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Experimental investigation of mechanical response and fracture failure behavior of wire rope with different given surface wear

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ABSTRACT

Wear is one of the primary factors for the degradation of the wire rope used for multi-layer winding hoist. It decreases the carrying capacity and service life of the hoisting rope, which will affect the mine safety directly. In this paper, the effects of the wear scars caused by sliding friction under different crossing angles and cross directions on the mechanical response of the wire rope were investigated through the breaking tensile test. Additionally, the fracture failure mechanism of the rope samples was discussed. Results show that the surface wear decreases the breaking force of the wire rope. The distribution of wear region and the maximum wear depth of the wear scar are the major influence factors on the mechanical properties of the rope. The variation range of the breaking force is larger for the rope with the wear scar under the sliding condition of right cross contact and the damage is more serious for that in the condition of left cross contact. There is obvious plastic deformation and temperature rise near the wear scar before the rope breaks. The fracture failure mechanism is ductile fracture with necking and dimples on the surface.

1. Introduction

With the increase of resource exploitation depths, multi-layer winding hoist, with its capacity to support a large hoisting load and height, has become the most suitable lifting equipment for ultra-deep coal mines in China [1,2]. The ability to withstand high axial loads coupled with high flexibility, compactness and high strength to weight ratio have determined the success of wire ropes as a critical component in the multi-layer winding hoisting system for coal mines [3], which play an important role in the reliability level and the hoisting capability of winder operations [4]. However, the wire ropes operate at high stress levels and are almost invariable subject to fluctuating loads under an ultra-deep coal mine (the load is more than 40 t, the height is more than 1700 m) [5,6], which will cause severe extrusion and relative sliding, then result in wear and the degradation of the wire rope among layers. Additionally, with the wire rope winds on and off drums in the process of hoisting, the external wear and plastic deformation, the primary degradation mechanism of wire ropes operating on mine hoisting drums [7], between adjacent ropes always occur periodically, which will affect its mechanical response, reduce the service life and ultimately lead to fracture failure. Moreover, due to the degradation of the rope's mechanical properties caused by the wear has not been understood, according to the coal mine safety rules in China [8], the number of winding layers of the wire rope on the drum must be one layer when lifting people in a vertical shaft and two layers when lifting materials alone. This seriously hinders the development of resource exploitation for an ultra-deep coal mine. Therefore, it is of great importance to investigate the wear characteristic and its effects on the mechanical response and failure behavior of winding hoist ropes, which can prolong the rope's service life and improve the operational reliability of the hoisting system.

As the wire rope is widely used, many scholars have carried out many research on the related characteristics of wire ropes in the past decades.

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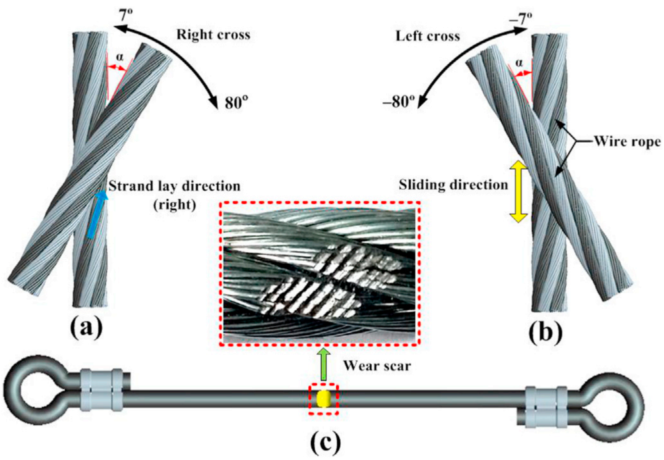

Fig. 1. 6 × 19 + FC wire rope sample (a): right cross contact for wear test; (b): left cross contact for wear test; (c): rope sample with given wear for breaking tensile test.

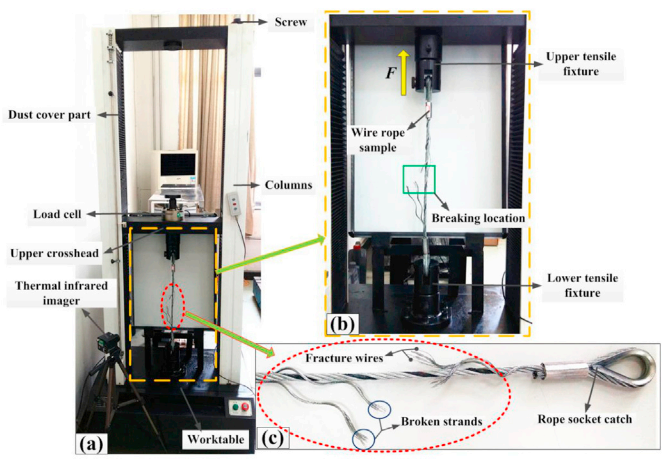

Fig. 2. Breaking tensile test apparatus.

