THE ROLE OF TWINNING IN THE FATIGUE BEHAVIOUR OF α-TITANIUM

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Coarse grained (~9-3 mm) α-titanium has been fatigued in tension-compression about a zero mean load to ~100 cycles/sec at normal temperature. Sections through fatigued specimens revealed that twin formation had occurred in grains completely constrained by surrounding material during cyclic loading and that fatigue damage was associated with some of these twins. A micro-beam X-ray and single face stereographic analysis technique combined with metallographic observations of the specimens revealed that {1012}, {1121} and {1122} twins had formed and that the internal fatigue damage was preferentially formed at the twin-matrix interface of the {1121} twins.

INTRODUCTION

Twin formation during fatigue of close packed hexagonal metals has been widely reported and it has been shown that twin-matrix interfaces can act as preferential sites for fatigue damage [1 – 5]. Previous investigations have mainly been concerned with surface observations but the present work has shown that fatigue damage associated with twins can also occur in internal regions which are totally constrained by surrounding material. Metallographic observations and X-ray determinations of twin and slip deformation modes, together with the stress dependence of the formation of fatigue damage, have been obtained from the same specimens.

Fatigue specimens of circular cross-section (~3-5 mm diameter) and having parallel sided gauge lengths (~31.7 mm) were machined from ~12.7 mm diameter bar of commercial purity α-titanium designated I.M.I. Titanium 115¹. The machined specimens were ground on a Morrison wheel and subsequently electropolished to remove surface deformation. Test specimens were vacuum annealed at 800°C for 24 hours to obtain a coarse grain size before fatigue testing at room temperature in a 10,000 kg capacity Amsler Vibrophore using a 2,000 kg load cell. Loads were applied in tension-compression about a zero mean load at a frequency of 100 cycles/sec to produce a fatigue stress range of ~8 to ~17 kg mm⁻². An apparent fatigue limit of ~9 kg mm⁻² was obtained. Specimens which had failed, or which at 10⁷ cycles were unbroken, were sectioned in planes parallel to the fatigue axis and mechanically polished to 0.25 micro diamond finish. To facilitate metallographic examination the mechanically prepared surfaces were chemically etched in a solution containing 2 ccs HNO₃, 2 ccs HF, 96 ccs H₂O. In some tests where particular emphasis was to be placed on surface examination, the original circular cross-section of the specimens


¹) The oxygen content as determined by vacuum fusion analysis was 0.085 wt.%.
was modified by preparing a flat face prior to testing as outlined above. This preparation was carried out using chemical polishing and electropolishing such that polarised light microscopy did not reveal the presence of twins.

**OBSERVATIONS ON INTERNAL SECTIONS OF FATIGUED SPECIMENS**

Comparative metallographic observations were made on the deformed gauge lengths and undeformed heads of internal sections of the fatigued specimens. Twin formation was observed to have occurred as a consequence of cyclic loading over the whole stress range examined. To establish the twinning modes, a micro-beam Laue technique developed by Otte and Cahn [6] was employed. X-ray beams of diameter 25 or 50 microns permitted Laue images to be obtained from twin-free areas of individual grains. Single face stereographic analysis of the twin traces from 24 different grains revealed that twins of the \{10\bar{1}2\}, \{11\bar{2}1\} and \{11\bar{2}2\} types had formed during fatigue deformation. The \{10\bar{1}2\} and \{11\bar{2}1\} type twins were observed more frequently than the \{11\bar{2}2\} type twins.

A predominant feature of the fatigued gauge sections was the association of permanent fatigue damage, in the form of voids or cracks, with the twins. This was observed to occur in both surface and internal grains as shown in Fig.1 (App. VII, p. 418v). The occurrence of surface nucleated cracks was evident over the whole stress range examined, but the incidence of internal damage was more prevalent at the higher stress levels. Permanent fatigue damage was observed to be almost exclusively associated with \{11\bar{2}1\} type twins. This observation contrasts with that of Partridge [4], who reported permanent fatigue damage associated with \{10\bar{1}2\} type twins in \alpha\text{-titanium. The damage associated with \{11\bar{2}1\} type twins in internal grains appeared as discrete holes along the twins (Fig. 2, App. VII, p. 419v). In some cases damage of this form (Fig. 2) appears at twin-twin intersections but there is not a one-to-one correlation and in most instances the damage is present in the absence of an intersecting twin. The role of internal twin damage in the fatigue process appears to be one of offering relatively low energy propagation paths for surface nucleated cracks.

**SURFACE OBSERVATIONS ON FATIGUE SPECIMENS**

Both twin and slip band formation were observed on the specimen surfaces, the intensity of the deformation modes increasing with applied stress level. The microbeam X-ray and stereographic analysis techniques revealed that the operative glide planes were of the \{10\bar{1}0\} type. Taking the slip directions to be of the \langle11\bar{2}0\rangle type, slip band formation was predominant on those glide planes with the maximum resolved shear stress. Twins of both \{10\bar{1}2\} and \{11\bar{2}1\} types were formed during cyclic loading and fatigue damage was again almost exclusively associated with \{11\bar{2}1\} type twins. There was no indication of permanent fatigue damage at slip bands formed during these tests.

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