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High temperature internal friction in a Ti–46Al–1Mo–0.2Si intermetallic, comparison with creep behaviour

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ABSTRACT

Advanced γ-TiAl based intermetallics Mo-bearing have been developed to obtain the fine-grained microstructure required for superplastic deformation to be used during further processing. In the present work we have studied an alloy of Ti–46.8Al–1Mo–0.2Si (at%) with two different microstructures, as-cast material with a coarse grain size above 300 μm, and the hot extruded material exhibiting a grain size smaller than 20 μm. We have used a mechanical spectrometer especially developed for high temperature internal friction measurements to study the defect mobility processes taking place at high temperature. The internal friction spectra at different frequencies has been studied and analyzed up to 1360 K in order to characterize the relaxation processes appearing in this temperature range. A relaxation peak, with a maximum in between 900 K and 1080 K, depending on the oscillating frequency, has been attributed to Ti-atoms diffusion by the stress-induced reorientation of Al–V_{Ti}–Al elastic dipoles. The high temperature background in both microstructural states, as-cast and extruded, has been analyzed, measuring the apparent activation parameters, in particular the apparent energies of $E_{cast}(IF) = 4.4 \pm 0.05$ eV and $E_{ext}(IF) = 4.75 \pm 0.05$ eV respectively. These results have been compared to those obtained on the same materials by creep deformation. We may conclude that the activation parameters obtained by internal friction analysis, are consistent with the ones measured by creep. Furthermore, the analysis of the high temperature background allows establish the difference on creep resistance for both microstructural states.

1. Introduction

γ-TiAl-based alloys are one of the most important materials targeted for industrial applications in particular in aerospace and automotive engines. Among its amazing properties, a low specific weight (3.8–4.1 g/cm^3), good oxidation and burn resistance (up to 800 °C) together with a high elastic stiffness and enhanced high temperature strength are remarkable [1–5]. These exceptional properties made these alloys potentially attractive for applications under high thermal and mechanical load [6–8]. In addition those TiAl-based alloys submitted to an appropriate microstructural refinement may even exhibit super-plasticity [9–11], which from a technological point of view would notably improve the potential applications of the material. After the first generation of binary γ-TiAl alloys, a second generation of ternary alloys with several minor alloying elements and grain refiners was developed [12,13]. Then a third generation with a higher Nb content and B as grain refiner, called TNB, was designed to increase room-temperature ductility and high-temperature creep resistance [12,14]. Finally a fourth generation, called TNM, containing both Nb and Mo in order to stabilize the β phase, allowing a near conventional processing and creep-resistance for long-term service up to 1025 K [15], is being developed. Recent overviews on the development of γ-TiAl alloys can be found in Refs. [14,16].

The research on γ-TiAl has undergone a renewed interest since the announcement in 2010 of the introduction of cast blades, made of second generation γ-TiAl, in the low-pressure turbine of the General Electric engine [17], which at present is equipping the Dream Liner 787 from Boeing [18].

One of the key points to improve the new generation of γ-TiAl is

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to acquire a deep comprehension of the microscopic mechanisms controlling the high temperature creep deformation. In the last decade a new approach, by mechanical spectroscopy, is being used to study the mobility of defects at high temperature in structural intermetallics as FeAl [19–22] and TiAl [23–27]. A relationship between the internal friction high temperature background (HTB), measured by mechanical spectroscopy, and the high temperature creep behaviour in intermetallics has been proposed in several works [21,22,24,26] being still a matter of discussion.

In the present work we approach the study of the defects mobility on a prototype alloy with 1% Mo, which could be considered as belonging to the second alloy's generation, but with an added interest for the development of the fourth alloy's generation. This alloy has been also selected because in previous studies [28,29] its creep behaviour was studied and the activation enthalpies for two different microstructural conditions were determined through standard creep tests. In particular, the Ti–46Al–1Mo–0.2Si alloy in the as-cast and the hot extruded conditions show different creep properties but the activation energies for creep were very similar, 395 kJ/mol (4.1 eV) and 420 kJ/mol (4.35 eV) (1 eV = 96,2 kJ/mol) respectively [29]. These activation energies are similar to that for aluminium diffusion in TiAl. The creep behaviour, therefore, was related to a dislocation creep mechanism controlled by lattice diffusion of the slowest moving specie.

Independently of the particular deformation mechanism controlling creep, the internal friction high temperature background (HTB), measured by mechanical spectroscopy, may contribute to the determination of the atom mobility during deformation of a given material and, in turn, to determination of the temperature dependence of creep rate. This could be of technological interest, because creep tests are time consuming and usually require relatively large samples. In addition, mechanical spectroscopy is a non-destructive technique, use small samples and many experiments can be performed under different conditions in a reasonable time. So both techniques could be used collaboratively if their results could be reliably comparable.

