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# Torsional fretting and torsional sliding wear behaviors of CuNiAl against 42CrMo4 under dry condition

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ABSTRACT

Many wear failures are caused by a combination of fretting wear and sliding wear. In this study, the torsional fretting and torsional sliding wear properties of CuNiAl against 42CrMo4 were comparatively investigated under dry condition using a flat on flat contact tester. Experimental results showed that the sliding friction coefficients declined more dramatically than the fretting friction coefficients when the normal load increased. The fretting wear rate was lower than the sliding wear rate, which was partly due to the solid lubrication effect of the wear debris and strain hardening of the worn surfaces. The dominant wear mechanisms for the fretting tests were oxidation, cracks and delamination, while for the sliding tests were abrasion combined with plastic deformation.

## 1. Introduction

Torsional wear can be defined as wear under rotational motion of a pair under a normal load. It is widely occurred in the human hip joint, knee joint, slewing ring bearing used in engineering machine, center plate of a bogie, and other reciprocating rotation parts of conveyances [1,2]. Depending on whether the motion amplitude is in micrometer or millimeter scale, it can be classified into torsional fretting wear and torsional sliding wear.

In many engineering applications, the wear failures are caused not just by torsional fretting or torsional sliding but by a combination of them. For example, Fig. 1 shows the cross-section of a controllable pitch propeller (CPP), in which the blade carrier, the blade foot together with the hub form a blade bearing. Godjevac et al. [3,4] reveal that both torsional fretting and torsional sliding wear can happen on the inner radial part of the blade bearing. The fretting wear happens when the pitch is fixed, but due to the fluctuation of wake flow field and rotation of the CPP a maximum 500 μm fretting motion can happen within the clearances of the bearings. The sliding wear happens when the pitch is adjusted under the push of a hydraulic system. Similarly, in the artificial hip joints and the bogie in a railway carriage, etc., the wear failures are also caused by a combination of torsional fretting and torsional sliding wear [5–7].

Investigations on torsional fretting and torsional sliding have been reported by many researchers. Quan H et al. [8] evaluated the torsional fretting wear proprieties of three porous bio-coatings modified with anodic oxidation, acid–base treatment, and alkali–heat treatment. Zhang X et al. [9] proposed an efficient numerical model for predicting the torsional fretting wear, which considers the evolution of surface profile variables with the number of fretting cycles. Xu Z B et al. [10] studied the effects of torque and contact pressure on torsional fretting behavior of 316 L austenitic stainless steel in a cylinder-on-cylinder contact configuration. Wang S et al. [11,12] studied the torsional wear behavior of monomer cast nylon (MC nylon) composites reinforced with glass fiber with a self-made torsional friction tester. Chen K et al. [13] investigated the torsional friction contact state and the transformation mechanism of PVA/HA composite hydrogel against CoCrMo femoral head, besides, the effect of load as well as torsional angle on torsional friction behavior was also studied.

However, the above literature review indicates that the torsional fretting and torsional sliding are generally investigated separately rather than comparatively. Besides, the studies are usually carried out under ball on flat contact and rather than under flat on flat contact. The torsional test contact configurations can be basically divided into ball on flat contact, ball on concave contact and flat on flat contact, as shown in Fig. 2. The contact configuration has a great influence on the wear behavior, as the contact stress, contact stiffness, debris behavior are distinctly different under various contact configurations [14]. To better understand the wear mechanisms of the blade bearing, etc., it is necessary to study the torsional fretting and torsional sliding comparatively, and under flat on flat contact rather than commonly used ball on flat contact.

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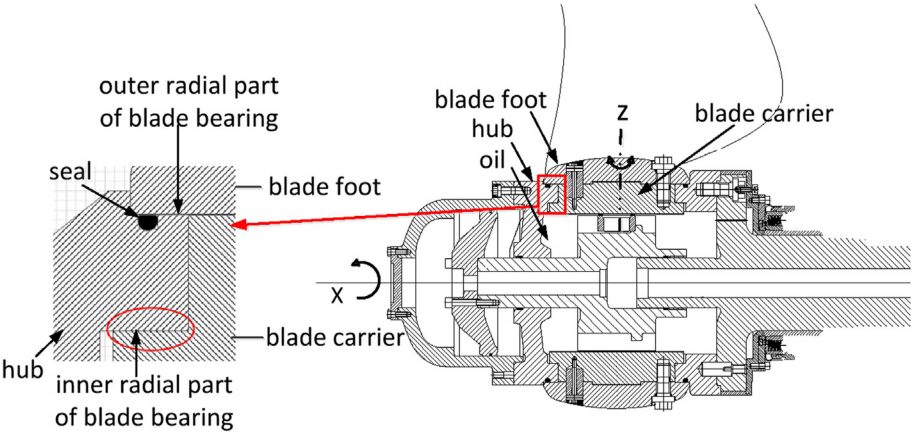

