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On the damage mechanisms of bending fretting fatigue

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ABSTRACT

The bending fretting fatigue tests of 316L austenitic stainless steel, 7075 aluminum alloy, LZ50 steel and 30CrNiMo8 steel have been carried out under different bending stresses and normal contact stresses. The *S–N* curves of varied materials are set up accordingly, which present the shape like the Greek letter "ε" and can be divided into three running regimes similar to fretting wear. Based on the OM, SEM, EDS and TEM, the fretting fatigue damages have been analyzed in detail. The fretting wear damage mechanisms of fretting zone are abrasive wear, oxidative wear and delamination, a damage physical model in the MFR is proposed. According to the TEM results, two crack initiation mechanisms have been proposed based on different material characteristics.

1. Introduction

Fretting is the small-amplitude oscillatory movement which may occur between contacting surfaces [1], and may lead to surface damage [2–4], which was first reported in the open literature about one century ago [5]. Fretting research is composed by fretting wear, fretting fatigue and fretting corrosion. As a rule, fretting fatigue failure results from crack formation and propagation in a component under the combined action of two factors: (a) the total cyclic stress on the component and (b) the local stress arising from the relative slip of the surfaces of the two elements in contact under the pressure. Contact stresses resulting from surface fretting can dramatically reduce the fatigue strength of a component as compared to the same component sustaining only the bulk fatigue loads [6–12]. According to the modes of body cyclic stress, the fretting fatigue can be divided into three sample types, *i.e.* tension–compression (or tension–tension) fretting fatigue, bending fretting fatigue and torsional fretting fatigue, as shown in Fig. 1. There are many research mainly focused on the priority mode up to the present; however, the studies on the two latter modes are still insufficient, especially on bending fretting fatigue [6–10].

The bending fretting fatigue can be defined as the damage is the consequence of a cyclic bending load imposed to the contacting components to shorten the fatigue strength of the components early, where the relative movement of fretting is resulted from the cyclical bending stress. Failure phenomena of bending fretting fatigue broadly occur in the modern industrial fields, such as electrical motor shaft and pinion shaft of motors, dovetail groove matching in turbine engines, overhead electrical wires, and other shrink-fitted components. However, more studies extensively focused on the wheel-on-axle assembly, especially axles of railway vehicles [3–5].

Many researchers have investigated the tension–compression or tension–tension fretting fatigue widely [11–16]; however, the mechanisms of bending fretting fatigue are still not clear now, so it is necessary to systematically study the bending fretting fatigue. On the other hand, in order to enhance the reliability and the service life of components, the damage behaviors of fretting fatigue under bending conditions are also worth to study. In the previous works of the authors′ group, the behaviors of bending fretting fatigue of medium carbon steel (LZ50 steel [8]), aluminum alloy (7075 [10]) and stainless steel (316L steel [9]) have been investigated in detail. Recently, other different steels (30CrNiMo8 and 17CrNiMo6 alloy steels) have been investigated under the same conditions. Thus, in this paper, the mechanisms of bending fretting fatigue are outlined according to the results obtained from the varied materials.

2. Bending fretting fatigue testers and test parameters

On a hydraulic servo fatigue test machine, through the new design of clamps, two contact configurations (*i.e.* line and point contacts) of bending fretting fatigue can be fulfilled as shown in Fig. 2 [8–10]. The test rig of bending fretting fatigue as shown in Fig. 2 is mounted on a T-slot of the pedestal of the fatigue machine, and the detail specimen geometries and mechanical properties of varied materials are represented in Fig. 3 and Table 1. A normal load imposed on the fretting pads is maintained at a constant

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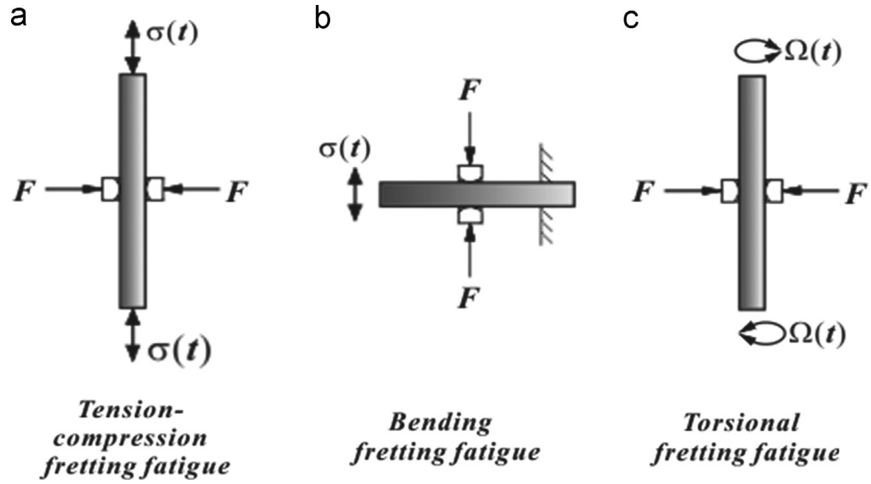

Fig. 1. Three simple fretting fatigue modes.

