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Effect of contact pressure on torsional fretting fatigue damage of 316L austenitic stainless steel

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ABSTRACT

Fretting is the small amplitude relative oscillatory motion between two solid contact surfaces. Many factors would make impacts on the fretting process, the body stress and contact pressure can be regarded as two major independent factors resulting in the fretting fatigue. The effects of torque and contact pressure on torsional fretting behavior of 316 L austenitic stainless steel are studied in a cylinder-on-cylinder contact configuration. The results indicate that torsional fatigue life drops rapidly due to fretting. The *S-N* curves of torsional fretting fatigue show a shape of "*C*". Along with increasing the contact pressures, the fretting fatigue life decreases and enters to a platform area. The variety law of friction coefficient under different contact pressures is obtained. Both fatigue fracture and fretting scar are analyzed with SEM, EDX, XPS and three-dimensional white light interferometer (3D). The study shows that the torsional fretting fatigue is influenced by fretting running behavior. Meanwhile, the depth of crack initiation position would also be affected by contact pressure. In this paper, we proposed the failure mechanisms of the fretting zone, including plastic deformation, delamination, plow and oxidative wear.

1. Introduction

Fretting is a small-amplitude oscillation occurring at the asperities contacting surfaces, which may lead to surface damage [1]. According to the types of body cyclic stress, fretting fatigue can be divided into three typical types: tensional-compression (or tensional-tensional), bending and torsional [2]. Tension-compressions and bending fretting fatigue have been investigated intensively in previous studies [2–7]. Wu studied the push-pull fretting fatigue performance of Ti-1023 titanium alloy compared to the plain fatigue [4,5]. Based on the bending fretting fatigue, Zalnezhad [6] and Ahmed [7] had researched the effect of surface hardness and thin film titanium nitride coating on fatigue lifetime of AL7075-T6 alloy, and found that the fretting fatigue life at low stress can be improved by high surface hardness, while at high stress the results were reversed. The high surface hardness TiN coating can improve the fretting fatigue life of the base material. Whereas, torsional fretting fatigue is extensively existed in engineering components, for example bolts, motor shaft, overhead electrical conductors and wheel-sets [8,9]. Therefore, it is worthy to study the torsional fretting fatigue with various factors.

The influence of contact pressure on fretting fatigue of various materials has been studied by researchers using a series of test methods. While, there is not a consistent conclusion until now [10–15] and [17]. Endo and Goto experimentally investigated the carbon steel and found that with an increase in contact pressure, the fretting fatigue life decreased [10]. Same experimental results have also been obtained by Gaul and Duquette in 4130 steel [11], as well as Mall and coworkers in Ti6Al4V alloy [12]. However, Lee and Adibnazari et al., who researched the high strength steel and 7075-T6 aluminum alloy, showed that contact pressure had no effect on the fretting fatigue life. They believed that when the contact pressure is large enough, the fretting fatigue has little difference with the contact pressure changing [13,14]. Whereas, the investigation of Fernando et al. in BS L65 4% Cu-Al alloy had indicated a totally different result. When the contact pressure is low, the fretting life decreased with an increase in contact pressure at low cyclic stress level. Under the condition of high contact pressure, fretting fatigue life increased with an increase in contact pressure [15]. Furthermore, Naidu and Raman [16] showed that the fretting fatigue life of Al-Mg-Si alloy 6061exhibited a minimum and a maximum with the increase in contact pressure. Many researchers have investigated the effect of contact pressure on tension-compression or tension-tension fretting fatigue widely. However, the effect of contact pressure on torsional fretting

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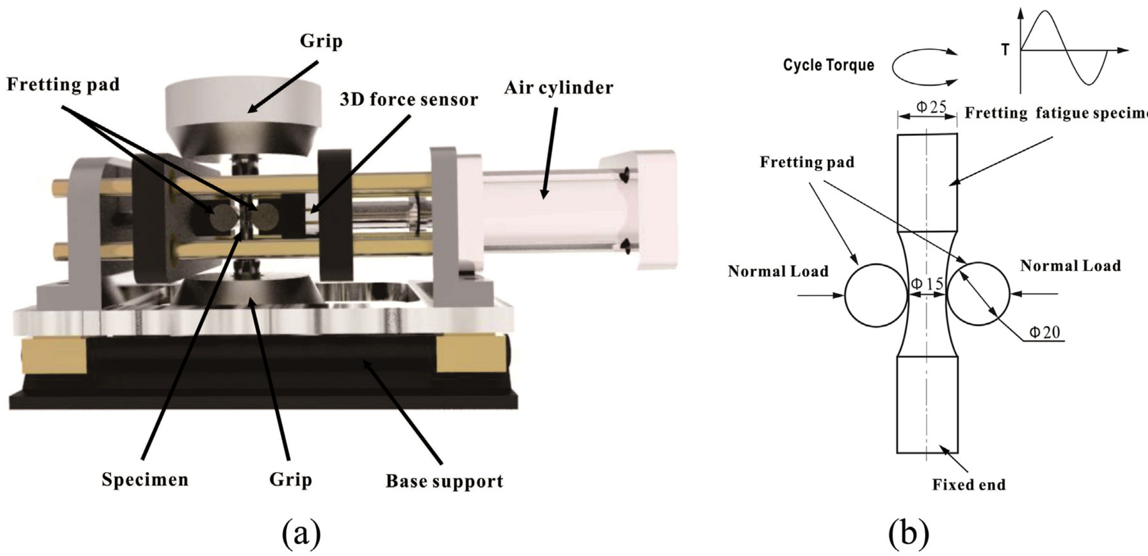

