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Creep behaviour of a cast TiAl-based alloy for industrial applications

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Abstract

The creep behaviour of a cast TiAl-based alloy with nominal chemical composition Ti–46Al–2W–0.5Si (at.%) was investigated. Constant load tensile creep tests were performed in the temperature range 973–1073 K and at applied stresses ranging from 200 to 390 MPa. The minimum creep rate is found to depend strongly on the applied stress and temperature. The power law stress exponent *n* is determined to be 7.3 and true activation energy for creep *Q* is calculated to be 405 kJ/mol. The initial microstructure of the alloy is unstable during creep exposure. The transformation of the $\alpha_2(Ti_3Al)$-phase to the γ(TiAl)-phase, needle-like B2 particles and fine Ti_5Si_3 precipitates and particle coarsening are observed. Ordinary dislocations in the γ-matrix dominate the deformation microstructures at creep strains lower than 1.5%. The dislocations are elongated in the screw orientation and form local cusps, which are frequently associated with the jogs on the screw segments of dislocations. Fine B2 and Ti_5Si_3 precipitates act as effective obstacles to dislocation motion. The kinetics of the creep deformation within the studied temperature range and applied stresses is proposed to be controlled by non-conservative motion of dislocations.

Keywords: A. Titanium aluminides, based on TiAl; B. Creep (properties and mechanisms); C. Casting (including segregation); D. Microstructure (as-cast, deformation-induced, recrystallization-induced); F. Electron microscopy, transmission

1. Introduction

Low density, high melting temperature, good elevated-temperature strength and modulus retention, high resistance to oxidation and excellent creep properties of TiAl-based alloys make them potential candidate structural materials for various applications in the gas turbine and automotive industry. In recent years, a particular interest was devoted to an alloy with a nominal chemical composition Ti–46Al–2W–0.5Si (at.%), which was designated as ABB-2[1] [1–3]. The alloy was developed by Nazmy and Staubli [4] for investment cast turbine blades and turbocharger wheels with improved creep properties. Depending on processing technologies and subsequent heat treatments, the ABB-2 alloy exhibits three different types of microstructures: duplex, near lamellar and fully lamellar microstructure [5–9]. The fully lamellar or nearly lamellar microstructure, consisting of the TiAl (γ-phase) and a small volume fraction of Ti_3Al (α_2-phase), exhibits better creep resistance (apart from primary creep), higher fracture toughness and crack propagation resistance than duplex microstructure [1,2,10,11]. On the other hand, higher tensile strength, ductility, and longer fatigue life are achieved for an alloy with duplex microstructure [11].

For rotating components like turbine blades, creep resistance of the blade material is of primary importance. Although the maximum overall creep strain allowable for turbine blades depends on the engine tolerance, this strain is usually less than 1% [1]. Therefore, the primary and adequate part of secondary creep stage is of the largest engineering interest. In spite of several studies published on the creep behaviour of the ABB-2 alloy [1–3,11,12], information about creep behaviour and deformation structure of large cast components like turbine blades are still lacking in the literature. As shown in our previous studies [3,5], the microstructure of large cast turbine blades from the ABB-2 alloy after post-solidification thermo-mechanical treatment combined with subsequent heat treatments is not homogenous and changes from fully or nearly lamellar in the vicinity of the blade surface to duplex one in the central part. Such microstructural variations affect

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[1] Designation ABB-2 is not trademark of the alloys but dates back to European project COST-501.

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Table 1
Chemical composition of the investment cast turbine blade (at.%)

Ti	Al	W	Si	C	Fe	Cu	O	N	H
Balance	46.88	1.96	0.53	0.024	0.041	0.004	0.193	0.032	0.040

significantly local creep properties of the cast components [3].

The aim of this paper is to investigate creep behaviour of TiAl-based alloy with nominal chemical composition Ti–46Al–2W–0.5Si (at.%) prepared by investment casting in the form of a large turbine blade. The deformation structure of crept specimens is characterised and the controlling mechanisms of creep deformation are discussed.