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Table 1
Parameters of the tensile testing machine.

Parameter	Value
Maximum test force	100 KN
Maximum test stroke	1000 mm
Accuracy of force	1 N
Accuracy of displacement	0.001 mm
Acquisition frequency	1000 Hz

To investigate the tribological properties of ropes, McColl et al. [9] examined the influence of low viscosity oils, with and without graphite additions, on the fretting behavior of a high-strength eutectoid steel rope wire. The surface feature of the fretting scar was analyzed. Zhang et al. [10] carried out a series of experiments on the fretting wear and fatigue of steel wires, the wear depth and the fracture life under contact loads were studied after each fretting friction test. Additionally, as the effect of the contact pressure and crossing angle on the wear of the rope wires are very important, Cruzado et al. [11,12] designed many experiments and explored the influence of this two factors on the fretting wear behavior of thin steel wires for dry friction. Wang et al. [13–15] carried out a lot of fretting fatigue tests to investigate the failure mechanism of hoisting rope. He analyzed the wear mechanism of the fretting contact scars and fretting fatigue life under different displacement amplitude and strain

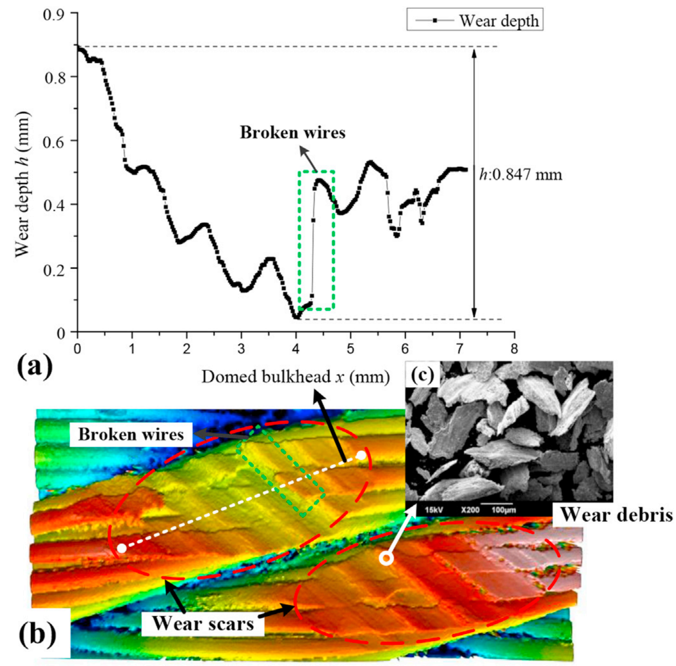

Fig. 3. Research parameters for the wear scar (a): profile curve; (b): three-dimensional contour map of the wear scar; (c): SEM Images of wear debris.

amplitude. Considering the complex hoisting conditions, the effect of different corrosive media on the fretting fatigue damages of mine rope wires were studied. Furthermore, Wang et al. [16] investigated the dynamic wear evolution and crack propagation of steel wires during fretting-fatigue. The wear scar and wear depth profiles were quantitatively analyzed. However, there are great differences of the wear characteristics between wires and ropes, to understand the wear of the rope more comprehensively, Oksanen et al. [17,18] studied the wear mechanisms between the roller and the wire rope through experiments. In our previous studies, a series of friction and wear tests were conducted using a self-made test rig and the tribological properties between winding hoisting ropes under different sliding conditions were analyzed [1,2,19]. As the wire rope is constructed of an assembly of steel wires, which are manufactured by the coal drawing process from high quality carbon structural steel, the studies of the relative materials are also significant. Velkavrh et al. [20,21] studied the influence of temperature on the friction and wear behavior of unlubricated steel/steel contact in different anaerobic gaseous atmospheres. The wear mechanisms under different conditions were analyzed, and they found that the beneficial effects of the anaerobic gaseous atmospheres on friction and wear compared with an air atmosphere were more pronounced at high temperatures than at ambient temperatures. Alemani et al. [22] investigated the tribological behavior of a commercial low-steel friction material dry sliding against a pearlitic cast iron disc using a Pin-on-Disc (PoD) testing rig, the friction layer properties on each surface and the characterization of the wear debris were analyzed and found that the lower contact pressure and temperature, that do not help the compaction of the debris to form the friction layer. Lemm et al. [23] investigated the role of the hardness of steel on its fretting wear behavior and the experiments point to the fact that debris retention in the contact (or removal from the contact) is a complex phenomenon, which is not simply controlled by specimen hardness. Verma et al. [24] presented a streamline characterization protocol for debris coming from wear tests on materials used for disc brake assemblies, different forms of wear debris were analyzed.

The degradation of wire rope will seriously affect its mechanical properties and safety use. To explain the structural features and mechanical response, Costello [25] and Feyrer [26] deeply analyzed the