Ta Reduced Activation Ferritic–Martensitic (RAFM) steel for fusion reactor application. Creep studies were carried out at 773, 823 and 873 K over a stress range of 100–300 MPa. The creep deformation of the steel was found to proceed with relatively shorter primary regime followed by an extended tertiary regime with virtually no secondary regime. The variation of minimum creep rate of the material with applied stress followed a power law relation, $\dot{\epsilon}_m = A\sigma^n$, with stress exponent value 'n' decreasing with increase in temperature. The product of minimum creep rate and creep rupture life was found to obey the modified Monkman–Grant relation. The time to onset of tertiary stage of deformation was directly proportional to rupture life. TEM studies revealed relatively large changes in martensitic sub-structure and coarsening of precipitates in the steel on creep exposure as compared to thermal exposure. Microstructural degradation was considered as the prime cause of extended tertiary stage of creep deformation, which was also reflected in the damage tolerance factor λ with a value more than 2.5. In view of the microstructural instability of the material on creep exposure, the variation of minimum creep rate with stress and temperature did not obey Dorn's equation modified by invoking Lagneborg and Bergman's concepts of back stress.

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1. Introduction

High chromium (9–12 wt.%) ferritic–martensitic steels have shown good performance in applications of conventional fossil fired power plants, petrochemical plants and steam generators because of their good creep rupture strength, adequate corrosion/oxidation resistance, lower thermal expansion coefficient and higher thermal conductivity as compared to austenitic stainless steels with virtual immunity to stress corrosion cracking in caustic and aqueous medium. Some of these ferritic steels with suitable compositional modifications are now under consideration for blanket module of nuclear fusion reactors because of their inherent void swelling resistance along with lower shift in ductile brittle transition temperature (DBTT) on neutron irradiation [1]. Realization of fusion reactor technology depends on the development of materials resistant to the simultaneous effects of high-energy neutron irradiation and intense thermo-mechanical loads [2]. The structural material is exposed to bombardment by very high energy neutrons (~14.1 MeV) which produce atomic displacement cascades and transmutation nuclear reactions within the materials

making them highly radioactive. Elements like molybdenum, niobium, nickel and nitrogen transmute on intense neutron irradiation to long-life radioactive nuclides. This creates handling and disposal issues of fusion reactor structural components. This requirement of low residual radioactivity strongly limits the number of suitable materials, which can be used for structural components to a few families of alloys known as low activation materials. The chemical composition of conventional modified 9Cr–1Mo steel has been tailored by substituting the elements having long half-life transmutants like Mo, Nb, Ni, Cu, Co, Al, and N with comparatively lower activation counterparts such as W, Ta, Mn, V, and C to develop Low Activation Ferritic–Martensitic (LAFM) steels. The decay time of such steels for shallow burial is evaluated to be below 100 years [3]. At this stage of development, the LAFM steels are referred to as Reduced Activation Ferritic–Martensitic (RAFM) steel because of the technological limitation of controlling the undesirable elements to the required ppm levels.

The decision to introduce new steels in reactors requires a thorough knowledge of the material's behaviour and its microstructural stability under high temperature and stress. In this work, creep deformation and rupture behaviour of an indigenously produced RAFM steel has been studied. Attempt has been made to understand the creep deformation, fracture behaviour and microstructural stability of the material under creep conditions.

* Corresponding author. Tel.: +91 44 27480500x21085; fax: +91 44 27480075.
 E-mail address: laha@igcar.gov.in (K. Laha).

Table 1
Chemical composition (wt.%) of the RAFM steel.

wt.%	Element									
	Cr	C	Mn	V	W	Ta	N	O	P	S
	9.04	0.08	0.55	0.22	1.00	0.06	0.0226	0.0057	0.002	0.002
wt.%	Element									
	B	Ti	Nb	Mo	Ni	Cu	Al	Si	Co	As + Sn + Sb + Zr
	0.0005	<0.005	0.001	0.001	0.005	0.001	0.004	0.09	0.004	<0.03

2. Experimental

The RAFM steel was produced indigenously by M/s. Mishra Dhatu Nigam Limited (MIDHANI), Hyderabad, India by using virgin

charge of very high purity. Chemical composition (wt.%) of the steel is shown in Table 1. Vacuum induction melting followed by vacuum arc refining routes was adopted to ensure a tight control of the chemistry of the steel. The thermo-mechanical processing

