INVESTIGATION INTO VARIABLE CONTACT LOAD EFFECTS ON FRETTING FATIGUE BEHAVIOR OF Ti-6Al-4V

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Summary Fretting fatigue behavior in titanium alloy, Ti-6Al-4V, a common material widely used in commercial and military aero-engines, was investigated under the realistic loading conditions. Previous studies in this context have employed the cyclic bulk load on the substrate (specimen) and cyclic tangential load on fretting pads while the contact load is kept constant. However, the realistic conditions involve all these three loads as variable (cyclic). Therefore, a test set-up was developed which provided a capability to apply these three loads as cyclic type. Several tests were conducted using a cylinder-on-flat configuration. These tests showed that fretting fatigue lives are reduced under the variable contact load relative to their counterparts under the constant contact load. Finite element analysis was conduced to compute a critical plane based multiaxial fatigue parameter. This parameter was then evaluated based on their ability to predict the crack initiation location, crack orientation angle, and the number of cycles to fretting fatigue crack initiation. These predictions were compared with their experimental counterparts. These comparisons showed that fretting fatigue crack initiation mechanism in the tested titanium alloy is governed by both shear and normal stresses on the critical plane

INTRODUCTION

Fretting fatigue causes a considerable reduction in life of machine components as compared to plain fatigue, i.e. conventional fatigue without fretting. There are numerous practical situations where the machine components have failed prematurely due to fretting fatigue. As an example, the blade/disk dovetail joint in turbine engines commonly fails due to fretting fatigue, and these are of great concern because of an excessive number of in-service failures, high maintenance costs, and the impact on operational readiness of gas turbine engines in military and civilian aircraft fleet. These failures are related to high cycle fatigue (HCF). This problem is further exacerbated due to the difficulty in detecting fretting fatigue crack initiation and propagation during service. Also, engine components experience loads which are variable (cyclic) in nature. Almost all the previous studies on fretting fatigue involved the constant contact load, i.e. majority of previous studies in this context have employed the cyclic bulk load on the substrate (specimen) and cyclic tangential load on fretting pads while the contact load was kept constant [1-4]. However, the realistic conditions involve all these three loads as variable. Therefore, the objective of the present study was to investigate fretting fatigue behavior of titanium alloy, Ti-6Al-4V, a material widely used in commercial and military aero-engines, under the realistic loading conditions involving all three loads as cyclic. Both experiments and finite element analyses were conducted.

EXPERIMENTS

A fretting fatigue test was developed utilizing a multi-axis test machine, which consisted vertical servo-hydraulic actuator, and two side (horizontally opposed) actuators. The vertical actuator applied the cyclic axial load on the specimen, and side actuators through a specially designed fixture applied the cyclic contact load as well as the cyclic tangential load through a pair of pads. The test system was capable to control the frequency, waveform and phase among three loads: axial, tangential and contact loads. The tangential load was the function of the axial load and stiffness of the fretting fixture. Several tests were conducted at 20 Hz where all three loads were of sinusoidal wave form and in phase under the laboratory ambient conditions. The contact condition involved cylinder-on-flat where cylindrical pads had 50 mm radius from the same material as the flat specimen, Ti-6Al-4V. Two series of tests were conducted, first one with constant contact loads of 450, 500, 900 or 1000 N/mm, and the second one with a cyclic contact load varying from 450 to 900 N/mm or 500 to 1000 N/mm. All tests were stopped as soon as a crack of ~ 0.1 to 0.2 mm length was detected as in the previous studies [1-4]. It was about 90 to 95% of cycles for the complete specimen fracture (i.e. total life).