2. Experimental procedure

Creep experiments were conducted on the ABB-2 alloy with the chemical composition given in Table 1. The material was provided by Alstom Ltd. in the form of an investment cast turbine blade [5]. The as-received material was subjected to hot isostatic pressing at a pressure of 172 MPa and a temperature of 1533 K for 4 h, which was followed by solution annealing at 1623 K for 1 h and gas fan cooling. The heat treatment was completed by stabilisation annealing at 1273 K for 6 h and furnace cooling to room temperature.

Cylindrical creep specimens with a gauge length of 20 mm and gauge diameter of 4 mm were cut from the central part of the turbine blade airfoil part by electro spark machining. The longitudinal axis of the creep specimens was parallel to the longitudinal axis of the turbine blade. After lathe machining, the specimen surface was polished to a roughness of about 0.3 μm. Constant load tensile creep tests were performed at temperatures of 973, 1023, and 1073 K under initial stresses ranging from 200 to 390 MPa. The test temperature was monitored with two thermocouples touching the specimen gauge section and held constant within ± 1 K for each individual test. The specimen displacement was measured using a high-temperature extensometer attached to the ledges of the creep specimen. The extensometer was equipped with a linear variable displacement transformer (LVDT). The continuous acquisition of time-elongation data was accomplished by a computer and data processing was performed by a computer program.

The microstructure evaluation was performed by optical microscopy (OM), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and energy-dispersive X-ray (EDX) spectroscopy. OM and SEM samples were prepared using standard metallographic techniques and etched in a solution of 150 ml H_2O, 25 ml HNO_3 and 10 ml HF. TEM samples were mechanically thinned to a thickness of about 50 μm and thinning was completed by ion milling. The volume fractions and size of coexisting phases were determined by computerized image analysis.

3. Results and discussion

3.1. Microstructure before creep

Fig. 1 shows the typical microstructure of the samples before creep. The microstructure consists of lamellar (66 vol.%), feathery (26 vol.%) and γ-rich (8 vol.%) regions. The lamellar regions are composed of α_2 (ordered Ti_3Al-phase with $D0_{19}$ crystal structure) and γ (ordered TiAl-phase with $L1_0$ crystal structure) lamellae with a mean α_2–α_2 interlamellar spacing of 530 nm and mean γ-lamellae width of 120 nm. Numerous nanometer-scale B2 (ordered Ti-based solid solution) and Ti_5Si_3 precipitates were observed at the apparently smooth α_2/γ interfaces [13,14]. In addition, discontinuous α_2-lamellae contain fine needle-like particles with average width of 25 nm and length of 200 nm, which were identified as B2-phase [13,15]. As reported by Seo et al. [16,17], fine B2 precipitates formed at the α_2/γ interfaces before creep testing improve the creep resistance of the alloy by impeding interface dislocation mobility, reducing the generation of γ matrix dislocations from lamellae and preventing dislocations from passing through lamellar interfaces. In the case of the ABB-2 alloy, the strengthening effect of the B2 precipitates is enhanced by co-precipitation of fine Ti_5Si_3 particles along the lamellar interfaces with a similar effect on the dislocation mobility. Some lamellar regions contain large blocky type B2 particles (1 vol. %) with an average size of about 20 μm.

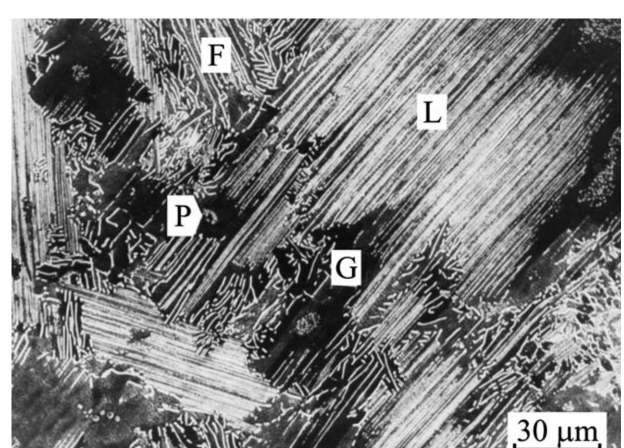

Fig. 1. SEM micrograph showing the typical initial microstructure of creep specimens: L, lamellar region; F, feathery region; G, γ-rich region; P, Ti_5Si_3 precipitates.