Wear 368-369 (2016) 423–434

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Sliding friction and wear behavior of winding hoisting rope in ultra-deep coal mine under different conditions

Peng Yu-xing [a,b], Chang Xiang-dong [a,b,*], Zhu Zhen-cai [a,b], Wang Da-gang [a,b], Gong Xian-sheng [c], Zou Sheng-yong [d,e], Sun Shi-sheng [a,b], Xu Wen-xue [a,b]

[a] School of Mechanical and Electrical Engineering, China University of Mining and Technology, Xuzhou, Jiangsu Province 221116, China
[b] Jiangsu Key Laboratory of Mine Mechanical and Electrical Equipment, China University of Mining & Technology, Xuzhou, Jiangsu Province 221116, China
[c] College of Mechanical Engineering, Chongqing University, Chongqing 400044, China
[d] CITIC Heavy Industries Co. Ltd., Luoyang, Henan Province 471039, China
[e] Luoyang Mining Machinery Engineering Design Institute, Luoyang, Henan Province 471039, China

ARTICLE INFO

Article history:
Received 7 June 2016
Received in revised form
11 October 2016
Accepted 13 October 2016
Available online 15 October 2016

Keywords:
Wire rope
Winding hoist
Sliding friction
Temperature rise
Wear mechanism

ABSTRACT

Wear problems exist in multi-layer windings of ultra-deep coal mine hoisting ropes that are wound around drums. Wear decreases the life of such hoisting ropes directly, and that in turn threatens mine safety. An investigation of winding hoisting ropes was conducted using a custom test rig to study the effects of different contact loads, crossing angles and displacement amplitudes on rope friction and wear. Results show that the coefficient of friction (COF) in the steady-state period changes very little with an increase in contact load and that it stabilizes at about 0.61. Additionally, the COF slightly decreases with an increase of crossing angle. As the amplitude of sliding motion increases to 30 mm and 50 mm, the COF increases linearly. Using thermal imaging, the temperature rise in the steady-state period increases with the contact load and crossing angle. Moreover, the maximum wear depth increases linearly with an increase of contact load. Nevertheless, the wear depth changed very little when the amplitude is less than 30 mm, but it increases rapidly until an amplitude of 70 mm. The major wear mechanisms of ropes without lubrication include adhesive wear, abrasive wear and fatigue wear.

1. Introduction

With a shortage of global resources and energy, the demands of economic social development for mineral resources are rapidly rising. Exploring more deeply into the earth for mineral resources has become an important strategic choice for countries. Multi-layer winding hoist (Fig. 1), with its capacity to support a large hoisting load and height (the load is more than 40 t, the height is more than 1700 m), has become the best choice for ultra-deep coal mine hoisting in China. Wire rope is an important part of the multi-layer winding hoist, and the mechanical properties of this wire rope determine the safety of mine production. However, in the process of ultra-deep coal mine hoisting, vibration, great contact pressure and friction always exist among the layers, which will result in the relative slide friction of the hoisting rope between the internal layer and the outer layer. Furthermore, severe extrusion contact and relative sliding periodically occur in the same place between the adjacent wire ropes when it winds on the drum during the continuous hoisting process. Such contact and slide can cause wear, crack and fatigue fractures of wire ropes, then affect the safe use of wire rope and reduce its service life. Thus, according to the coal mine safety rules in China [1], 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, which is in contradiction with the necessity of multi-layer windings for an ultra-deep coal mine. Therefore, it is of great importance to investigate the sliding friction characteristics of winding hoisting rope to provide the important basic data for the design of a multi-layer winding hoist for an ultra-deep coal mine.

In recent years, many scholars have carried out research on the friction and wear of wire rope. Considering the damage resulting from the fretting of steel wires, McColl et al. [2] examined the fretting behavior of steel wires, the wear volume and the coefficient of friction were analyzed under different lubrication conditions. Zhang et al. [3,4] studied the fretting wear mechanism and fatigue properties of steel wires in hoisting rope through experiments in which the effects of the contact load on the wear of wires

* Corresponding author at: School of Mechanical and Electrical Engineering, China University of Mining and Technology, Xuzhou, Jiangsu Province 221116, China.