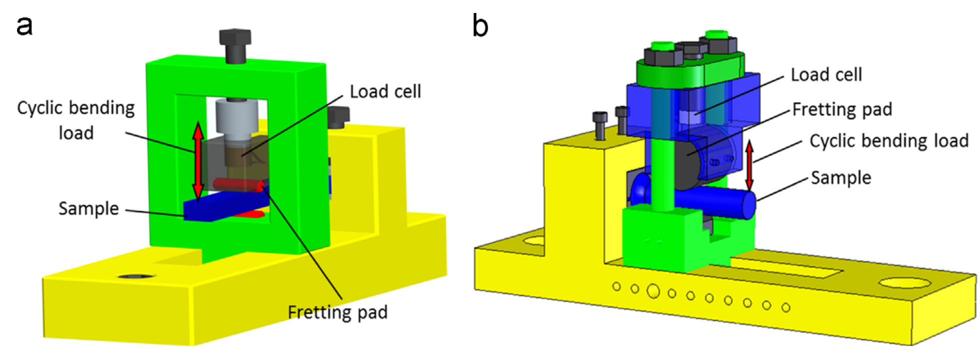

Fig. 2. Two contact configurations of bending fretting fatigue test rig. (a) Line contact and (b) point contact.

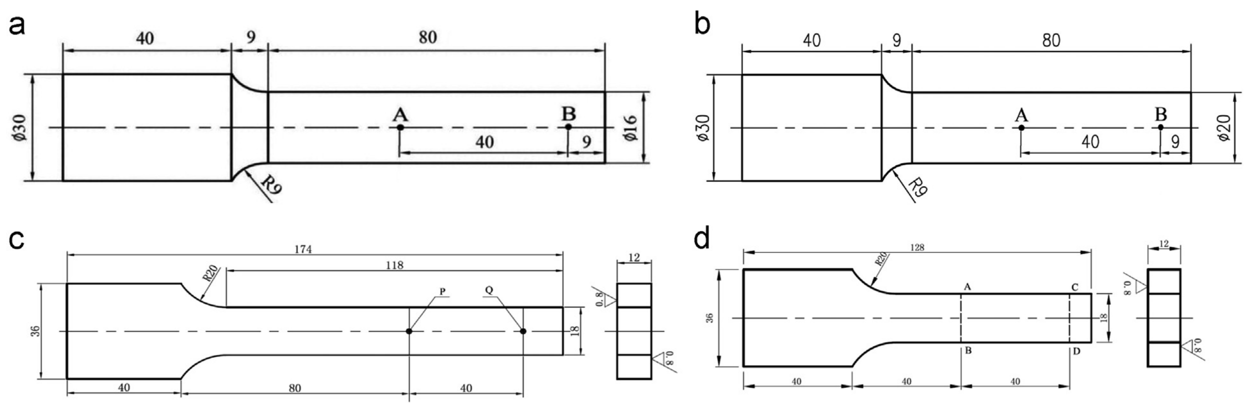

Fig. 3. Bending fretting fatigue specimen geometry. (a) 30CrNiMo8, (b) 7075 alloy, (c) LZ50 steel and (d) 316L steel.

Table 1
Main mechanical properties of the materials.

Mechanical properties	$\sigma_{0.2}$ (MPa)	σ_b (MPa)	E (GPa)	HV
30CrNiMo8	969	1095	210	330
7075 Aluminum alloy	604.0	647.4	71	150
LZ50 Steel	309.0	584.3	210	200
316L	282	555	191	135

level, which can be calculated by the Hertz contact theory, and the normal load is measured by a load cell. The bending stresses can be loaded by the piston of the hydraulic servo machine. The fretting damage occurs in the contact zone between the sample and fretting pad.

In this paper, the bending fretting fatigue behaviors of varied contact pairs, such as LZ50/52100 (sample/fretting pad), 7075/52100, 316L/52100, 30CrNiMo8/17CrNiMo6 and 17CrNiMo6/40CrNi2MoA, were tested and analyzed with contact configurations of cylinder-on-flat and cylinder-on-cylinder. The normal contact load varied from 250 N to 1000 N, and the bending load varied from 4.75 kN to 8 kN. The test frequency was 20 Hz all the time. The fretting damage zone and fracture surface were observed by an optical microscopy (OM) and a scanning electric microscopy (SEM, Quanta 2000) with EDX (EDAX-7760/68 ME) electron