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Fretting fatigue behavior of steel wires contact interface under different crossing angles

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ABSTRACT

Fretting fatigue tests on steel wires were conducted on self-made fretting fatigue test equipment. Fretting fatigue behavior and the influence of crossing angles on this behavior are studied by analyzing the F_t-D-N curve. The results show that contact load increases as total wear volume and the friction coefficient of steel wire decrease with the crossing angle of 18° in the mixed and partial slip regimes. In the slip regime, both variables increase. When the strain ratios decrease, fretting amplitude increases and the fretting regime shifts from the partial slip one to the mixed and slip regimes, the total wear volume, friction coefficient, and friction surface area of the loaded steel wire all increase, whereas the contact load in the fretting area of this wire decreases. Lower contact load, total wear volume and friction coefficient and longer fretting fatigue life were induced by the crossing angle of 18° than when this angle is 90°. Few wear particles and furrows are observed in the three fretting regimes of the wearing surface. The main wear mechanisms are adhesive and fatigue wear. However, more obvious wear particles and furrows can be observed with the crossing angle of 90°.

1. Introduction

Fretting is a low-amplitude oscillatory movement between two approximate tight-fitting contact surfaces under a vibrating environment. Fatigue cracks are formed in the fretting region under alternate loads that the fretting fatigue of the component is occurred much less than material fatigue limit [1]. The steel rope is subjected to an axial alternate load and bending load when it used (it runs over a sheave), which generates fretting wear among wires and strands [2,3]. Thus, the fretting fatigue of the steel rope affects the performance of the equipment as well as safe mine production. Fretting fatigue can accelerate crack initiation and extension on the contact surface of a fretting component, thereby reducing fatigue life significantly and generating disastrous results. Thus, the steel wire fretting problem in steel ropes must be investigated to increase the lifespan and reliability of steel ropes.

Many researchers [4–10] have conducted many studies on fretting fatigue behavior. Ding [11,12] proposes two factors, namely, fretting conditions and the material surface damage after fretting, to describe the fretting fatigue behavior of the materials. This scholar also points out that the possibility of microcrack production is less in the total sliding state than in the partial sliding state. Neslen et al. [13] analyzed surface morphologies to evaluate the level of fretting damage and determined that the fretting fatigue parameter increases with cycles. The cracks produced through fretting that were larger than 200 μm were effectively monitored with thermal imaging technology. Naidu et al. [14] suggested that the contact fatigue life of Al–Mg–Si alloys decreases when contact load is in the range of 100–150 MPa.

With respect to the fretting fatigue of cable components, Zhou et al. [15–17] examined the fretting wear of electrical cables. They determined that plastic deformation and the initiation of wear and cracks are the main causes of cable fatigue. The four fretting maps of fatigue are expounded on in detail in this paper. Zhang et al. [18,19] studied the influence of factors such as fretting amplitude, contact load, and strain ratio on fretting wear and fatigue of steel wires. Cruzado et al. [20,21] examined the effect of different contact pressure on the fretting fatigue of steel wire; these researchers concluded that wear coefficient increases with normal load and stroke for the same sliding distance. They also studied the influence of crossing angles on fretting; as the crossing angle decreases, the contact pressure decreases as well, which caused the less wear and longer life.

Many factors influence the fretting fatigue behavior of steel wire; however, the number of studies on the fretting fatigue behavior of steel wire has declined recently. Moreover, existing works mainly focus on the vertical contact between steel wires. In the present research, a fretting fatigue experiment is conducted with steel wire at crossing angles of 18° and 90° to determine the influence of such angles on the fretting fatigue behavior of steel wire.

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Table 1
Chemical composition of wire specimens (wt/%).

Composition	Fe	Mn	Si	Ni	C	S	P
Percentage	94.62	4.53	0.02	0.01	0.84	0.001	< 0.001

Table 2
Mechanical properties of wire specimens.

Material	Tensile strength (MPa)	Yield strength (MPa)	Modulus of elasticity (MPa)	Percentage elongation (%)
Steel wire in hoisting rope	1600	640	2.03×10^5	1.9

