MICROSTRUCTURAL STABILITY OF Ti-46Al-8Ta DURING CREEP

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Resume
The effect of long-term creep exposure on the microstructure stability of a new cast air-hardenable intermetallic alloy with nominal chemical composition Ti-46Al-8Ta (at.%) was studied. Constant load creep tests were performed at the temperature 750°C and at applied stress 250 MPa up to 3479.3 h. The initial γ(TiAl) + α2(Ti3Al) microstructure of the alloy is unstable and transforms to α2 + γ + τ type. During creep the formation of cavities along the lamellar colony and grain boundaries is observed. The specimens fail by the growth and coalescence of such cavities with intergranular type of fracture.


1. Introduction
Intermetallic TiAl-based alloys are currently the subject of intensive research. Titanium aluminides represent an important class of alloys providing a unique set of physical and mechanical properties such as high melting point, low density of 3.9-4.2 g/cm³, high elastic modulus, low diffusion coefficient, good structural stability and good resistance against oxidation. Interesting mechanical properties predispose them to high-temperature structural applications in automotive and aerospace industries, such as blades for aircraft engines, high-pressure compressor blades, diffusors and turbocharger wheels [1,2].

The disadvantage of these alloys is their low ductility and fracture toughness at room temperature. These properties result from the structure of the alloy, which consist of γ(TiAl) and α2(Ti3Al) phases. The formation of coarse-grained microstructures during solidification, which deteriorate the properties of these alloys can be avoided by adding elements such as Nb and Ta, which have low diffusion coefficients in both α(Ti-based solid solution with hexagonal crystal structure) and γ phases [3]. These elements favour the diffusionless massive transformation to form massive γM from α-phase field over the lamellar formation at low cooling rates. Massive γM grains nucleate at the boundaries of the original grains and lead to a refinement of the structure and thereby to achieve the required mechanical properties, i.e. optimal combination of ductility at room temperature, fracture toughness, tensile strength and resistance to high cycle and low cycle fatigue [4,5]. Based on this concept, a new air-hardenable Ti-46al-8Ta (at.%) was designed. This alloy belongs to the latest 4th generation of TiAl-based alloys, which has been developed for turbine blade applications within the European integrated project IMPRESS [6].

According to ternary Ti-Al-Ta phase diagram thermodynamically modelled by Witusiewicz, two-phase α2+γ microstructure of the alloy was predicted to be stable below
1050 °C. However, Lapin et al. [7,8] observed precipitation of new τ phase with $B8_2$ crystal structure and chemical composition Ti-(36-40)Al-(12-15)Ta (at.%) during long-term ageing of Ti-46Al-8Ta (at.%) alloy at 750 °C. Based on this experimental findings was the ternary Ti-Al-Ta phase diagram re-evaluated as is shown in the Fig. 1. [8]. According to the thermodynamic calculations, the microstructure of the Ti-46-Al-8Ta (at.%) alloy is expected to transform to the equilibrium $\gamma+\tau$ type during long-term ageing below 870 °C. However, this calculated type of microstructure has not been proved experimentally yet. Hence, the study of microstructural stability of this alloy is of great practical interest.

Fig. 1. Ternary Ti-Al-Ta phase diagram [8]

The aim of the present work is to characterise microstructure of new air-hardenable intermetallic Ti-46Al-8Ta (at.%) alloy after creep at the temperature 750°C and at applied stress 250 MPa in air.

2. Experimental procedure

The studied Ti-46Al-8Ta (at. %) alloy was provided by ACCESS [12] in the form of centrifugally cast and heat treated cylindrical bars with a diameter of 13 mm and length of 120 mm. Heat treatments consisted of hot isostatic pressing (HIP) at an applied pressure of 200 MPa, temperature of 1260 °C for 4 h, which was followed by solution annealing at 1360 °C for 1 h and air cooling. The heat treatment was finalized by HIP ageing at an applied pressure of 150 MPa, temperature of 1260 °C for 2 h followed by cooling at a rate of 0.083 °Cs⁻¹.

Cylindrical creep specimens with a gauge diameter of 6 mm and gauge length of 30 mm were lathe machined from the as-received bars. The surface of the specimens was polished to a roughness of about 0.3 mm. Constant load tensile creep tests were performed at the temperature 750°C and at applied stress 250 MPa. The test temperature was monitored with two thermocouples touching the specimen gauge section and held constant within ±1 °C. 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), backscattered scanning electron microscopy (BSEM), and transmission electron microscopy (TEM). Samples were prepared using standard metallographic techniques and for OM etched in solution of 100 ml H₂O, 6 ml HNO₃ and 3 ml HF. TEM samples were mechanically thinned to a thickness of about 50 mm. The thinning continued in a solution of 300 ml CH₃OH, 175 ml 2-butanol and 30 ml HClO₄ at a temperature of -10 °C and voltage of 40 V using TenuPol-5 apparatus until the sample perforation. Volume fractions of coexisting
phases were determined from digitalized micrographs using a computer image analyser.