Fig. 1. Torsional fretting fatigue test system. (a) Photo of loading device. (b) Schematic drawing of fretting fatigue test samples.

Table 1
Chemical composition of 316L austenitic stainless steel and GCr15 steel (wt%).

Materials	Fe (%)	C (%)	S (%)	Si (%)	Mn(%)	P (%)	Cr (%)	Ni (%)	Cu (%)
316L	Balance	0.0212	0.015	0.45	1.116	0.0258	16.681	10.163	0.3020
GCr15	Balance	0.95	0.02	0.25	0.30	0.02	1.5	0.20	0.15

Table 2
The main mechanical properties of 316L austenitic stainless steel and GCr15 steel.

Mechanical properties	$R_{p0.2}$ (MPa)	R_m (MPa)	E (GPa)	HV
316L	282	555	191	135
GCr15	1700	2000	210	850～876

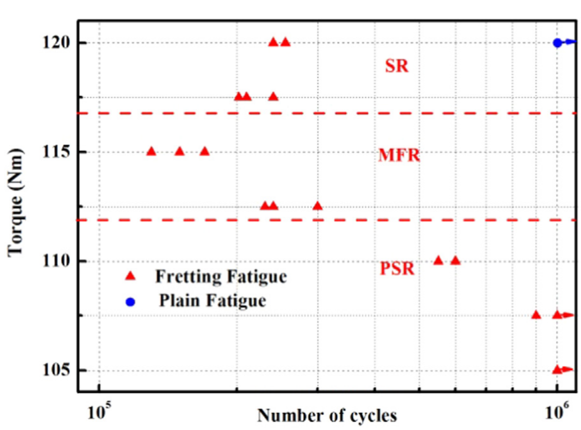

Fig. 2. *S-N* curves of torsional fretting fatigue for contact pressures of 120MPa.

fatigue is still not clear [17–20].

In this study, the influence of contact pressure on torsional fretting fatigue behavior of 316L austenitic stainless steel has been investigated by using a new test facility. The data display the change rule of friction coefficient with contact pressure. In order to study the evolution of fretting damage zone, the fretting scar is analyzed by a series of testing technology. The fatigue fracture was also analyzed to determine the relationship between the crack initiation or propagation depth and fretting fatigue strength.

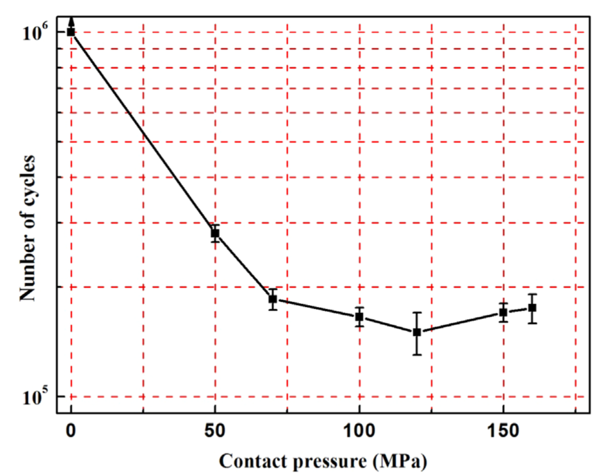

Fig. 3. Contact pressure vs. number of cycles (under 115 Nm torque).

2. Experimental details

A torsional fretting fatigue apparatus (Fig. 1(a)) based on a servo hydraulic fatigue-testing machine (*Walter+Bai LFV100-T500-HH* servo fatigue machine) is used to the experimental investigations. As shown in Fig. 1(a), the top grip is connected with hydraulic cylinder by the load cell, while the bottom grip is fixed on the apparatus base. A pneumatic loading device serves as the torsional fretting fatigue machine, which has a vertical crossed cylindrical contact configuration to apply normal load. The tests are conducted as following steps. Firstly, the fretting fatigue sample is fixed on the bottom grip and clamped by the top grip. Moreover, the fretting pads are mounted on the clamp of vertical crossed actuator. Secondly, the solenoid valve is triggered to control the movement of air cylinder, and the normal load is applied on the sample. The 3D force sensor can show the magnitude of the normal load. According to the requirement of the fretting fatigue,