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Investigation into effects and interaction of various fretting fatigue variables under slip-controlled mode ☆

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Abstract

Fretting fatigue behavior of unpeened and shot-peened Ti–6Al–4 V was investigated using a dual-actuator test setup which was capable of applying an independent pad displacement while maintaining a constant cyclic load on the specimen. The fretting regime was identified based on the shape of the hysteresis loop of tangential force versus relative slip range and the evolution of normalized tangential force. The fretting regime changed from stick to partial slip and then to gross slip with increasing relative slip range, and the transition from partial to gross slip occurred at a relative slip range of 50–60 μm regardless of the applied cyclic load, surface treatment, contact load and contact geometry. The fretting fatigue life initially decreased as the relative slip range increased and reached a minimum value, and then increased with increase of the relative slip range due to the transition in fretting regime from partial slip to gross slip. Shot-peened specimens had longer fatigue life than unpeened specimens at a given relative slip range, but the minimum fatigue life was found to be at the same value of relative slip range for both shot-peened and unpeened specimens. Tangential force was directly related to relative slip and this relationship was independent of other fretting variables.

Keywords: Fretting fatigue; Relative slip; Shot peening; Titanium alloy

1. Introduction

Fretting fatigue occurs when a component subjected to cyclic loading is in contact with other component under a lamping force. Surface or subsurface damage is induced by the microscopic motion at the contact surface between these two components which in turn reduces the fatigue life as compared to plain fatigue without fretting. Due to the complex nature of fretting fatigue, its behavior is influenced by several variables [1] such as applied cyclic load, applied contact load, relative slip, coefficient of friction, contact geometry, compliance of fretting setup, etc. Further, these variables are normally closely inter-related to each other during a fretting fatigue test. Therefore, there is always a need to control these variables or factors in a fretting test. This study focused on the effects of relative slip on the fretting behavior and its interaction with other variables.

A dual-actuator fatigue setup was capable of applying fretting pad displacement independent of other loads. The major advantage of this dual-actuator fatigue setup is its ability to apply any prescribed value of relative slip at a given applied cyclic load to the specimen. In a conventional fretting fatigue setup which uses a single actuator, it is impossible to apply relative slip independently since the magnitude of relative slip is determined by other fretting variables such as applied cyclic load, contact load, coefficient of friction, and compliance of fretting fixture setup. Relative slip between two mating components has been investigated extensively and has been shown to be important in characterizing fretting fatigue behavior [2–9]. The effect of relative slip on fretting fatigue was first investigated by Nishioka and Hirakawa [2,3] who found that an increase in relative slip reduced fretting fatigue life of a carbon steel. Later, Vingsbo and Soderberg [4] conducted a more systematic study and found similar

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results. Favrow et al. [5] and Anton et al. [6] investigated the effects of relative slip on fretting fatigue behavior under the gross slip condition using a dual-actuator fatigue setup. They found that relative slip had a dominant effect on fretting fatigue behavior of titanium alloy, Ti–6Al–4 V. Later, Jin and Mall [7,8] conducted an investigation on the fretting fatigue behavior of Ti–6Al–4 V under slip-controlled mode. They observed that the magnitude of relative slip controlled the fretting fatigue regime, i.e. stick, partial slip, and gross slip contact conditions, which in turn had a significant effect on the fretting fatigue life as well as on the surface damage mechanism.

Components subjected to cyclic loading are often surface treated to enhance their fatigue resistance since fatigue cracks initiate generally at the surface. Several studies have shown that shot-peening also improves the fretting fatigue strength of materials [9–12]. Shot-peening induces a residual compressive stress on the surface and a compensating residual tensile stress inside the component away from the surface. The compressive residual stress tends to prevent crack initiation by canceling out the effect of applied tensile stress up to a certain level. In addition, the compressive residual stress closes the pre-existing crack if it is within the compressive stress zone. Distortion of grains near the surface induced by shot-peening process reduces the propensity for crack propagation [11].

The present study addresses the investigation of fretting fatigue behavior of titanium alloy, Ti–6Al–4 V, in unpeened and shot-peened conditions, under relative slip-controlled mode in which a prescribed relative slip is applied by an aforementioned dual-actuator fatigue setup. This titanium alloy is commonly used in the dovetail contact region of blade/disk attachments in gas turbine engines where fretting fatigue-induced damage is present. This study particularly focused on the effects and interactions of several fretting fatigue variables, including relative slip, tangential force, contact load and surface treatment, on the fretting fatigue regime and fatigue life under the slip-controlled mode.

2. Experimental procedure

2.1. Material and specimen

Specimens were machined from a forged plate of titanium alloy, Ti–6Al–4 V. Prior to machining, material was preheated and solution treated at 935 °C for 105 min, cooled in air, vacuum annealed at 705 °C for 2 h, and then cooled in argon. The resulting microstructure showed the nucleation of 60% volume of α (HCP) phase (platelets) in 40% volume of β (BCC) phase (matrix). The measured grain size was about 10 μm. The material has an elastic modulus of 126 GPa and a yield strength of 930 MPa. Dog-bone-type specimens were used in the present study. The width and thickness of the reduced area were 6.4 and 3.8 mm, respectively. The specimen was first cut by the wire electrical discharge machining method. It was then subjected to the low stress grinding to reduce the residual stress due to machining. Finally, they were polished using 600 grit silicon carbide papers. After machining, some specimens were shot-peened as per SAE Aerospace Material Specification (AMS) 2432 standard, using a computer-controlled equipment with an intensity of 7 Almen. The process was conducted with ASR 110 cast steel shots with 100% surface coverage. Two types of fretting pads were used, i.e. cylindrical pad and flat pad with rounded edges. The dimension of both types of pad was 9.5 mm × 9.5 mm and the radius of cylindrical pad was 50.8 mm. The flat pad with round edges had edge radius of 2.54 mm and flat region of 4.45 mm. Fig. 1 shows a schematic of the specimen and pads.

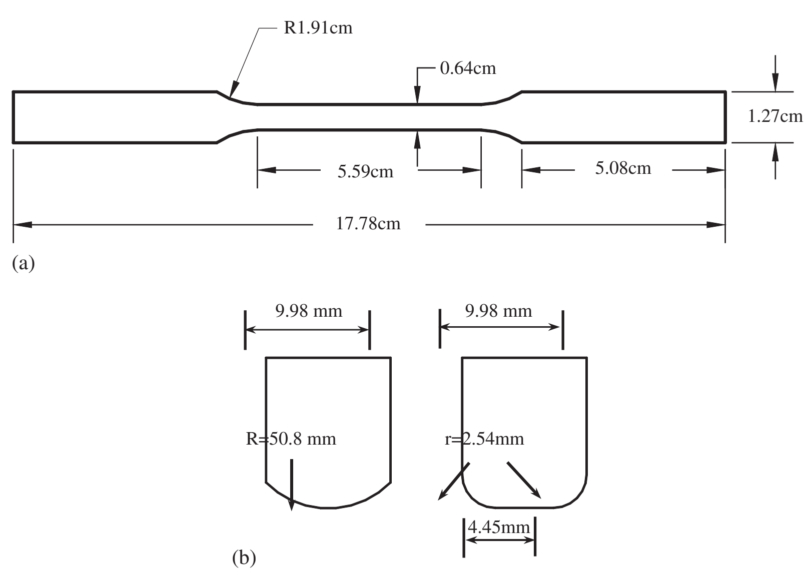

Fig. 1. Schematics of (a) specimen and (b) pad.