Proceedings of WTC2005
World Tribology Congress III
September 12-16, 2005, Washington, D.C., USA

WTC2005-63536

EFFECT OF CRYSTALLOGRAPHIC TEXTURE ON DEFORMATION FIELDS IN FRETTING CONTACTS

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ABSTRACT

Fretting contacts in the partial slip regime are simulated by a finite element model of a rigid cylinder on an elastic-crystal viscoplastic half-space. The half-space is modeled as duplex Ti-6Al-4V, a polycrystalline metal alloy consisting of equiaxed primary alpha grains and secondary lamellar alpha+beta grains. Various realistic 3-D crystallographic textures are considered. The deformation fields generated by fretting are quantified in terms of cumulative effective plastic strain distributions and plastic strain maps. The results clearly demonstrate the importance of the various sources of microstructural heterogeneity in the surface layers. The main sources of microstructural heterogeneity include the distribution of phases, slip system strength anisotropy, and crystallographic texture. In basal textured materials with fretting on the edge, the plastic strain is more evenly distributed in the subsurface regions than in other textured cases. This is explained by the greater number of grains able to deform by soft slip modes and the symmetry of this type of texture relative to the fretting orientation. Transverse and basal/transverse textures result in more heterogeneously-distributed plastic strain with strain often concentrated in narrow vein-like structures with maximum accumulation near alpha/alpha+beta grain boundaries. Elastic shakedown is more difficult to achieve in the later case. Ratcheting is the primary mechanism for cyclic plastic strain accumulation.

INTRODUCTION

In the partial slip regime of fretting fatigue, the center of the contact area experiences no relative motion between the two mating surfaces. However, at the edges of contact there is a small amount of relative tangential displacement. Under these conditions there are two main contributions to the accumulation of cyclic plastic strain: a contribution due to the small amount of relative sliding between the mating surfaces at the edge of contact, and a component due to the cyclic tangential load in the presence of the constant normal contact pressure. In the case where the applied normal load is on the order of the load required to initiate yield in the subsurface region, the volume of material undergoing plastic deformation is on the order of microstructural dimensions. Therefore the local variation in material properties at the microstructural level due to the grain orientation, phase distribution, etc. becomes extremely important in capturing the heterogeneous nature of the deformation fields in the subsurface region, and must be accounted for when developing life prediction models under these loading conditions.

The main goal of this work is to investigate the cyclic plastic strain behavior of Ti-6Al-4V, a typical gas-turbine blade material, during fretting fatigue in the partial slip regime using a crystal viscoplasticity model which is capable of capturing the local variation in material properties at the constituent level of grains. It is expected due to the combination of the low symmetry of the hcp structure of the primary alpha-phase and the slip system strength anisotropy, that the crystallographic texture with respect to the fretting orientation will significantly influence the characteristics of the subsurface plastic deformation fields.

