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Fretting wear of steel wires in hoisting ropes

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Abstract: To investigate the fretting wear of steel wires in hoisting ropes, specimens were made of 6 × 19 point contact ropes. A model for the fretting wear was developed and a fretting wear test rig was designed in laboratory. A series of experiments were performed on this test rig. The wear volume was taken as a characteristic parameter to describe the fretting wear in relation to the contact load, reciprocating cycles and amplitude. Moreover, the wear mechanisms were discussed in the fretting process.

Key words: fretting wear; steel wires; test rig; morphology

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Steel ropes play an important role in many applications because of their good flexibility and ability to transfer load. A hoisting steel rope is an important part of winding equipment in coalmines, whose function is to link winding vessels to driving drums. The intensity and fatigue life of hoisting ropes will take great effect on the reliability level of winders and directly affect the safe operation of winders. Investigations revealed that the reduction in total metal cross-section area resulted from broken wires were one of the main reasons for replacement of hoisting ropes.

For hoisting steel ropes operate in extreme non-repairable conditions and lubricant grease inside the ropes is gradually extruded and runs off, the major difficulty is keeping good lubrication of the interior wires. Therefore, wires in the ropes are put into contact in the dry friction condition and exposed to wear. Structurally, the hoisting ropes are twisted tightly between strands and strands, wires and wires [1]. The greatest stress in the ropes is hertzian and occurs at the point of contact between wires. Small amplitude sliding occurs among strands and wires when the ropes bear axial tension load and bending stretch load on drums and guide wheels, which is fretting.

Fretting is surface damage induced by small amplitude oscillatory displacements between metal components in contact. Fretting wear and fretting fatigue have been identified as a major cause for the wire failure of steel ropes under tensile load, because it reduces the cross-section area of wires and provides initial sites for fatigue [2-4]. In this point of view, reducing the fretting damage of steel wires will be an effective method prolonging the service life of the hoisting rope.

Some researches have been carried out. Waterhouse's studies [5-7] stated that contact load influenced fretting wear and fretting damage in the surface layer nearest to the outer surface of ropes was caused by contact stress. Fretting wear, residual stress and bending stress in the ropes promoted the early initiation of fatigue cracks and caused the fracture of single wires, and lubrication in the fretting zone could obtain a low friction coefficient and reduce fretting wear. Guo [8] studied the wear resistance mechanism of high polymer materials and the measures to prevent fretting damage and to decrease wear on the steel wires. But it is still needed a further study on the mechanisms of fretting wear of steel wires. This paper focuses on the effect of fretting conditions on the wear amount of steel wires, particularly, on the change of wear mechanisms during fretting process.

1 Experimental

Relative displacement between the specimens is the most important parameter characterizing the type and severity of the fretting process. Its amplitude is a major factor to be controlled in most of the fretting experiments [9].

In order to carry out the satisfied experiment of fretting of steel wires, a model for the fretting wear of

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hoisting ropes was simplified and a fretting test rig for the steel wires was developed on the principle of elastic bending and proportion enlargement of an elastic beam [10], which could attain a stable displacement. Two wire specimens were aligned in an angle of 90° to each other.

The specimens of steel wires of 1 mm in diameter were made of 6 × 19 point contact ropes. Their chemical composition is as follows: Mn 0.39%, Si 0.02%, Ni 0.01%, C 0.87%, S < 0.001%, and P < 0.001% in mass fraction, and the experimental conditions are given in **table 1**.

Table 1 Experimental fretting conditions

Amplitude / μm	59, 102.5, 127.5, 145
Contact load / N	10-40
Frequency / Hz	8.3
Reciprocating cycles	8.0×10^4-2.0×10^5
Temperature	Room temperature

2 Results

The wear volume was taken as a parameter to describe the fretting wear of steel wires. Because the wear scar was generally very small, SEM photographs of the wear scar were used to measure the length and width of the scar and to calculate the wear volume. In order to investigate the relation of the fretting wear of steel wire specimens with the contact load, reciprocating cycles and sliding amplitude, a series of tests were carried out on the self-made fretting rig, and the results are shown in **figures 1-3**.