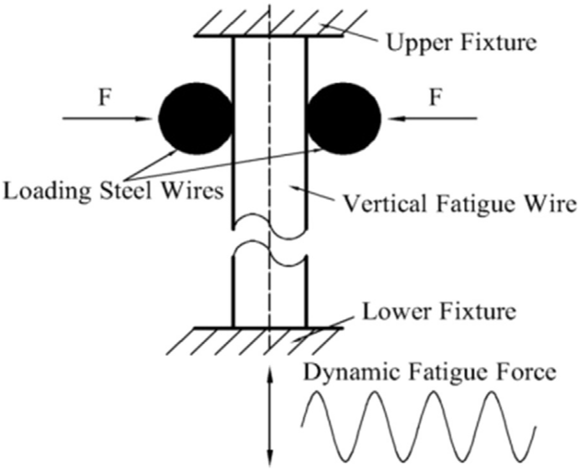


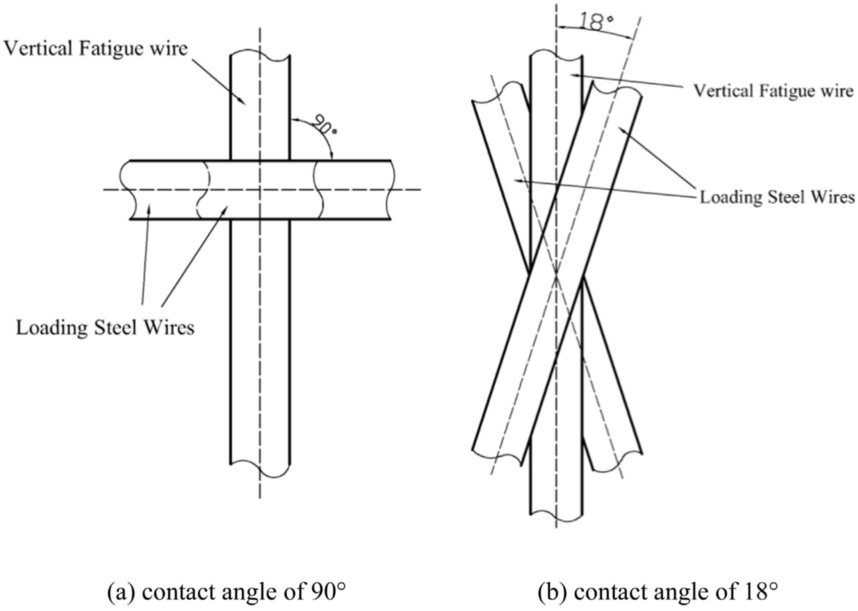
Fig. 1. Schematic diagram of fretting fatigue principle.

2. Experimental method

The cold drawing high quality carbon structural steel wires are taken as the research sample. Its chemical composition and mechanical properties are shown in Tables 1 and 2, respectively. The self-made device for the fretting fatigue experiment is installed on a computer-controlled electro-hydraulic servo fatigue test machine to facilitate the tension-tension process in the experiment. Fig. 1 illustrates the material composition diagram of the steel wire. The diameter and the tensile length of the steel wire sample are 1 mm and 386 mm, respectively. A vertical tensile steel wire is fixed on the fatigue experiment device, and a specific strain value is prefabricated. The steel wires, which facilitate contact load, are fixed on two fretting sliders that are positioned on both sides of the vertically fatigued steel wire. The loaded steel wire and vertical tensile steel wire form contact angles of 90° and 18°, as is shown in Fig. 2. The reciprocating movement of the fatigue experiment machine piston generates alternate strain in the vertical tensile steel wire. Accordingly, fretting occurs on the contact surface between the steel wires during the uploading process until fractures are initiated in the vertical tensile steel wire. After fixing the uploading steel wire, fretting amplitude is adjusted based on slider height, it is adjusted by the maximum strain and strain ratio of the vertical tensile steel wire. The experiment parameters, which are presented in Tables 3 and 4, indicate that the fretting amplitude across steel wires increases when the strain ratio decreases. The dynamic signal analyzer records the friction force signal from the tension and compression sensor and the displacement signal. The 3D curve of the running characteristic of fretting is drawn based on the characteristics of the fretting region and of dissipation energy, which is determined according to the friction (F_t)-displacement amplitude (D)-cycle (N). An optical microscope is utilized to measure the length and width of the wear notch; thus, maximum wear depth, total wear volume (wear volume of the vertical fatigue wire and two loading steel wires), and wear coefficient can be calculated [19]. The morphologies of the fatigue fracture and fretting wear are observed through an S-3000 scanning electron microscope (The morphologies of the wear scars are studied in the vertical fatigue wire.); these observations can explain the fracture and the wear mechanism.

Table 3
Parameter of fretting fatigue of steel wire under contact angle of 18°.

Maximum axial strain (ε_{max}/%)	Cyclic frequency (f/Hz)	Strain ratio (r)	Contact load (F_n/N)
1.4	5	0.90, 0.85, 0.825, 0.80	40, 50, 60, 70



(a) contact angle of 90° (b) contact angle of 18°

Fig. 2. Contact models of steel wires.