http://dx.doi.org/10.1016/j.wear.2016.10.012
0043-1648/

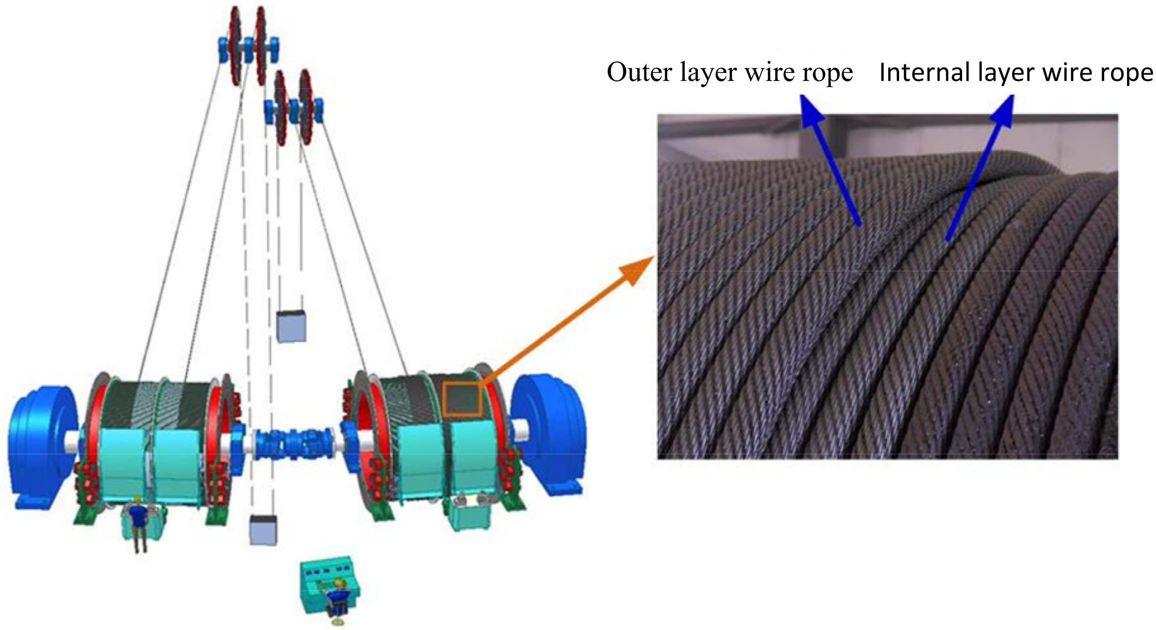

Fig. 1. Multi-layer winding hoist.

were analyzed. Wang et al. [5–7] investigated the fretting fatigue behavior between wires under different strain amplitudes. The terminal mass and displacement amplitude conditions as well as the fretting fatigue life were analyzed. Cruzado et al. [8,9] studied the influence of contact pressure and crossing angle on the fretting wear of thin steel wires under the condition of dry friction. The fretting characteristics and the variation of test parameters in different periods were revealed. Furthermore, to simulate the actual hoisting conditions, Zhao et al. [10] employed a self-made test machine to investigate the fretting fatigue of steel wires in alkaline corrosive media and reported the effect of the contact load. The coefficient of friction and the fatigue fracture surface at different stages and regions were analyzed. Xu et al. [11] investigated the effect of an acid medium on the fretting wear behavior and compared the results with the condition of dry friction. Wang et al. [12] selected different corrosive media (alkaline, neutral and acidic solutions) as the experimental conditions for quantitative analysis of the roles of anti-wear properties, dissipated energy and fretting fatigue lives. In addition, because the friction damage of wire rope is varied, Chaplin et al. [13] introduced different types of wire rope and failure mechanisms. Oksanen et al. [14,15] studied the sliding wear behavior between the roller and the wire rope. The wear mechanisms and the effect of contact pressure were analyzed through experiments. Peng et al. [16] explored the effect of the dynamic and the thermomechanical properties of friction lining on the coefficient of friction between the wire rope and the lining, found that the coefficient of friction increases linearly with the loss factor. Ma et al. [17] studied the effect of friction-promoting grease on the sliding friction and wear properties between the wire rope and the friction lining. The differences between dry-friction and the greased condition were compared, and they also found that the wear of the friction lining was aggravated with the increase in sliding speed and the contact load. Considering the material of the wires in the hoisting rope, the friction behavior between steel and steel was investigated. Hu et al. [18] analyzed the influence of underwater laser texturing on the friction characteristics of the stainless steel surface and proved that the laser surface texturing can reduce the friction and wear between steel contact surfaces. Tinubu et al. [19] investigated the effects of friction stir processing on the friction behavior of A-286 stainless steel. The microstructure and wear mechanisms were analyzed under different processing conditions. 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 coefficient of friction and 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. Hirsch et al. [22,23] investigated the changes in friction characteristics between two types of steel with the temperature increases from 20 °C to 250 °C and found that the stabilized coefficient of friction decreases with increasing temperature, and the resistance to fatigue damage is reduced at the high temperature. Moreover, many scholars have employed simulation technology to investigate the damage properties. Stanova et al. [24,25] created a mathematical geometric model of multi-layered strands in CATIA V5 software and implemented a finite element program through ABAQUS/Explicit software to predict the behavior of the wire rope under tensile loads. The results obtained through experiments and theory were compared. Cruzado et al. [26,27] developed a finite element fretting wear simulation model in which the wear scars were predicted accurately and the effects of fretting wear on the fatigue of wires were analyzed. Argatov et al. [28] developed a mathematical model of fretting wear based on the Archard-Kragelsky wear law, and the wear parameters between wires were analyzed. From the literature mentioned above, previous efforts focus mainly on fretting friction and fatigue behavior of steel wires, sliding friction characteristics between rope and friction lining, wear mechanisms in steel to steel contact and the theoretical simulation analysis of wire rope. However, the sliding friction properties of winding hoisting ropes between layers in an ultra-deep coal mine have not previously been reported.

Therefore, the objective of the present study is to explore sliding friction characteristics of winding hoisting rope in an ultra-deep coal mine. Many tests under different contact loads, crossing angles and sliding amplitudes have been carried out using a custom test rig. To understand the effect of sliding parameters on friction and wear, the coefficient of friction, friction temperature, wear scar sizes and wear mechanisms were analyzed. Those