



Modification methodology of fretting wear in involute spline



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ABSTRACT

This paper develops a method on predicting the fretting wear of spline couplings, which includes coefficient measurement, mechanism analysis, method development and model prediction. The friction and wear coefficients of spline material were measured by a programmable commercially-made friction tester. The wear mechanism of spline couplings was discussed. The contact stress and slide distance of spline couplings was investigated via finite element method. The fretting wear was calculated using modified Archard's equations which integrated the adhesive wear, abrasive wear and oxidation wear. Results showed that the friction coefficient decreased whereas the wear coefficient increased with the increasing normal load from 160 to 900 N. The contact stress showed an increase with the increasing torque, decreased firstly before an increase when the contact region moved from the tooth top to root. Following an increase, the slide distance started decrease along the axial direction of spline tooth. The variation of fretting wear was similar to the contact stress. Relatively low wear was obtained at the tooth middle. These confirmed that the contact stress was vital for the fretting wear. The calculated fretting wear agreed well with the actual value, indicating that the modified model had high accuracy on predicting the fretting wear.

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1. Introduction

With a high specific capacity of transferring torque and an excellent ability of enduring misalignment and movement, involute spline couplings are favorite candidates employed in mechanical transmission systems of aero-engines. The involute spline couplings have to experience very complex loading modes, typically of small amplitudes, including torque, axial load transmission, and rotating bending moments during the take-off, landing and other maneuvers of airplanes. Under these complex loadings, the failure of spline couplings by fretting wear damage becomes a critical case, which has promoted serious concerns on the stability and safety of aero-engines [1,2]. Consequently, many studies have been contributed to predict the fretting wear and design the geometry of spline couplings [3,4].

The fretting wear of involute spline couplings is heavily affected by two parameters of contact stress and relative slide, and the contact stress is considered as a dominant factor. It has been revealed by several studies focusing on the load distribution of spline couplings, and a conclusion is achieved that the contact stress sharply increases along the axial direction [5–8]. Based on the load distribution, a modification method is employed by several researchers to optimize the profile of spline teeth. The

uniformity of contact stress increases and the failure probability of spline couplings caused by fretting wear decrease after this modification [9–11]. Among the works on the modeling and simulation of fretting wear, McColl has simulated both the fretting wear and the evolution of fretting variables subjected to wear cycles in a cylinder-on-flat fretting configuration. In this work, the finite element method and modified version of Archard's equation were presented [12]. Leen has studied the three-dimensional frictional contact in a helical splined coupling to assess the macroscopic fretting variables. Moreover, the profile of spline teeth is modified to reduce the axial contact stress with a consideration of the effect of friction coefficient [13]. Ratsimba has introduced a methodology for predicting the fretting wear, where the validation is based on the results obtained from a reduced scale aero-engine spline coupling subjected to complex cyclic load cases. A modified Archard equation is also used to calculate the wear depth according to the distribution of contact stress and relative slide [14]. Madge has studied the effect of fretting wear on the fatigue life of involute spline using an approach based finite element method [15]. Despite an increase of the understanding on the general fundamentals of fretting wear phenomenon, few works have been focused on the specific topic of predicting the fretting wear of aero-engine spline couplings based on the wear mechanism. Moreover, the wear mechanism is considered as only one type of the adhesive wear. The friction coefficient and wear coefficient currently used in calculating the fretting wear come from empirical or referenced sources. So, significant disagreements are

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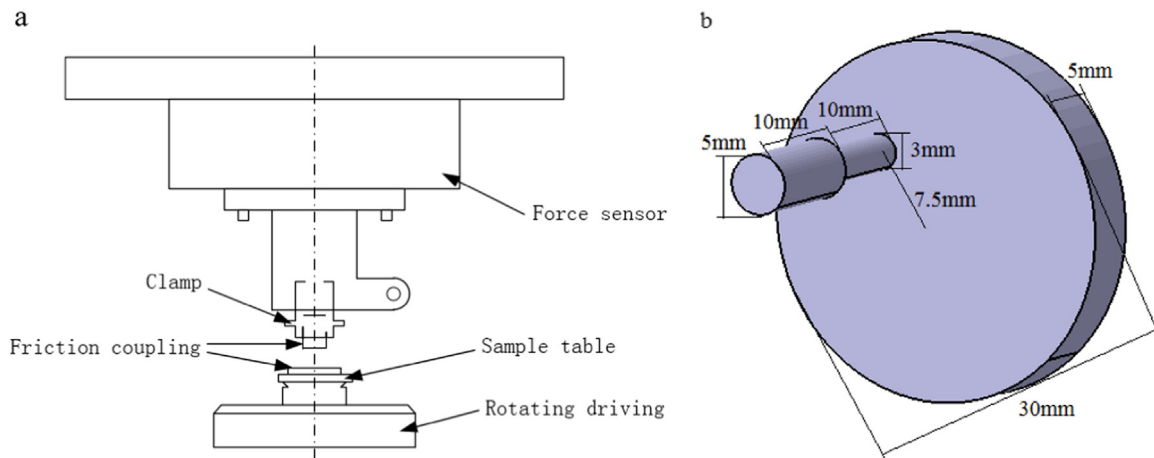


Fig. 1. Schematic of friction tester and cylinder-on-plate configuration: (a) friction tester and (b) cylinder-on-plate specimen.

