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The effect of single and multiple overloads on the fatigue crack growth of high strength titanium aluminides

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Abstract

Samples of fully lamellar titanium aluminides with randomly orientated colonies were exposed to single and multiple overloads. Damage was monitored by acoustic emission to determine its extent, its microstructural location, and to consider how damage may be introduced under single and multiple loading. The samples were then exposed to cyclic fatigue so as to evaluate any effects of these overloads upon subsequent fatigue life. After fatigue detailed microstructural and fractographic evaluation has been carried out.

Keywords: γ-TiAl; Fatigue; Overloading

1. Introduction

The good high temperature specific strength and stiffness characteristics, as well as oxidation resistance, of γ-titanium aluminides (γ-TiAl) have made them candidate materials for applications in gas turbine components where nickel based alloys are currently used. In order to further this aim alloy development, microstructural control, processing and mechanical understanding of these materials [1–4] are being improved. Prior to the implementation of these alloys into production gas turbines several areas require further development. These areas include the development of a method for the economical production of the relevant components and a greater understanding of the fatigue properties that may be expected in service. The properties of the lamellar microstructure are dominated by the interlamellar and translamellar modes of crack advance. The interlamellar fracture mode has low toughness and will always occur. Deflection of the growing crack by the interlamellar mode therefore depends upon colony orientation with respect to the mode I crack propagation direction. In general, large interlamellar areas will contribute to easy mode I crack extension, promote premature failure, and hence must be avoided. Under three-dimensional stress fields this effect can be minimised only by producing microstructures with a small colony size so that a significant number of colonies of a similar orientation would be required to produce an area of interlamellar failure large enough to damage component integrity significantly. As part of production route criteria the manufacture of components via the wrought route of hot extrusion of a billet, from which the components may be machined, is under consideration [4]. This aims to provide the required microstructural refinement and mechanical properties, whilst overcoming the economical barrier to implementation expected due to the high cost of the wrought method [4,5].

Fatigue requires improved understanding in order to enable the prediction of complex component lifetimes prior to component testing [4]. Towards this end the balance between static and dynamic failure modes under fatigue loading requires investigation to address potential responses to single monotonic and repeated fatigue overloads superimposed on subsequent uniform fatigue loading of single amplitude.

2. Experimental procedure

Samples of the alloy Ti–46Al–5Nb–1W (at.%) were used in this study. This material was produced as a vacuum arc melted ingot and subsequently canned, hot extruded and heat-treated by Plansee to give a series of bars with an extrusion ratio of 14:1, a diameter of ≈43 mm and a fully lamellar (FL) microstructure with a colony size ≈75 μm (see Fig. 1). The detailed composition of these bars is given in Table 1 [5]. Fatigue samples measuring 10 mm × 10 mm × 80 mm were taken from these bars using wire electro-discharge machining (EDM) and were tested in four-point bending (see

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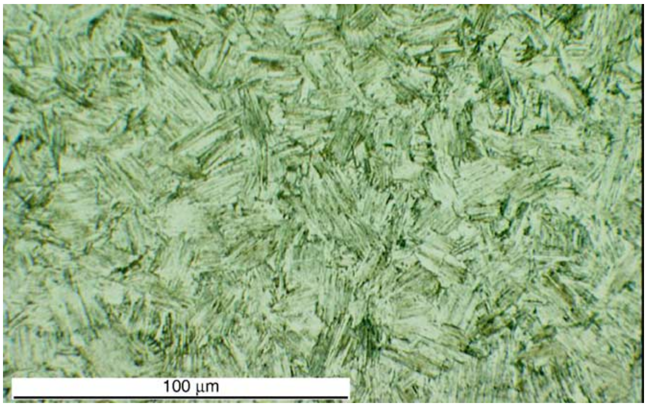

Fig. 1. Fully lamellar (FL) microstructure, with average colony size ≈75 μm.

Table 1
Nominal compositions of Alloy 7 bars from which the fatigue samples were machined

	Nominal composition					
	Al (at.%)	Nb (at.%)	W (at.%)	O (ppm)	N (ppm)	C (ppm)
Ti–46Al–5Nb–1W	46.6	5.0	0.9	1290	251	126

Fig. 2). Sample tensile faces were ground and polished to 0.05 μm, removing approximately 200 μm from each tensile surface.

