GRAIN BOUNDARY SLIDING AND INTRAGRANULAR SLIP MEASUREMENT *IN-SITU* DURING CREEP

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Abstract

Creep in future long-term space technology materials is a critical concern due to the duration of potential missions to Mars and beyond. Structural and skin components in long-term mission spacecraft will undergo creep deformation and eventual failure if not designed to be sufficiently creep resistant. The microstructural deformation mechanisms that control the creep behavior must be understood to intelligently inform the design of new creep resistant alloys and enhance those already in service. Using lightweight single phase β Ti alloys, an analysis tool was developed to measure grain boundary sliding (GBS) and intragranular slip in-situ via a Heaviside function-based algorithm. The data needed for the analysis tool includes an electron backscattered diffraction generated microstructural map and high-resolution digital image correlation (HRDIC) strain fields. This testing technique advances the state of the art by facilitating *in-situ* measurement of these microstructural deformation mechanisms without the need to interrupt creep testing and introduce unwanted thermic cyclic effects. Proof-of-concept experiments utilizing this analysis tool on a single phase β Ti alloy in room temperature creep rapidly identified the dominant deformation mechanism to be intragranular slip and glide creep without the need for destructive and expensive post-mortem testing.

1. Introduction

Single phase β Ti has been used in aerospace with its lightweight and high strength mechanical properties, and it is preferred in creep to α Ti as β Ti is less prone to dislocation motion. The further improvement of creep resistance in single phase β Ti is possible through microstructure deformation analysis of GBS and intragranular slip. Through improved understanding of creep and rupture resistance as it relates to microstructural texture, components can be processed to optimize resistance to creep deformation and failure. The analysis tool is used to quantify GBS through measuring grain rotation and displacement across grain boundaries, and this quantification is used to find the critical GBS that causes void initiation, particularly at triple junctions. The intragranular slip is investigated by comparing slip traces to slip systems predicted by Schmid factor and displacement across slip traces which finds optimal crystal orientation to resist slip and critical dislocation pileup at high-angle grain boundaries to cause crack initiation by stress concentration. The combination of the analysis of these microstructure deformation mechanisms reveals the dominant deformation mechanism and sources of creep rupture. This research executed proof-of-concept experimentation on single phase β Ti in room temperature creep to develop the analysis tool and test room temperature creep properties of single phase β Ti.

2. Results

Two room temperature creep tests with the analysis tool enabled were performed using $Ti_{80}(AlCrNb)_{20}$ (Ti80) at ~85% yield stress with two different solutionizing treatments (ST). The two ST utilized were 1100°C for 12 hr and 1100°C for 0.25 hr with ST done via quartz encapsulation in an argon atmosphere as Ti readily oxidizes at high temperatures. The final HRDIC images for these room temperature creep tests are shown in Fig. 1. These ST yielded drastically different ductility, 4.6% and 28.2% respectively, which was expected to also yield drastically different results when analyzing the microstructure deformation in creep. The creep tests found that Ti80 followed the standard primary, secondary, and tertiary creep regimes with a high steady-state creep rate and an extremely high creep exponent of 124 for the 0.25 hr ST Ti80 samples. Utilizing the analysis tool, the 0.25 hr ST Ti80 sample was found to have significantly more intragranular slip activity with a larger displacement magnitude as well. It was also observed slip was able to pass through the obstacle of low-angle grain boundaries. Both of these observations correspond well with the increased tensile ductility of Ti80 samples with the 0.25 hr ST. Minimal GBS was observed in Ti80 samples with either ST which is hypothesized to be due to the combination of large grain size and lack of thermal activation. The average grain sizes were measured to be 261.21 µm and 406.14 µm for the 0.25 hr ST and 12 hr ST, respectively, which is sufficiently large to resist GBS rotation. The dominant deformation mechanism was determined to be glide creep without thermal activation. The significant amount of slip observed aligns with this as the slip traces align slip systems predicted by Schmid factor. The slip traces terminated against high-angle grain boundaries, transmitted through low-angle grain boundaries, and a lack of thermal activation prevented dislocation climb to bypass obstacles. The addition of thermal energy would have a significant impact on creep with potential for dominant mechanism change, increased ease of dislocation motion, and penetrating oxidation.

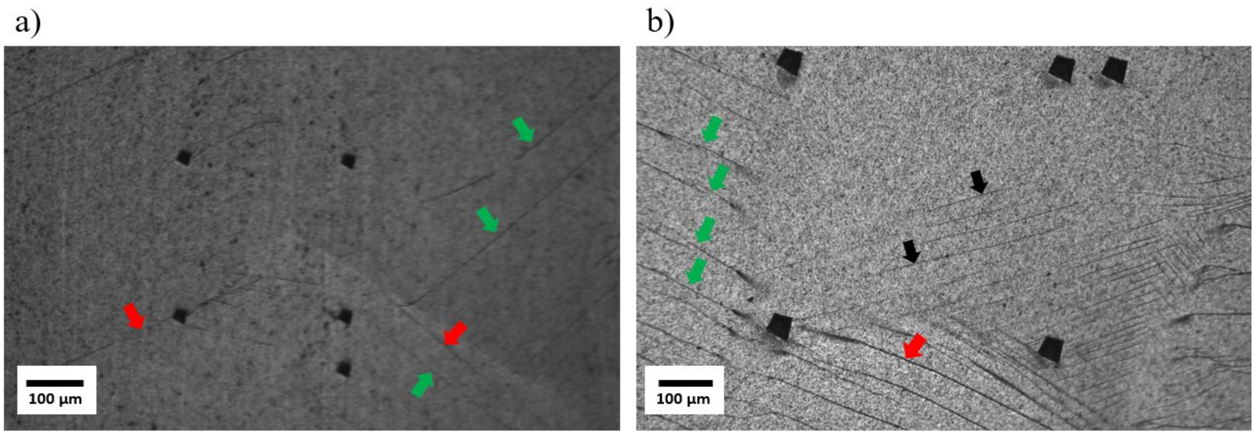

Fig.1 – Final HRDIC images of the analysis tool enabled creep tests. Red arrows indicate GBS sites, green arrows indicate slip traces, and black arrows indicate slip traces that cross low-angle grain boundaries. a) HRDIC image of 1100°C for 12 hr ST b) HRDIC image of 1100°C for 0.25 hr ST.

3. Conclusions

The analysis tool enabled creep tests resulted in determination of the dominant deformation mechanism of Ti80 in room temperature creep. This proof-of-concept experimentation found that GBS and instragranular slip can be measured *in-situ* without the need to interrupt testing and found a methodology for future testing on more viable alloys at elevated temperatures.

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