15th International Conference on Fracture (ICF15)
June 11-16, 2023 Atlanta, GA USA

FATIGUE AND DWELL-FATIGUE BEHAVIOR OF A FORGED TI-6AL-4V ALLOY INVESTIGATED BY HIGH-RESOLUTION DIGITAL IMAGE CORRELATION

Fabien Briffod[1]*, Haoyu Hu[1], Takayuki Shiraiwa[1] and Manabu Enoki[1]

[1] Department of Materials Engineering, the University of Tokyo, Tokyo, Japan
** Presenting Author email: briffod@rme.mm.t.u-tokyo.ac.jp*

Abstract
The present work is dedicated to a comparative analysis of strain accumulation and damage initiation in a forged Ti-6Al-4V alloy subjected to either fatigue or dwell-fatigue condition. To this end, high-resolution digital image correlation analyses were carried out on fatigue specimens interrupted at different number of cycles to clarify the grain-scale strain activity and correlate it with local micro-mechanical features and crack initiation sites.

1. Introduction
Ti-6Al-4V alloy is among the most widely applied titanium alloy due to its high specific strength, corrosion and fatigue resistance. The fatigue response of Ti-6Al-4V alloy is complex and depends on various micro-mechanical parameters such as the stress ratio, the crystallographic texture or the presence of macrozones[1-2]. In particular, the presence of a holding period at high peak stress, known as dwell, was found to significantly reduce the fatigue life. Although extensive research has already been carried out on this topic, the underlying mechanisms responsible for the lower fatigue life are still subject to discussion. Indeed, the existence of a “rogue grain” combination of neighoring soft and hard grains is often argued to be the crack initiation mechanism under dwell-fatigue following the Stroh model[3]. However, recent reports showed different potential mechanisms such as intergranular cracking due to the presence of twist boundaries[4]. Consequently, the present work is dedicated to a comparative analysis of local strain activity and crack initiation mechanism of a forged Ti-6Al-4V alloy under fatigue and dwell-fatigue condition.

2. Materials and Method
The material investigated was a forged titanium alloy, Ti-6Al-4V (in wt%) having a bimodal microstructure. Dog-bone shape specimens were cut from the forged materials, polished and etched by Kroll’s reagent. Nano-scale speckle patterns were then produced on the specimens surface by vapor-assisted remodeling of a gold nanolayer film as depicted in Fig.1(a). The specimens were either subjected to uniaxial fatigue with a stress ratio of 0.1 or dwell-fatigue with the same ratio and a dwell period of 120 s. The tests were interrupted at different cyclic numbers and a series of high-magnification scanning electron microscop (SEM) images were taken covering an area of about 600x450 µm². Digital Image Correlation (DIC) analysis were performed using the open-source toolbox Ncorr[5]. Slip trace analyses were performed for each identified slip lines from DIC using the crystal orientation of each individual grain obtained by electron backscattered diffraction (EBSD) measurement. The local slip activity and crack initiation sites were comparatively analyzed for the two loading conditions on the basis of various parameters: the Schmid factor of the activated slip systems, the geometrical compatibility factor, the mean equivalent plastic strain...

3. Results
The apparent decrease in fatigue life and increase in strain accumulation when applying a dwell period is reported in Fig. 1(b-c). The obtained gold speckle pattern depicted in Fig. 1(a) together with an example of the subset radius of 20 pixels used for the DIC analysis allowed the observation of discrete slip bands within grains with varying intensity as shown in Fig. 1(d). Slip trace analysis after the first few applied cycles revealed a majority of slip lines originating from basal and prismatic slip with a predominance of the former one suggesting that it is the softest deformation mechanism. When comparing the plastic activity between fatigue and dwell-fatigue, a higher number of slip lines and faster strain accumulation was observed under dwell-fatigue. The mean equivalent strains along all the slip bands within the investigated region were extracted for the different interruption cycles and reported in Fig. 1(e) for the fatigue experiment. While the majority of the slip bands exhibited a limited strain accumulation ranging from 0% to about 12% strain, on slip band exhibiting clear damage such as the example reported in Fig. 1(f) showed a much higher and

faster strain accumulation. These sites were often associated with the presence of macrozones or significant slip transfer across grain boundaries.

