Wear 380-381 (2017) 6–14

Contents lists available at ScienceDirect

Wear

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

Torsional fretting wear behavior of CuNiAl against 42CrMo4 under flat on flat contact

Po Zhang [a], Wenlong Lu [a,*], Xiaojun Liu [a], Mingzhuo Zhou [a], Wenzheng Zhai [a], Gengpei Zhang [b], Wenhan Zeng [c], Xiangqian (Jang) Jiang [c]

[a] The State Key Laboratory of Digital Manufacturing Equipment and Technology, School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China
[b] Bohai Drilling Engineering Company Engineering Technology Research Institute, Tianjin 300280, PR China
[c] EPSRC Centre for Innovative Manufacturing in Advanced Metrology, University of Huddersfield, Huddersfield, HD1 3DH, UK

A R T I C L E I N F O

Article history:
Received 1 July 2016
Received in revised form
27 February 2017
Accepted 8 March 2017
Available online 9 March 2017

Keywords:
Torsional fretting
Flat on flat contact
Fretting running behavior
Wear mechanism

A B S T R A C T

Torsional fretting exists in many engineering applications and the contact configurations have great effects on the fretting wear behavior. Influence of angular displacement amplitudes and normal loads on torsional fretting were investigated under flat on flat contact. Friction torque versus angular displacement amplitudes and friction torque versus number of cycle curves were used to analyze the fretting kinetics behavior. Evolution of accumulated dissipated energy (E_T) and wear volume (V_W) with the change of angular displacement amplitudes were analyzed. The wear mechanisms were studied base on examinations under optical microscope (OM), scanning electron microscope (SEM) and Energy Dispersive X-Ray Spectroscopy (EDX). It is found that E_T and V_W analysis helps to reveal the variation of failure mechanisms with the change of angular displacement amplitudes. Uneven spread of wear scar under mixed slip resulted from the effects of debris on stress-redistribution. Similar to ball on flat contact, the torsional fretting wear mechanism under flat on flat contact was a combination of deformation, cracks, delamination abrasive wear and oxidation wear.

1. Introduction

Fretting wear is a phenomenon that occurs between two surfaces which have a relative oscillatory motion of small amplitude, typically smaller than 1 mm [1]. According to the direction of relative motion, four basic fretting modes can be distinguished: i.e. tangential, radial, rotational and torsional fretting [2]. Torsional fretting happens not only in human body such as hip joints and knee joints, but also in many engineering applications, such as ball stocks in automobiles and the center plate on a railroad car [3–6].

Efforts have been made on torsional fretting. Cai et.al [7–10] not only investigated the fretting wear behavior of metallic materials and polymers, but also sought measures such as lubrication, coating and atmosphere controlling for fretting alleviation. A semi-analytical method [11] and finite element code ABAQUS [12] were applied for the torsional fretting simulation. While most of the work were focused on the fretting behaviors under the ball on contact mode. As shown in Fig. 1, the contact configurations under torsional fretting can be basically divided into ball on flat contact, ball on concave contact and flat on flat contact. The contact configuration has a great influence on the fretting wear behavior, as the contact stress, contact stiffness and debris behavior are distinctly different under various contact configurations [13].

In many engineering applications, torsional fretting happens in the form of flat on flat contact, such as the blade bearing in a controllable pitch propeller and the center plate of a bogie in a railway carriage [1,14,15]. In this paper, a test rig was developed to realize torsional fretting with flat on flat contact, materials of CuNiAl and 42CrMo4 used for the controllable pitch propeller were chosen as the research materials. The fretting running behavior and wear mechanisms under various normal loads and angular displacement amplitudes were systematically investigated.

2. Experimental details

Fig. 2 shows the cross-section of a controllable pitch propeller (CPP), the blade carrier together with the blade foot and the hub form a blade bearing. For the blade bearing interface, when the pitch is adjusted, sliding wear happens due to the push of hydraulic system; while when the pitch is fixed, fretting wear happens due to the fluctuation of wake flow field. Though both sliding

* Corresponding author.
E-mail address: hustwenlong@163.com (W. Lu).

http://dx.doi.org/10.1016/j.wear.2017.03.002
0043-1648/

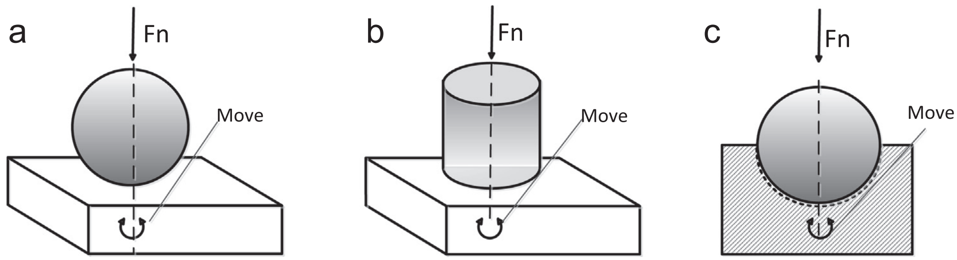

Fig. 1. Torsional fretting wear under different contact configurations. (a) Ball on flat contact; (b) Flat on flat contact; (c) Ball on concave contact.