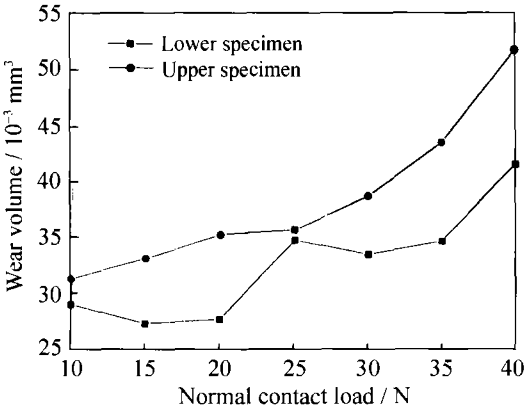

Figure 1 Relationship of the wear volume with the contact load under an amplitude of 102.5 μm after 1.5 × 10^5 cycles.

The curves in figure 1 indicate that the wear volume of upper and lower wire specimens increases in a non-linear relation to the contact load. For smaller contact loads, the wear volume grows slowly with the increasing load. When the contact load is over 30 N, the wear volume exhibits an evident increase. Such a non-linear relation was caused by the difference in contact stress for varying load, which lead to the change in wear rate and the generation of wear debris in different size.

The regression relations between the wear volume of upper and lower wire specimens and the reciprocating cycles can be respectively obtained as

$$V_U = 20.344 + 1.442n \tag{1}$$

$$V_L = 15.52 + 0.948n \tag{2}$$

where V is the wear volume of steel wires, in the unit of 10^{-3} mm^3, n is the reciprocating cycles, in the unit of 10^4 cycles.

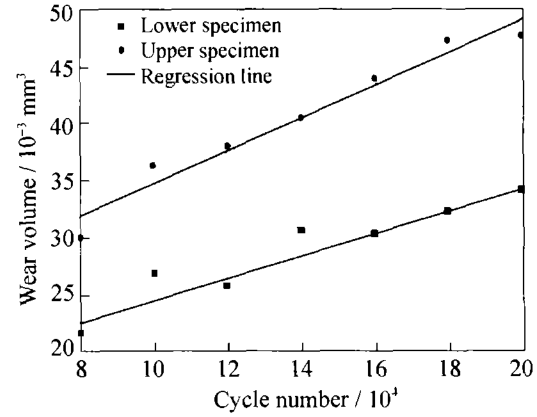

Figure 2 Relationship of the wear volume with the reciprocating cycles under a contact load of 30 N and an amplitude of 102.5 μm.

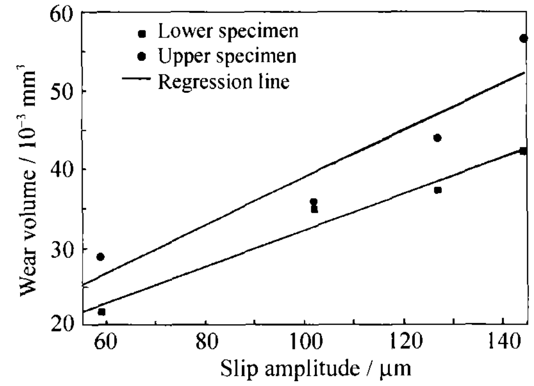

Figure 3 Relationship of the wear volume with the amplitude under an contact load of 25 N after 1.5 × 10^5 cycles.

The regression relations of the wear volume of upper and lower wire specimens with the amplitude can be respectively obtained as

$$V_U = 9.035 + 0.296A \tag{3}$$

$$V_L = 9.582 + 0.224A \tag{4}$$

where A is the oscillating amplitude, in the unit of μm.

The regression results showed that the wear volume of wires nearly appeared a linear relation to the reciprocating cycles and amplitude, as shown in figures 2 and 3. Because the fretting wear is a surface rubbing lost accumulated by sliding distance, the phenomena in figures 2 and 3 can be explained by Archard's model for sliding wear. The changes in reciprocating cycles and amplitude will produce an equivalent influence on the fretting wear of steel wires to the change of sliding distance between fretting surfaces. Increase in cycles or amplitude will obtain a result of accumulating abrasion between the fretting area on steel wires.