3. Results and discussion

3.1. Microstructure before creep

The typical fine grain microstructure of the as-received Ti-46Al-8Ta (at. %) alloy is shown in Fig. 2.

The convoluted type of $\alpha_2+\gamma$ microstructure of the as-received material consists mostly of plate-like $\alpha_2$ phase which forms small colonies within the $\gamma$ phase. This convoluted type of microstructure is formed by precipitation of the $\alpha$ and/or $\alpha_2$ phases on four equivalent $\{111\}$ planes of the massively transformed $\gamma_M$ during the second HIP-ing at 1260 °C and cooling from two phase $\alpha+\gamma$ field [4].

![Fig. 2. BSEM micrograph of the as-received Ti-46Al-8Ta (at.%) alloy](image)

There are two main differences in the microstructure of the aged samples (Fig. 4) when compared to that of the as-received one (Fig. 2): (i) precipitation of white colour phase particles predominantly at the grain and lamellar colony boundaries and (ii) the dark colour grain colony boundaries clearly visible on BSEM images. The white colour particles with slightly varied chemical composition of Ti-(36-40)Al-(12-15)Ta (at.%) were identified to be a ternary $t$ phase with $B8_2$ type crystal structure (space group $P6_3/mmc$, Pearson symbol $hp6$) and Ni$_2$In symmetry [8].

![Fig. 3. Microstructure before creep: (1) lamellar area $\alpha_2+\gamma$, single-phase $\alpha_2$ and $\gamma$ area](image)

![Fig. 4. Microstructure in gauge region after creep with marked phases, BSEM](image)
the studied alloy during creep. To estimate the impact of stress on the microstructural changes in the studied alloy, was also analyzed microstructure in head of specimen after creep.

![X-ray diffraction patterns of the as-received alloy and after creep](image)

**Fig. 5. X-ray diffraction patterns of the as-received alloy and after creep [7]**

Typical microstructure in head of specimen is shown in Fig. 6.

![Microstructure in head of specimen after creep with marked phases, BSEM](image)

**Fig. 6. Microstructure in head of specimen after creep with marked phases, BSEM**

Change in volume fraction of $\alpha_2$, $\gamma$, a $\tau$ before and after creep at 1023 K/250 MPa is shown in Table 1.

| Volume fraction of coexisting phases $\alpha_2$, $\gamma$, a $\tau$ |
|-----------------|-----------------|-----------------|
| As-received     | $29.8 \pm 2.3$  | $70.2 \pm 2.3$  | 0               |
| In head of specimen after creep | $23.5 \pm 1.3$  | $76.3 \pm 1.8$  | $0.2 \pm 0.1$   |
| In gauge region after creep     | $22.7 \pm 0.8$  | $76.8 \pm 1.1$  | $0.5 \pm 0.3$   |

The initial convoluted $\alpha_2 + \gamma$ microstructure of the as-received creep specimen is thermodynamically unstable and transforms to the $\alpha_2 + \gamma + \tau$ type during creep. Particles of $\tau$ phase are formed at the expense of the $\alpha_2$ lathes, which partially transforms to the $\gamma$ matrix and $\tau$ particles during creep. The stress applied during creep accelerates this transformation.

During the creep the formation of cavities along the lamellar colony and grain boundaries were observed, as shown in Fig. 7a. Deformation of the sample reached 21.1%. The specimen fail by the growth and coalescence of such cavities exhibiting intergranular type of fracture after 3479.3 h, as shown in Fig. 7b.

![Micrographs showing fracture features of 3479.3 h creep tested specimen at a temperature of 1023 K and applied stress of 250 MPa: (a) longitudinal section of the gauge section showing cavity formation along the grain boundaries fracture; (b) fracture surface illustrating intergranular type of fracture](image)

**Fig. 7. Micrographs showing fracture features of 3479.3 h creep tested specimen at a temperature of 1023 K and applied stress of 250 MPa: (a) longitudinal section of the gauge section showing cavity formation along the grain boundaries fracture; (b) fracture surface illustrating intergranular type of fracture**
4. Conclusions

The investigation of microstructural stability of Ti-46Al-8Ta (at. %) alloy during long-term creep exposure at temperature 750 °C and at applied stress 250 MPa suggests the following conclusions:

1. The initial microstructure of the as-received material consists mostly of plate-like $\alpha_2$ phase which forms small colonies within the $\gamma$ phase. The convoluted $\alpha_2 + \gamma$ microstructure of the creep specimens is unstable and transforms to the $\alpha_2 + \gamma + \tau$ type during creep. The stress applied during creep accelerates this transformation.

2. The particles of the new $\tau$ phase with B8$_2$ crystal structure are preferentially formed along grain and lamellar colony boundaries at the expense of the $\alpha_2$ lathes, which partially transform to the $\gamma$ matrix and $\tau$ particles during creep.

3. During the creep the formation of cavities along the lamellar colony and grain boundaries were observed. The specimen fail by the growth and coalescence of such cavities exhibiting intergranular type of fracture.

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