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Fractographic Analyses of Creep and Fatigue Induced Failures in an Alpha Titanium-Aluminum Alloy

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The mechanical performance of engineering titanium alloys has long been known to be sensitive to the to nature of applied load waveform. Sustained load hold periods imposed during the fatigue loading of two-phase alloys has been shown to be detrimental to material performance [1,2]. A number of factors, including material texture, slip behavior, and load history, are thought to affect the dwell fatigue responses of these materials. This study utilizes a combination of tilt fractography and orientation microscopy to examine the roles of slip character and applied load waveform on the mechanical and fracture responses of a single-phase α-Ti alloy.

Experiments were performed on an equiaxed-grained α-Ti-7 wt% Al alloy with average line intercept grain size of ~75 μm and a weak texture where most grains were orientated with their $\vec{c}$-axes more than 45^o to the test direction. Slip character was controlled by the manipulation of the degree of short-range ordering (SRO) of Ti and Al atoms. SRO was modified by thermal treatments; while ice water quenching (IWQ) minimized the presence of SRO, air-cooling (AC) produced strong SRO. Load controlled tensile creep, cyclic fatigue (triangular waveform, loading rate = 900 MPa/s), and dwell fatigue (trapezoidal waveform, loading rate = 900 MPa/s, dwell period = 120 s) tests were performed on round, sub-sized test bars.

As presented in Table I, it is found that SRO and waveform have significant influence over the cyclic fatigue, dwell fatigue, and creep responses and fracture behaviors of Ti-7Al alloy. These observations represent the first published observations of a dwell effect in a single-phase Ti alloy. Under dwell and creep loading, the homogenous slip observed in the IWQ material allows for damage to be distributed throughout the entire gage volume leading to greater elongation and cycles to failure, N_f. Additionally, the introduction of a dwell period to the fatigue waveform increases strain at failure, ε_f, and elongation at minimum strain rate while decreasing fatigue life. Fractographic images are shown Fig. 1. It was found that the cyclic loading induced surface initiated faceting at multiple locations in both the AC and IWQ materials; tilt studies indicate that these facets are inclined ~45^o to the stress axis. Dwell or creep loading induced internal crack initiation. Specimens failed under creep conditions show similar features to those failed under dwell fatigue loading for a given SRO state. In the AC material, faceted initiation sites were observed; Inclinations of facets to the tensile axis ranged from 10 to 45^o. Subtle fatigue crack growth markings on facet surfaces are the only features that differentiate dwell facets from creep facets demonstrating that dwell faceting is a progressive process. The fracture surfaces of the IWQ material failed under creep and dwell conditions showed no evidence of faceting; surfaces show extensive grain pullout and long cracks propagating along grain boundaries. Shallow dimples and ductile tears were found to cover surface features. These observations clearly demonstrate that stress concentrations resulting from highly planar slip are a primary factor determining facet formation. Orientation microscopy studies indicate that faceting under all conditions occurs on planes near the (0001) plane.

Table I. Tensile Creep and Fatigue Lives of Ti- 7 wt% Al

Waveform	**σ_{Max} / σ_{Peak} (MPa)**	**SRO**	N_f	$\varepsilon_{pl}\big\|_{\varepsilon_{min}}$	ε_f
Cyclic	709 / 50	AC	6050	1.3	3.2
		IWQ	9480	0.6	1.3
Dwell	709 / 50	AC	81	2.9	5.8
		IWQ	1155	11.1	14.0
Creep	709 / NA	AC	150*	1.2	1.7