Table 1

Chemical composition of alloy steel 18CrNi4A (wt%).

C	Mn	Si	Ni	Cr	S	P	Al	Fe
0.17	0.47	0.15	3.93	0.90	0.005	0.009	0.055	Remainder

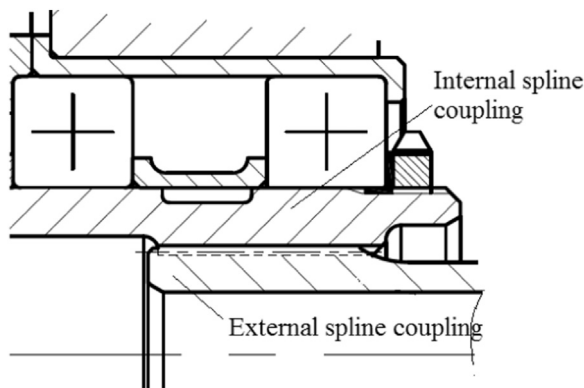


Fig. 2. Schematic of involute spline couplings assembled in aero-engine main reducer.

often produced between the prediction and actual results of fretting wear. It is thus important for carrying out relevant detailed studies to address the specifications.

The current work presents an investigation on some major

aspects affecting the prediction accuracy of fretting wear of aero-engine spline couplings. The friction and wear coefficients of the material used in aero-engine spline couplings were measured, which sets a basis for obtaining the relatively accurate results of fretting wear. The wear mechanism of aero-engine spline couplings was studied to provide an increased understanding on this phenomenon. The distribution of the contact stress and slide distance was calculated using finite element method. Furthermore, a modified model was developed to calculate the fretting wear based on the wear mechanism of aero-engine spline couplings. These studies are extremely significant to improve the reliability and lifetime of spline couplings and provide a basis for further study of fretting fatigue.

2. Experimental

The friction and wear tests were set up with a cylinder-on-plate configuration and performed in a UMT-2 multifunctional friction tester. The schematic of friction tester and cylinder-on-plate specimen was shown in Fig. 1. Alloy steel 18CrNi4A was chosen as the investigated target since it was employed in aero-engine spline couplings. The chemical composition of this alloy steel was listed in Table 1. The cylindrical specimen located at clamping was 5mm in diameter and at working part 3mm in diameter. The dimension of plate specimen was $\Phi 30 \text{ mm} \times 5 \text{ mm}$. The specimens were carburized before friction testing to enhance the surface hardness. The cylinder was fixed on the upper holder of the tester; the plate

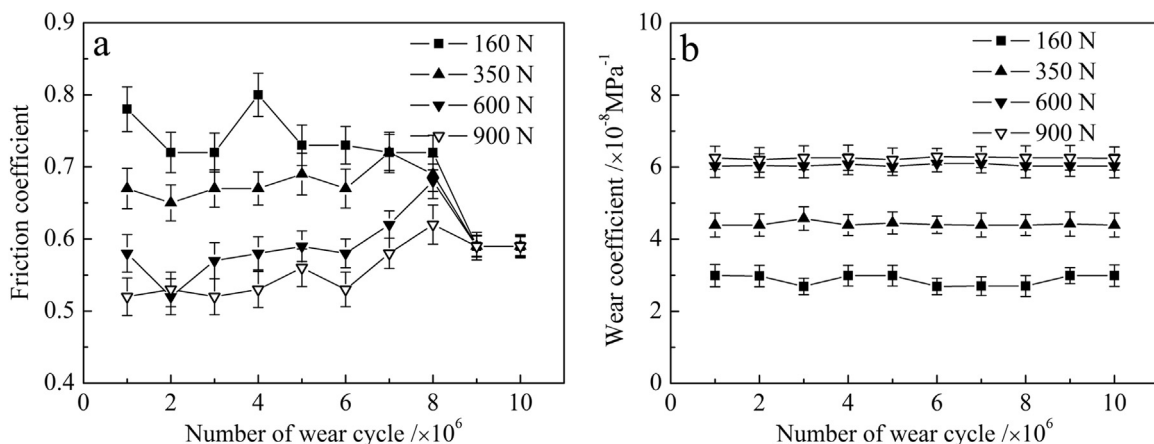


Fig. 3. Friction properties of the spline material: (a) friction coefficient and (b) wear coefficient.

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