International Journal of Fatigue 85 (2016) 65–69

Contents lists available at ScienceDirect

International Journal of Fatigue

journal homepage: www.elsevier.com/locate/ijfatigue

Fretting fatigue characteristic of Ti–6Al–4V strengthened by wet peening

Kang Li [a], Xue-song Fu [a], Rui-dong Li [a], Peng-tao Gai [b], Zhi-qiang Li [b], Wen-long Zhou [a,*], Guo-qing Chen [a]

[a] School of Materials Science and Engineering, Dalian University of Technology, Dalian 116085, PR China
[b] Beijing Aeronautical Manufacturing Technology Research Institute, Beijing 100024, PR China

ARTICLE INFO

Article history:
Received 18 August 2015
Received in revised form 26 October 2015
Accepted 18 December 2015
Available online 25 December 2015

Keywords:
Ti–6Al–4V alloy
Wet peening
Local fatigue
Fretting fatigue

ABSTRACT

This study investigated the effects of wet peening treatment on the fretting fatigue behavior and crack propagation in Ti–6Al–4V alloy. Wet peening induced a compressive residual stress at 0–160 μm depth and enhanced the hardness at 0–80 μm depth. Results of the fretting fatigue tests show that the fretting damage could efficiently reduce the fatigue life of both the un-peened and wet peened samples. Moreover, wet peening could effectively increase the fretting fatigue resistance. Investigation on crack propagation mechanism revealed that the increased resistance is due to the synergistic effect of the enhanced hardness and the induced compressive residual stress in the wet peening modified layer. The enhanced hardness could resist the local fatigue in the fretting cracking stage and the compressive residual stress could retard crack growth.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

In aeronautics, Ti–6Al–4V alloy offers wide industrial applications in the blade/disk attachments in gas turbine engines owing to its high specific strength and low density [1]. The fretting-fatigue-related failure is one of the most insidious, difficult, and costly problems in blade/disk attachments [2]. Under vibratory loading condition, the localized fretting wear at the blade/disc dovetail joint results in premature initiation and subsequent growth of fatigue cracks, leading to shorter fatigue life of a component or failure at a stress much lower than the fatigue strength of the Ti–6Al–4V alloy [3]. The co-action damage of fretting wear and fatigue in gas turbine engines is one of the well-known examples of fretting fatigue. Such damage has been assumed to have caused many unanticipated disk and blade failures in turbine engines and thus has gained considerable attention [4–7] over the years. Numerous surface modification techniques, such as shot peening (SP), surface mechanical attrition treatment, ultrasonic nanocrystalline surface modification, have been recently performed to improve the fretting fatigue life of various materials. Among these techniques, SP is probably the most popular surface modification technique [8]. SP could produce compressive residual stress beneath the surface to prevent crack initiation and to close preexisting cracks within the depth of the compressive zone [3].

SP produces compressive residual stress and enhances the hardness of the material surface. Previous studies have extensively discussed the beneficial effects of the compressive residual stress on fretting fatigue, however, discussion on the influence of enhanced hardness on fretting fatigue is few. In the case of fretting wear, numerous investigations have reported that the fretting wear resistance could be increased by increasing the hardness of contact surface [8–13]. Moreover, Ghosh et al. [14] proposed that surface hardness exerts a significant beneficial effect on crack initiation under fretting condition. Therefore, the hardness of the layer is suspected to be another key factor of fretting fatigue in addition to compressive residual stress.

Compared with the other SP methods, the wet peening (WP) technique is more economical and produces less amount of waste, and results in a lower surface roughness owing to the protection provided by of the water film when processing the blade/disk components [15,16]. The current investigation employed WP treatment in fabricating a modified surface layer of the Ti–6Al–4V alloy. X-ray diffraction (XRD) and nano-indentation were employed in investigating the residual stress and nano-hardness of the depth of the WP sample. The samples treated with and without WP were subjected to fretting fatigue test and the results were compared. The effects of the compressive residual stress and the enhanced hardness to fretting fatigue were also discussed. Scanning electron microscope (SEM) and metallographic microscope were used to investigating the fracture morphology and crack propagation rule of failed samples.

---

[*] Corresponding author.
E-mail address: wlzhou@126.com (W.-l. Zhou).

http://dx.doi.org/10.1016/j.ijfatigue.2015.12.013
0142-1123/© 2015 Elsevier Ltd. All rights reserved.

2. Experimental procedure

2.1. Materials and WP treatment

This work used a rolled plate of Ti–6Al–4V (3 mm thick) consisting of 6 Al, 4 V, 0.3 Fe, 0.2 O, 0.1 C, 0.05 N, 0.015 H, and the rest was Ti (all in wt%). All WP experiments were conducted using a mixture of ceramic beads (600 μm mean diameter, 7 GPa hardness) and water in the scale of 10 wt% and at an Almen target intensity of 0.25 mm N.

The small WP treated-specimens were cut into 10 mm × 10 mm pieces, and their compressive residual stress and hardness were detected using XRD (PANalytical Empyrean) and nano-indenter (nano-indenter XP with Berkovich diamond tip). To test the residual stress and hardness (H) at different depths, the surface layer of the specimens was etched using a solution consisting of 2 HF, 4 HNO_3, 94 H_2O in wt%, and each delaminated thickness was measured in micrometer during etching.