Samples were "overloaded" on a DMG servo-hydraulic testing machine equipped with a 100 kN load cell, operating at 0.25 Hz, a load range of ±20 kN and a position range of ±100 mm. These overloads were in the form of 1000 cycles at a maximum stress of 600 or 650 MPa or a single monotonic overload to a stress of 780–830 MPa at a ramp rate of 0.3 kN/min (a nominal stress rate of 9 MPa/min). Fatigue overloading was carried out using a trapezoidal waveform at 0.25 Hz, with 50% dwell time and an R ratio of 0.1 (where R is the ratio of minimum stress to maximum stress applied over the load cycle). These stress levels were selected with respect to 0.2% proof stress ($\sigma_{0.2\%}$) measurements taken from six samples from the same production batch (mean = 822 MPa, max = 830 MPa) [5]. The maximum stress levels of 650 ($\Delta\sigma = 585$ MPa) and 600 MPa ($\Delta\sigma = 540$ MPa) are therefore equivalent to ≈80 and 75% of $\sigma_{0.2\%}$ with 830 and 780 MPa being ≈100 and 95% of $\sigma_{0.2\%}$, respectively.

Damage caused by the overload exposures was continuously monitored using two physical acoustics corporation "Nano–30" acoustic emission (AE) sensors glued to the specimen ends recording acoustic emission events using a Mistras PC system. AE events were later categorised according to whether they occurred during a load rise, fall or during the dwell period of the trapezoidal waveform. Variables recorded include the number of cycles completed at the time of the event, amplitude of the AE waveform, position on the sample of the event and the load on the sample at the time of the event.

Following overloading many samples were investigated for cracks at surface breaking positions by heat tinting at 700 °C for 30 min prior to testing at a maximum stress of 550 MPa and $R = 0.1$. For an R ratio (where R is the ratio of minimum stress to maximum stress applied over the load cycle) of 0.1, in previous work a peak stress of 550 MPa ($\Delta\sigma = 495$ MPa) gave no specimen failure after 10^7 cycles (i.e. sample "run-out") and was therefore determined to be a materials "fatigue limit" [5]. Subsequent to overloading, samples were therefore fatigued at this level using Amsler Vibrophore electromagnetic resonance testing machines at frequencies within the range of 60–95 Hz. Any samples which fail during these cycles can therefore be deduced as having been damaged during overloading. Examination of sample microstructures and fracture surfaces was completed on JEOL 5410 and Phillips XL 30 scanning electron microscopes, in order to confirm colony size, failure initiation sites and fracture mechanisms.

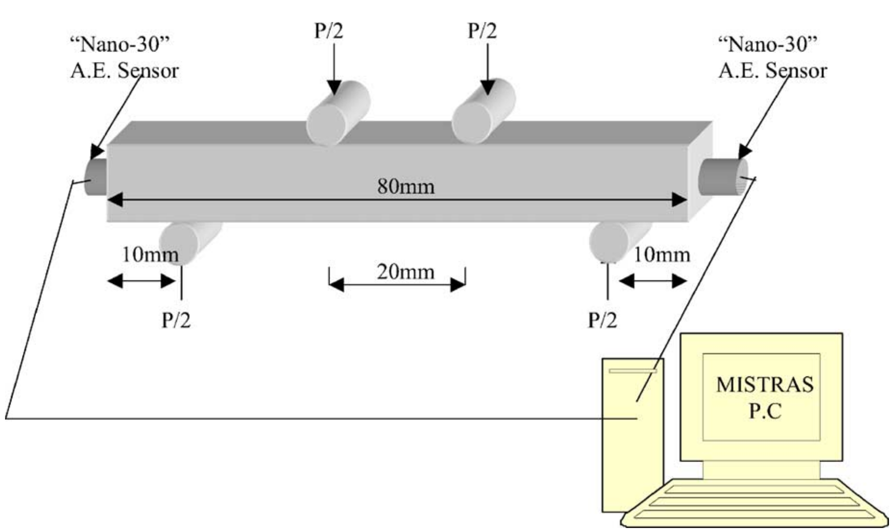

Fig. 2. Testpiece dimensions and loading geometry.