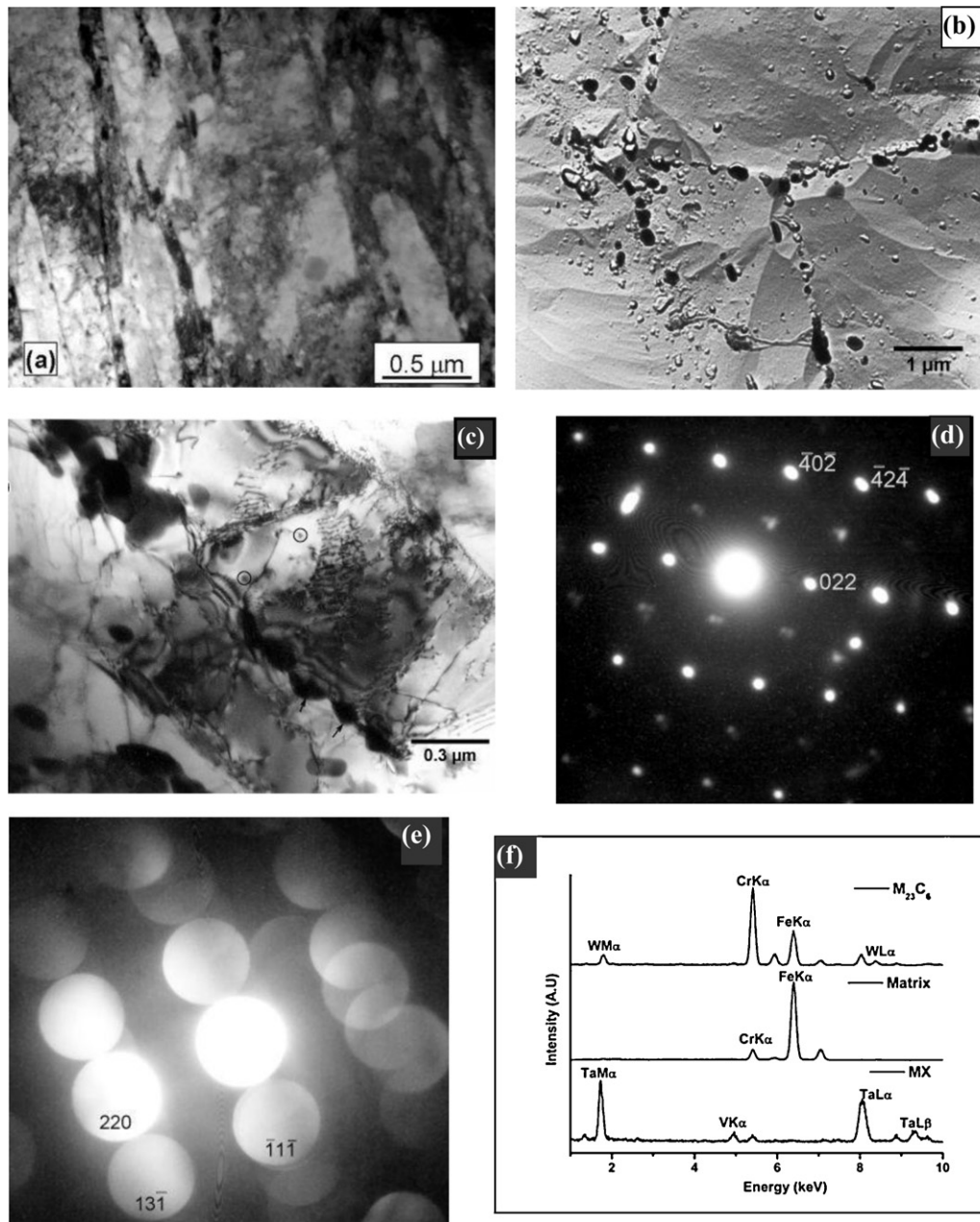


Fig. 1. TEM micrographs of the normalized and tempered steel showing (a–c) the lath structure with decoration of coarse carbides on PAG and lath boundaries; (d and e) SAD patterns from $M_{23}C_6$ (from an arrowed precipitate in (c)) and MX precipitates (from a circled precipitate in (c)) along $[1\bar{1}2]_2$ and $[1\bar{1}\bar{2}]_2$ zone axis respectively and (f) EDS spectra showing enrichment of Cr and W in $M_{23}C_6$ and Ta, V in MX precipitates.

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