2.2. Design of fretting fixture

A fretting fixture that is fixed on the fatigue test machine was designed and developed to investigate the fretting fatigue behavior of the Ti–6Al–4V specimen while in contact with two Ti–6Al–4V fretting pads. The schematic of the fixture is shown in Fig. 1. While the specimen suffers a cyclic bulk stress σ, the fixture produces a normal stress on the fretting pads, and the fretting fatigue test proceeded. In the fixture, the rotation disk produces normal stress, which could be recorded by a tension sensor. The linear guide ensures uniaxiality of the two fretting pads, moreover, the bulb design on the loading bar allows the fretting pads to self-regulate minor rotation to ensure flat-on-flat contact configuration.

2.3. Fretting fatigue tests

The fatigue specimens were prepared according to the Chinese standard GB3075-82. The Ti–6Al–4V fretting pads were polished with waterproof abrasive paper up to #1000. Fig. 2(a) shows the schematic of the fatigue specimen and the fretting pad. The fretting pad and the specimen were in contact face to face at a contact area of 120 mm^2. The tests were conducted under laboratory condition at room temperature on a servo-hydraulic fatigue test machine equipped with a rigid fretting fixture (Fig. 2(b)). The fatigue machine was controlled in the sinusoidal circle stress at a constant stress ratio ($\sigma_{\min}/\sigma_{\max}$) of 0.1 and uniform frequency of 20 Hz. The fretting pads were pressed on the specimen by a constant force of 100 N. The fatigue machine could record the circle index, which is the fretting fatigue life while the specimen fractured. After the fretting fatigue tests, the fretting regime and fractured surfaces were observed under SEM and metallographic microscope.

3. Results

3.1. Calibration for the WP modified layer

Fig. 3 shows the changes in residual stress and nano-hardness profiles of the WP samples with depth. The compressive residual stress and the nano-hardness H both decrease gradually with increasing depth. The compressive residual stress decreases gradually from 1115 MPa to 0 MPa starting from the surface down to 160 μm depth. In addition, the nano-hardness, decreases from 5.65 GPa to 4.5 GPa starting from 12 μm to 80 μm depth, and the decreasing trend becomes smooth beyond 80 μm depth. WP treatment affected the residual stress and hardness layer up to thickness of approximately 160 and 80 μm, respectively.

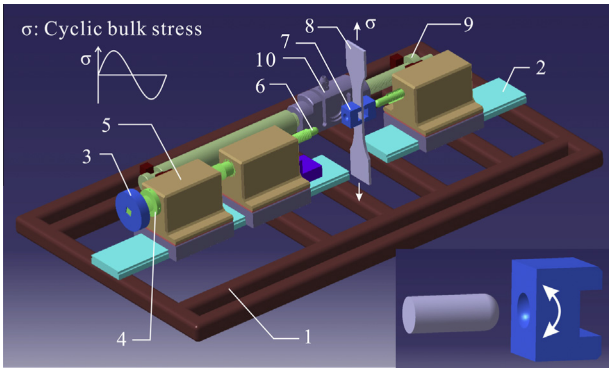

Fig. 1. CAD model of fretting fatigue fixture (1 – Bedframe; 2 – Linear guide; 3 – Rotating disk; 4 – Lock; 5 – Slider; 6 – Loading bar; 7 – Fretting pad; 8 – Specimen; 9 – Self-locking nut; 10 – Tension sensor).

3.2. Fretting fatigue tests

Fig. 4 shows the fretting fatigue stress-cycle number (S–N) curves of the Ti–6Al–4V alloys with and without WP treatment. For comparison, the fatigue results [15] on WP treated Ti–6Al–4V are shown in Fig. 4. For a better comparison, all results are detailed in Table 1. The fatigue life (Nf) of both the un-peened and WP samples is efficiently reduced by the fretting action. In this fretting fatigue test (the dashed line in Fig. 4), the WP treatment effectively prolongs the fretting fatigue life from (0.05, 0.16, 0.23, 0.28) × 10^6 to (0.15, 0.53, 0.9, 2) × 10^6 whereas the $\sigma_{\max}$ are 650, 600, 550, and 500 MPa respectively. The WP treatment is suggested to effectively increase both the fatigue and fretting fatigue resistance of Ti–6Al–4V alloy.

4. Discussion

The compressive residual stress introduced by WP treatment exerts beneficial effect on the fatigue resistance of Ti–6Al–4V alloy. Moreover, Chen et al. [15] found that crack initiation in WP sample occurs in the interior region beneath the surface owing to the influence of compressive residual stress. In the present study, the fretting fatigue tests show that the WP treatment could also efficiently prolong the fretting fatigue life of the alloy. The protective effects of the WP layer against fretting fatigue may be attributed to the synergistic effects of the compressive residual stress and the enhanced hardness. To discuss the enhanced effect of WP layer during the fretting fatigue test, the fracture surface, fretting scars, and fracture cross-section were investigated.

4.1. Fatigue crack initiation site

Fig. 5 shows the fracture surface morphologies of the un-peened and WP samples. The fatigue crack initiation sites are located in the surface of the un-peened and WP samples. The initial cracks of the un-peened specimen, which is induced by fretting, start from the surface and propagate into approximately 50 μm deep, and then transform into a fatigue crack source (Fig. 5(a)). Fig. 5(b) also illustrates the crack initiation site in the WP sample, the initial cracks are also induced in the surface, propagate into about 30 μm deep, and then transform into a crack source.

By contact, the crack initiation sites of the fatigue test specimens are located in the interior region beneath the surface owing to the strengthening effect of WP treatment [15]. However, the fretting damage action made the crack initiation site to return to the surface in the present fretting fatigue test. Compared with the depth of the initial crack propagation in WP sample, which is

Download English Version:

https://daneshyari.com/en/article/778161

Download Persian Version:

https://daneshyari.com/article/778161

Daneshyari.com