* Equivalent dwell cycles

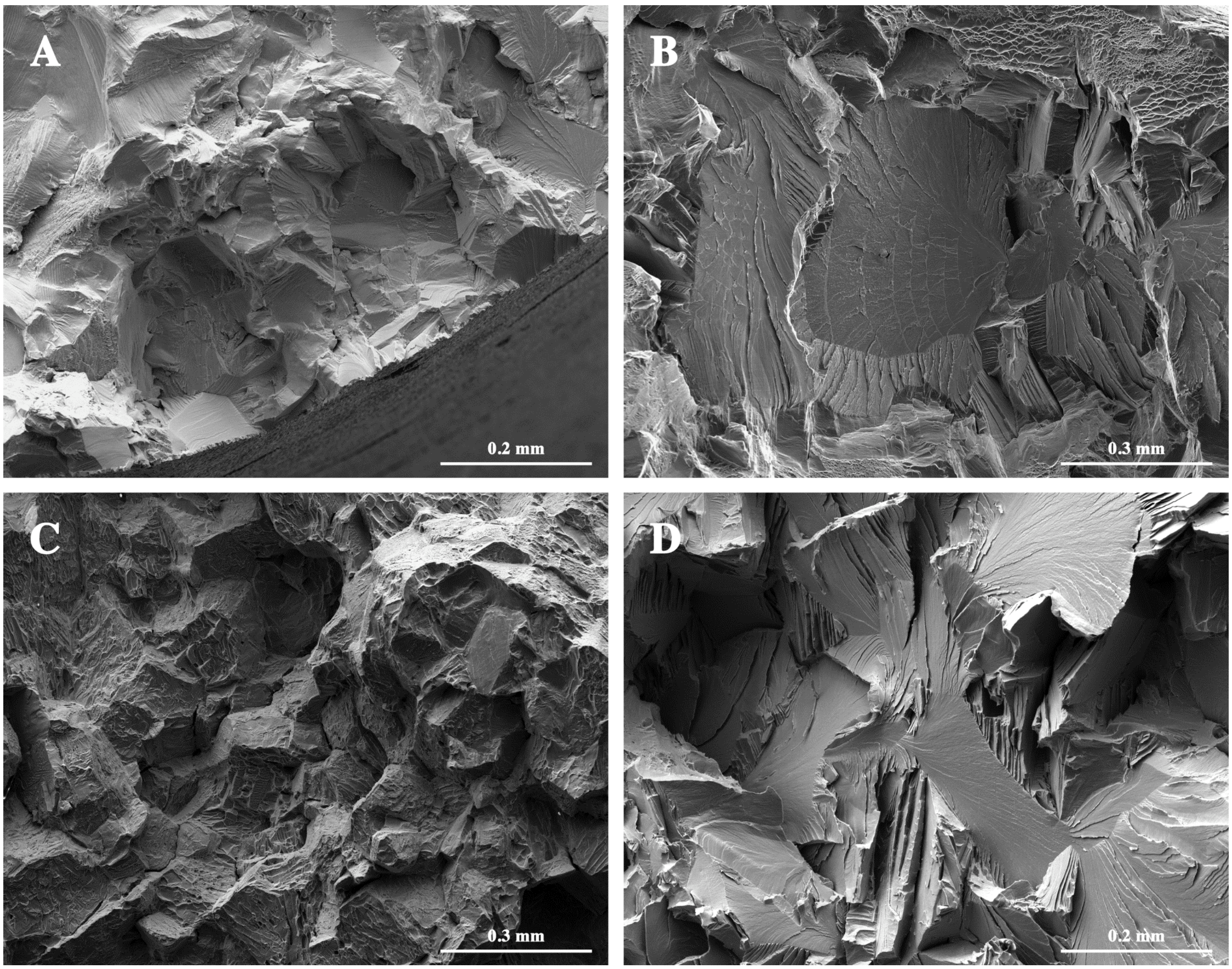

Fig. 1. Typical features observed on fracture surfaces: cyclic loading, AC and IWQ (A), dwell loading, AC (B), dwell and creep loading, IWQ (C), and creep loading, AC (D).

References

[1] M.R. Bache, Int. J. Fatigue, 25[9-11] (2003) 1079.
[2] J.C. Williams et al, US FAA, Annual Report, Contract #DTFA03-01-C-00019 (2008)

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