2. Experimental details

2.1. Materials and microstructural characterization

Mo-alloyed two-phase γ/α TiAl material of composition (in at.%) Ti–46.8Al–1Mo–0.19Si was produced in 50 kg ingots by vacuum arc melting [28]. As-cast ingots were refined by hot extrusion in the $\alpha + \gamma$ field at 1300 °C. The reduction in area of the extruded rods was 7:1. The microstructure features, phases, grain size, morphology … were studied using a field emission SEM microscope (JEOL JSM-7000F) operating at 20 KV and 10 KV using backscattered electrons (BSE). Prior to observation, the samples were polished with diamond paste of grain size down to 1 µm, and subsequently with a colloidal silica suspension.

Fig. 1 shows SEM micrographs of the as-cast material. Its microstructure is composed by coarse lamellar grains bigger than 300 µm in size, Fig. 1a, formed by a quasi-eutectoid solid-state reaction. Inside the grains, coarse alternated γ-TiAl and α_2-Ti_3Al lamellae are observed, Fig. 1b, as well as some β phase at the grain boundaries and triple points, Fig. 1c. The identification of the phases is indicated in Fig. 1c and a complete description is included as Supplementary material. However, extruded material exhibits a finer and not completely homogeneous microstructure composed by different extrusion bands, Fig. 2a. On the one hand we observe bands of grains up to ~10 µm in size, Fig. 2b, but in general the extrusion bands are formed by α and γ grains < 5 µm in size, Fig. 2c. On the other hand, an appreciable amount of Mo-rich particles of β phase are scattered around the grains, Fig. 2c and d. The identification of the phases is indicated in Fig. 2d and a complete description is included as Supplementary material.

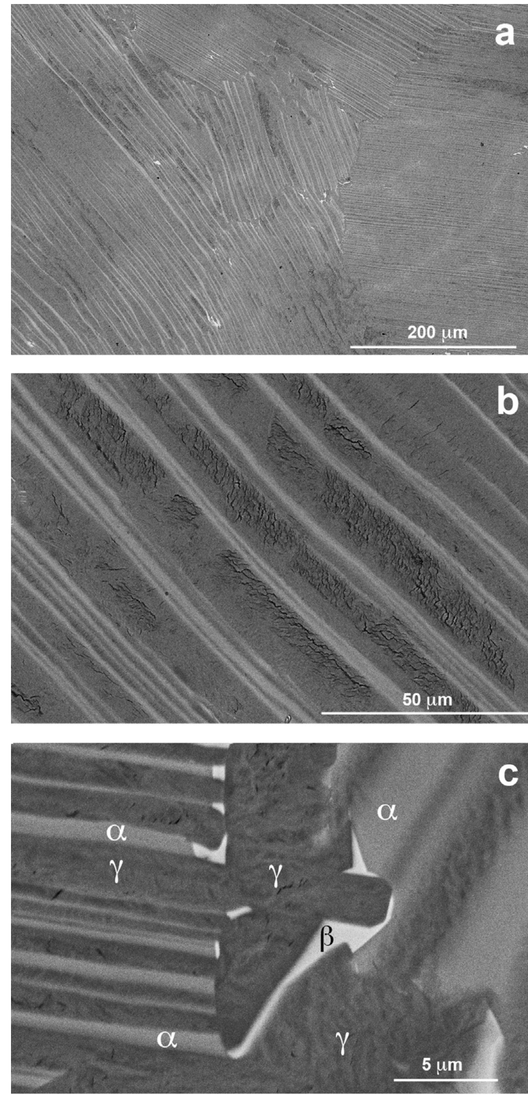

Fig. 1. (a) TEM-micrograph of the as-cast TiAl based alloy. (b) An alternation of γ-TiAl and α_2-Ti_3Al lamellae is observed inside the coarse lamellar grains. (c) Particles of β phase (white) are observed at grain boundaries and triple points.

2.2. Mechanical spectroscopy

The microscopic processes associated to the mobility of defects at high temperature have been investigated by mechanical spectroscopy. Samples were cut as parallelepipeds of approximate dimensions 50 × 5 × 1 mm^3, and lateral faces were polished with a diamond paste of grain size down to 1 µm. In this work the internal friction of both, the as-cast and extruded samples have been measured for various oscillating stress frequencies between 0.03 and 10 Hz in the temperature range from 600 to 1380 K.

Mechanical spectroscopy measurements have been carried out with an inverted torsion pendulum working in sub-resonant condition, measuring the internal friction Q^{-1} through the delayed phase angle ϕ between the applied oscillating stress and the resulting oscillating strain. The internal friction can be measured in two different working modes: (a) as a function of temperature (300 K–1800 K) at imposed frequency, and (b) as a function of