3 Morphology analysis

By using a scanning electronic microscope, some photos of the typical wear trace in the fretting zone were obtained. It was found that the fretting wear of steel wires exhibited different wear mechanisms for the change of test conditions, which included adhesive wear, abrasive wear, oxidation wear and fatigue wear.

The wear mechanism of fretting wires changed with the increase of contact load. When the contact load was light, the elastic contact between asperities was produced. In this condition, fine wear debris was produced and was easier to be removed out from the fretting zone. The rubbing mechanism controlled the wear between the fretting surfaces. When the contact load increased, more debris was produced between the wear surfaces which ploughed some grooves on the base bodies. The main mechanism of wear changed to the abrasive wear, as shown in **figure 4**(a).

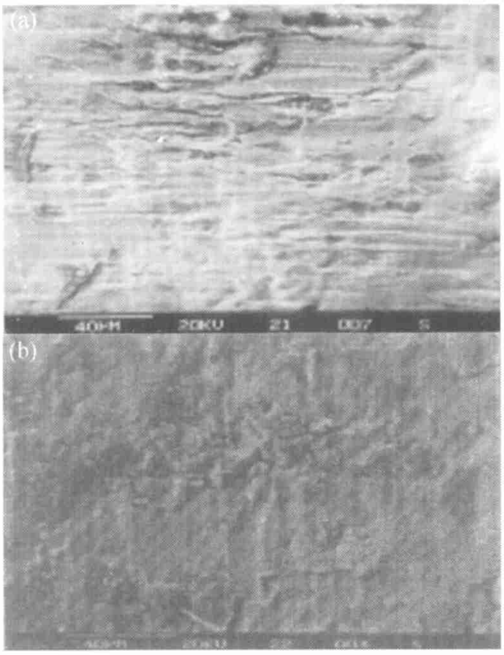

Figure 4 Morphologies of wear specimens under an amplitude of 102.5 μm after 1.5 x 10^5 cycles. The contact load is (a) 25 N and (b) 35 N, respectively.

When the load reached to a certain value, the contact stress increased which induce plastic deformation for most of asperities on the fretting zone. In this condition, fatigue damage was caused in the two surfaces and debris was removed out. A mass of particles were accumulated and studded on the surfaces, as shown in figure 4(b).

Reciprocating cycles played a role in the fretting wear of steel wires by contact fatigue stress. For lower reciprocating cycles, the fretting wear was in the initial phase. The wear surfaces produced a little debris and discharged debris easily from the wear surfaces. Therefore, the main wear mode at this stage was adhesive wear, as shown in **figure 5**(a).