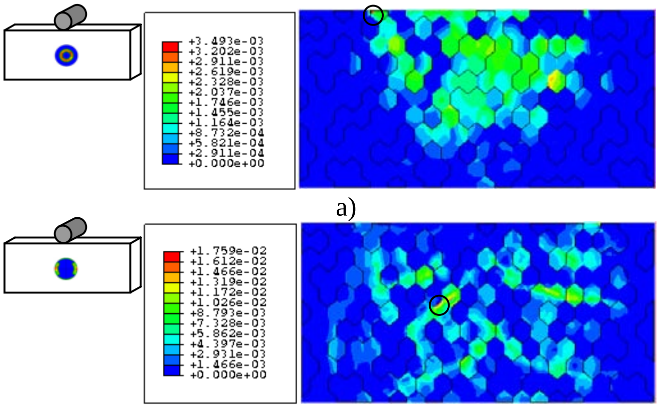
FINITE ELEMENT MODEL

The fretting model consists of a rigid cylinder in contact with an elastic-crystal viscoplastic half-space. To reduce the computational effort required for the simulations, the crystal plasticity model has only been used in the near surface regions and standard ABAQUS [1] material models have been used away from the area of interest. All of the plastic deformation is contained within the crystal plasticity portion of the model. Two-dimensional reduced integration generalized plane strain elements (CPE4R) have been used in the crystal plasticity region of the model allowing for the specification of 3-D crystallographic textures, which is equivalent to an ensemble of columnar grains. The grains are allowed to deform out-of-plane, but are restricted to do so uniformly. The radius of the rigid cylinder is 10 mm and the mesh size in the crystal plasticity region of the half-space is 0.005 mm which provides sufficient resolution of the number of elements spanning the contact width as well as a sufficient resolution of the number of elements per grain (~30 elements per grain). There are approximately 225 grains in the crystal plasticity portion of the model. The load history consists of the application of a normal force per unit length, P, which is held constant throughout the duration of the simulation. A tangential force per unit length, Q, is then applied and fully reversed from +Q to –Q for three complete loading cycles. No displacement boundary conditions are needed for the half-space as infinite elements have been employed at the outer boundary.

Three different types of textured materials common to Ti-6Al-4V have been simulated to investigate the influence of texture on the deformation fields during fretting fatigue. The three considered texture types are basal, transverse and basal/transverse. The simulation results presented herein are for the load case of $P/P^y = 1.0$ and $Q/P^y = 0.1$, where P^y is the force per unit length required to initiate yield in the subsurface region and varies for each type of texture. A constant coefficient of friction of $\mu = 1.5$ has been used in all simulations.

RESULTS

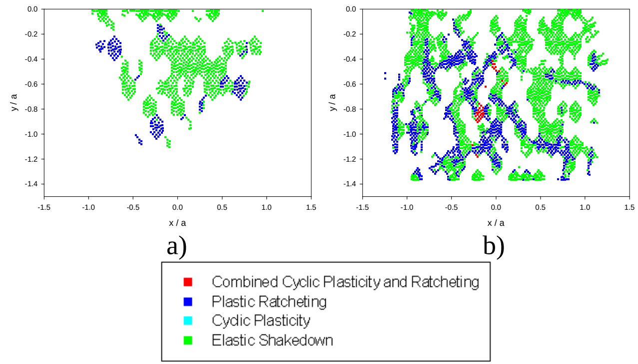
For all three types of textures considered, plastic ratcheting is observed to be the dominant mode of cyclic plastic deformation. This is in agreement with previous results from crystal plasticity fretting simulations with idealized 2-D textures [2,3]. The basal textured material exhibits the least amount of plastic ratcheting and correspondingly the most homogeneous distribution of cumulative effective plastic strain. This is direct result of all of the grains for this type of texture being favorably aligned for soft modes of deformation. As a by-product of the relatively homogeneous nature of deformation in the basal textured material, it is able to reach a state of elastic shakedown much earlier than mixed-types of textures. The transverse and basal/transverse textured materials exhibit significantly different behavior. Both of these materials display a highly heterogeneous distribution of cumulative effective plastic strain in the subsurface region. The plastic strain is partitioned in vein-like "soft" regions of the microstructure in which relatively few favorably oriented grains are surrounded by unfavorably oriented primary alpha grains and/or the harder secondary lamellar alpha+beta grains. The confined nature of the plastic strain for the transverse and basal/transverse textured materials leads to continued cyclic plastic ratcheting as smaller regions of the material are required to accommodate the plastic deformation. The maximum cumulative effective plastic strain values at the end of the 3rd cycle are 0.00349, 0.01759, and 0.01095 for basal, transverse, and basal/transverse textures, respectively. Illustrative results are quantitatively displayed for the basal and transverse textured materials in Figure 1 and Figure 2. Figure 1 gives the cumulative effective plastic strain distributions at the end of the 3rd cycle and Figure 2 shows the plastic strain maps [4] over the 3rd cycle. The locations of maximum cumulative effective plastic strain have been highlighted in Figure 1. The results clearly show the importance of considering crystallographic texture during the process of fretting fatigue.



a)

b)

Figure 1. Cumulative effective plastic strain distributions at the end of 3rd cycle. a) basal texture b) transverse texture.



a) b)

Figure 2. Plastic strain maps over 3rd cycle. a) basal texture b) transverse texture.

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