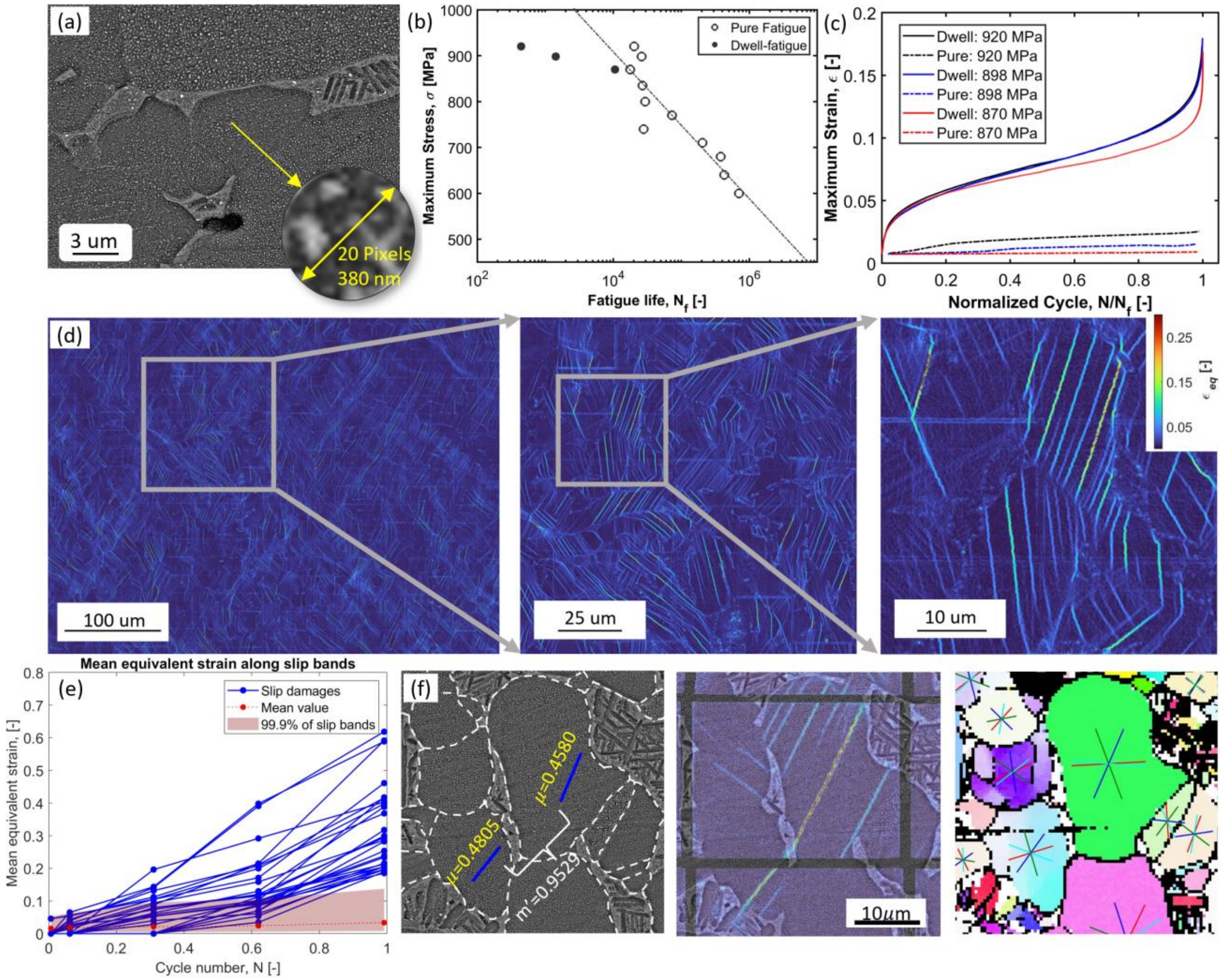

Fig. 1. (a) Gold speckle pattern observed in SEM. (b) S-N curve under fatigue and dwell-fatigue. (c) Difference in strain accumulation against the normalized number of cycles between fatigue and dwell-fatigue. (d) Example of equivalent plastic strain field estimated by DIC. (e) Strain accumulation for the slip lines in the analyzed region against the number of cycles. (f) Example of transgranular crack initiation analysis under fatigue condition.

Acknowledgements
This work was supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), "Materials Integration" for Revolutionary Design System of Structural Materials (Funding agency: JST) and by the JSPS KAKENHI for Early-Career Scientists (Grant No. 22K14139).

References
[1] F. Briffod, A. Bleuset, T. Shiraiwa and M. Enoki, Acta Materialia 177 (2019) 56-67.
[2] F. Briffod, T. Shiraiwa, M. Enoki and S. Emura, Materialia 22 (2022) 101401.
[3] M.R. Bache, Int. J. Fatigue 25 (2003) 1079-1087.
[4] C. Lavogiez, S. Hémery, P. Villechaise, Scripta Materialia 183 (2020) 117-121.
[5] J. Blaber, B. Adair and A. Antoniou, Exp. Mech. 55 (2015) 1105-1122.