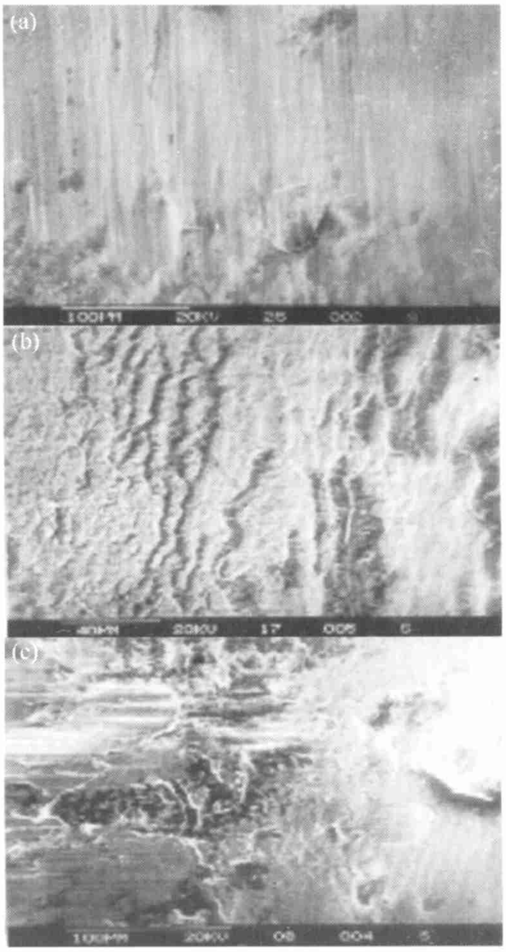

Figure 5 Morphologies of wear specimens under the condition of an amplitude of 102.5 μm and a contact load of 30 N. (a) after 8.0 x 10^4 cycles, (b) 1.8 x 10^5 cycles, and (c) 2.0 x 10^5 cycles, respectively.

As the reciprocating cycles increased, the amount of debris increased and the abrasive wear mode became dominant. When the cycles grew up to a certain value, the plastic deformation on the wear surfaces caused delamination wear or even contact fatigue wear, as shown in figure 5(b). When the reciprocating cycles reached 2.0 × 10^5, the fretting wear attained to the last period of fatigue wear and large flake debris and pits were produced. Figure 5(c) was a wear morphology under a contact load of 30 N after 2.0 × 10^5 cycles, from which it was concluded that the surfaces had already come to severe wear.

The influence of oscillation amplitude on fretting wear was mainly on the discharge of wear debris. When the oscillation amplitude was small, the overlap zone between the fretting surfaces increased. Under such condition, more opportunities of fatigue contact between the surfaces were provided as to increase the plastic deformation in fretting areas. The plastic deformation of ripple shapes in the wear surfaces was appeared in **figure 6**(a). These ripple shapes could be thought as a result of repeat contacting and plastic deformation between asperities. When the oscillation amplitude was comparatively large, the fretting wear was close to sliding wear and it was easier to remove wear debris from the fretting zone, and the main wear mode was adhesive wear, as shown in figure 6(b).

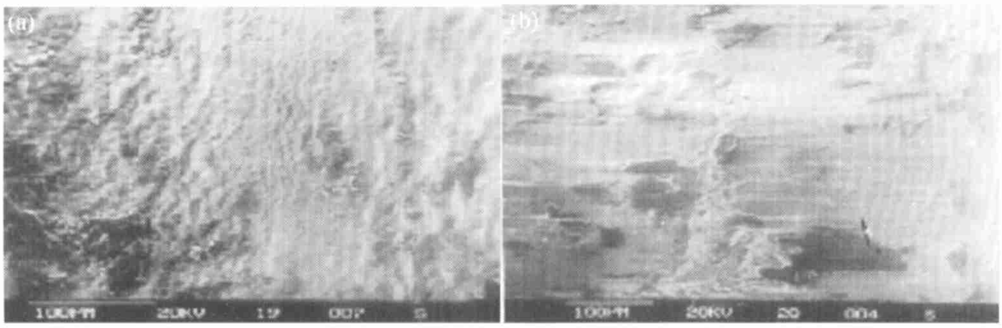

Figure 6 Morphologies of wear specimens under a contact load of 25 N after 1.5 × 10^5 cycles. The amplitude is (a) 59 μm and (b) 145 μm, respectively.

4 Conclusions

(1) The wear volume of upper and lower wire specimens increased in a non-linear relation to the contact load, but the wear volume of fretting wires was nearly proportional to the reciprocating cycles and amplitude.

(2) Different wear mechanisms were observed on fretting surfaces, which include adhesive wear, abrasive wear, oxidation wear and fatigue wear, *etc.* The changing rules of wear mechanisms with fretting wear conditions reflected the fretting states to some extent.

(3) The morphologies of wear surfaces changed with the increase of load, reciprocating cycles and amplitude. In general, adhesive wear appeared at the initial stages of wear or when the contact load was light or when the amplitude increased to a certain value. Abrasive wear was the main wear mode at the steady wear stages. When the load was larger than 35 N or the rubbing period was up to 2.0 × 10^5 cycles, fatigue delamination was produced in the fretting surfaces and severe wear was caused.

(4) Oxidation wear and abrasive wear appear in the whole fretting process, but their scales at different fretting stages are different.

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