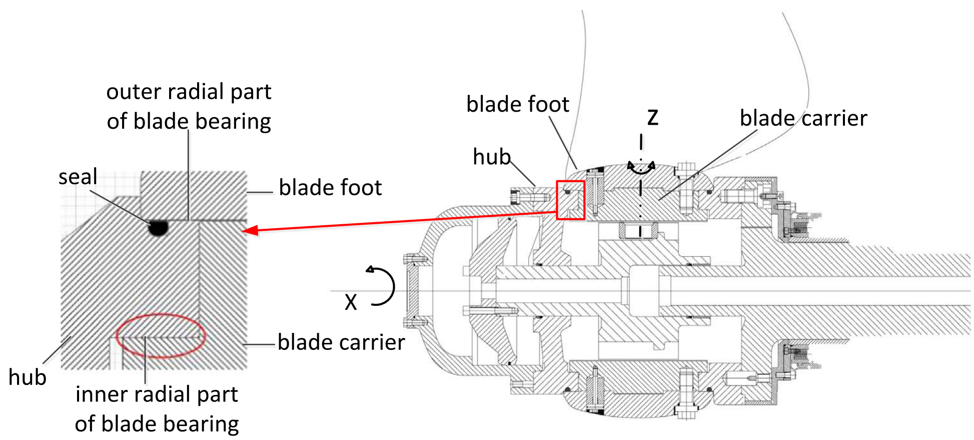

Fig. 2. Assembly of a controllable pitch propeller.

and fretting wear exist on the blade bearing, investigation carried out by M. Godjevac et.al [1,16] reveals that the total fretting displacement is about five times the total sliding displacement during a voyage, so fretting is the main reason for the wear failure of the blade bearing.

Fretting wear happens typically on the inner radial part of the blade bearing where the load is higher. Due to the restriction of the test apparatus, M. Godjevac et al. just investigated the fretting wear behavior of the interface under point contact and line contact with a tangential fretting wear test rig. However, the researchers themselves deem the research inadequate as both the fretting mode and contact configuration of the tests deviated from the actual situation. So it's necessary to do further investigation about the fretting behavior of the blade bearing.

2.1. Test materials

In this study, the inner radial contact interface of the blade bearing was chosen as the research object, so CuNiAl used for the hub and 42CrMo4 used for the blade carrier were selected as the materials for this study. Chemical compositions and other related physical and mechanical properties are shown in Tables 1–3.

2.2. Design of specimens

The investigated interface can be simplified as a full annulus, and the fretting situation can be simulated by applying a load on the reciprocating relative torsional motion specimens [15,17,19], as shown in Fig. 3(a). While in this study, the contact interface was designed into partial annulus contact with two raised 45° sectors (Fig. 3(b) and (c)), which can be advantageous [18,19]. Firstly, with the same loading system, reducing the contact area allows testing over a larger range of pressures. Secondly, reducing the contact area helps to mitigate influence of initial surface roughness and flatness on the test result. Thirdly, the wear rate is low in fretting tests, during the same test duration, reducing the contact area

Table 1
Composition of CuNiAl (wt %).

Al	Si	Mn	Fe	Ni	Cu	Zn	Sn	Pb
9.0–9.5	≤ 0.1	0.8–1.3	4.5–5.1	4.2–4.8	78.5–80.5	1.5–3.5	≤ 0.1	≤ 0.03

Table 2
Composition of 42CrMo4 (wt %).

C	Si	Mn	P	S	Cr	Mo
0.38–0.45	≤ 0.40	0.60–0.90	0.035	≤ 0.035	0.90–1.20	0.15–0.30

Table 3
Mechanical properties for the friction pair.

Material	Yield strength σ_s(MPa)	Tensile strength σ_b (MPa)	Elasticity modulus *E* (MPa)	Poisson's ratio υ	Hardness (HB)
CuNiAl	250	650	121000	0.33	127
42CrMo4	550	800	212000	0.3	220

facilitates the increment of the wear scar depth, and so wear volume can be measured more accurately. To minimize the influence of initial surface roughness, the initial contact surfaces of the specimens were polished to a roughness of 0.05 μm (R_a).

2.3. Fretting wear device and test conditions

The torsional fretting wear test rig is schematically shown in Fig. 4. The lower holder was driven by a closed-loop control high precise stepping motor (resolution of rotational angle, 0.018°). The angular displacement amplitude of the fretting test (setting range, 0.1° to 2°) was controlled by the impulse number in a fretting cycle; the frequency of the fretting test (setting range, 1 Hz to