ANALYSIS

A commercially available, finite element code ABAQUS was used, similar to that in a previous study [4] to obtain stress, strain, and displacement(s) in the contact region between pad and specimen. The master-slave interfacial algorithm developed for contact modeling was used along with four node plane strain quadrilateral elements. The applied loads, as measured in experiments, were applied with complete history effects. The analysis was carried out for all tests conducted in this work. Stress, strain, and displacement fields obtained from the finite element analysis were used to compute a critical plane parameter, modified shear stress range (MSSR) to characterize fretting fatigue behavior. The details of this parameter are given in a previous study [4] which was able to correlate the fretting fatigue crack initiation lives from different contact geometries.

RESULTS AND DISCUSSION

Figure 1 shows one of the typical results of this study where fatigue lives under the cyclic contact loads are compared with their counterparts from the constant contact loads. This figure shows a few results from fretting tests conducted under the constant contact loads, 450, 500, 900 and 1000 N/mm. As it can seen that as the contact load increased, the fatigue life decreased. The next series of tests shown in this figure are under the cyclic contact load varying from 450 to 900, 500 to 1000, and 750 to1000 N/m. As it can be seen that the fretting fatigue life under the cyclic contact load is generally less than the counterparts under the constant loads, e.g. life under the cyclic contact load varying from 450 to 900 N/mm is less than their counterparts with constant contact loads at 450 N/mm or 900 N/mm. Thus, it shows that cyclic contact load is more detrimental than constant contact load. The former represents the realist practical situation than the latter. A detailed finite element analysis of these tests provided the complete stress state in the contact region from which a multiaxial parameter, MSSR [4] was computed. The measured fatigue life data were correlated with the computed MSSR parameter from both series of tests, i.e. with constant and cyclic contact loads. They correlated well within a scatter band showing that this parameter is also capable to account the load history effects as it did the geometry effects in previous studies [3-4].

SUMMARY

Fretting fatigue behavior in titanium alloy Ti-6Al-4V under a realistic loading condition, which involved bulk load on substrate, tangential and contact loads on fretting pads all cyclic type, was investigated. Fretting fatigue lives were reduced under variable contact load relative to their counterparts under constant contact load. A critical plane based fatigue parameter was able to correlate the fretting fatigue crack initiation lives from both these loading conditions, i.e. cyclic versus constant contact loads.

References

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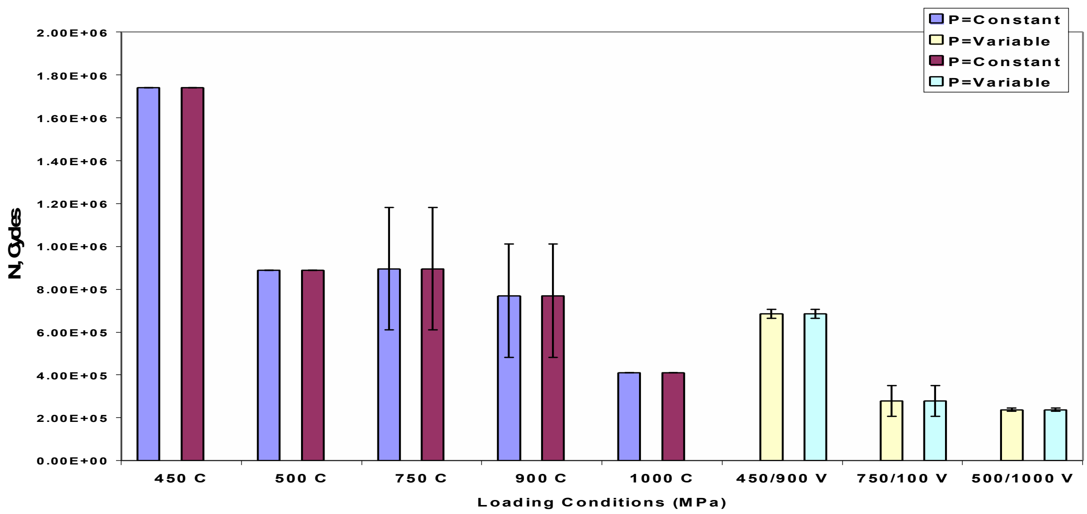

Fig. 1