**Fig. 1.** Assembly of a controllable pitch propeller.

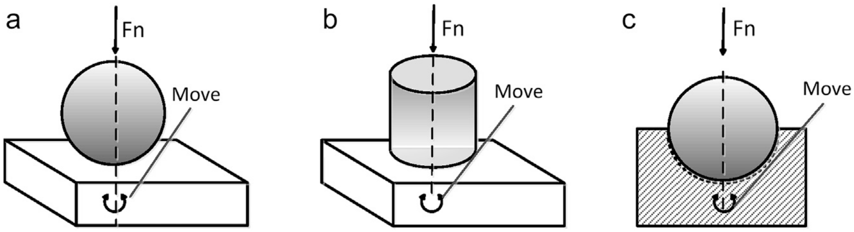

**Fig. 2.** Torsional fretting wear under different contact configurations: (a) Ball on flat contact; (b) Flat on flat contact; (c) Ball on concave contact.

**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 |

In this study, the inner radial part of the blade bearing was taken as the research object. The torsional fretting and torsional sliding wear behaviors were comparatively investigated. The tests were carried under dry condition and with a flat on flat contact test rig. Friction behaviors and wear mechanisms were discussed in detail. This investigation can provide some valuable information to understand the wear mechanisms of the blade bearing, and deepen our insight into the torsional wear.

## 2. Experimental details

### 2.1. Materials

In the blade bearing, CuNiAl and 42CrMo4 are the common materials used for the hub and blade carrier respectively [3,4]. In this study, CuNiAl was chosen as the material for the lower specimens, and 42CrMo4 was chosen as the material for the upper specimens. Chemical composition of the tested materials are listed in Tables 1 and 2. Their physical and mechanical properties are shown in Table 3.

### 2.2. Torsional fretting and torsional sliding tests

The fretting and sliding tests were evaluated on a flat on flat contact torsional wear test rig, which has been described in detail in previous research papers [15,16]. Basically, a closed-loop control step motor (resolution of rotational angle, 0.018°) was used to drive the relative movement between the upper and lower specimens. To ensure that the contact remains flat and the normal load is evenly distributed, the upper holder was designed to be self-aligned, similar with what B.D. Leonard did [17]. By varying the torsional angle of the step motor, both torsional fretting and torsional sliding tests could be carried out on it. A torque sensor (testing range: -2~2Nm, measurement error: less than 0.01Nm) was used to measure the friction torque. Contact between the specimens was designed into a partial ring rather than a full ring, as shown in Fig. 3. The purpose was to reduce the contact area and increase the wear depth so the wear volume could be measured more accurately.

The angular displacement amplitudes for the fretting and sliding tests were set at 1.5° and 22.5°, respectively, and the corresponding linear displacement amplitudes were 261 μm and 3.925 mm. The number of cycles for per fretting test was set at 60000 and for per sliding test was set at 4000. The total relative angular displacement during each fretting and sliding test was the same of 360000°. The normal loads were selected according to the practical operating condition of the blade bearing and they were set at 43 N, 86 N and 106 N [18]. Sliding speed has been proved to be influential in the sliding wear behavior [19], but its influence on the

**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 $\sigma_s$ (MPa) | Tensile strength$\sigma_b$ (MPa) | Elasticity modulus $E$ (MPa) | Poisson's ratio $\upsilon$ | Hardness(HB) |
|---|---|---|---|---|---|
| CuNiAl | 250 | 650 | 121,000 | 0.33 | 127 |
| 42CrMo4 | 550 | 800 | 212,000 | 0.3 | 220 |