Study on friction and wear behavior of braided wire rope for traction

Xiaoran Han¹, Jianbiao Zhang¹,², Hui Wang¹*, Weilin Gu¹ and Xiaoyang Li¹

¹School of Mechanical Engineering, University of Jinan, 250022, Jinan, China.
²Weifang branch of Hitachi Elevator (China) Co., Ltd, 261000, Weifang, China.
* Corresponding author. (e-mail: me_wangh@ujn.edu.cn).

Abstract. In this paper, the friction and wear properties of braided wire rope for cable traction engineering are studied. Through the observation of the wear morphology of the rope at different contact locations by VHX-5000, it is found that the rope between strands is in point contact state, which leads to stress concentration, so the wear is the most serious. The second is the "rope-wheel" contact rope, while the rope in the strand is only slightly worn. On this basis, by means of the analysis of scanning electron microscope (COXEMEM-30), it is revealed that the main wear types of braided wire rope in actual working conditions are adhesive wear and composite wear formed by fatigue wear and corrosion wear.

1. Introduction

As the main tool and instruments of power grid construction project, braided wire rope plays the vital role of traction cable to realize its tension erection. In the process of using braided wire rope as the traction wire of the traction rope, one end of the braided wire rope is used for traction and connected with the wire. Under the traction effect of the wire rope, the wire is led from the wire reel at the paying off end, and the other end of the wire rope is pulled by the traction machine to complete the erection of the wire between the towers. The construction site is shown in figure 1. (working condition). In the process of stringing, the braided wire rope bypasses the rope wheel by the friction force with the groove of the traction wheel, and is subjected to repeated tension, extrusion, bending, torsion and other loads, resulting in the wear of the wire rope and the fatigue fracture failure. The friction and wear of wire rope have a great influence on its performance. If it is not replaced in time, it may cause serious accidents and major property losses. Therefore, it is necessary to explore its friction and wear behavior, so as to lay a foundation for predicting the failure of wire rope.

Figure 1. Schematic diagram of tension wire construction work
At present, the research on the friction and wear of steel wire rope at home and abroad mainly focuses on the twisting wire rope. Wang et al. [1] studied the fretting corrosion behavior of steel wire rope for mine hoisting under different corrosive media. The three corrosive media accelerated the wear of steel wire in different degrees, changing the damage mechanism of steel wire. Singh et al. [2] studied two kinds of mining failure wire ropes, including parameter detection, wear morphology and lubrication state research, and concluded that the long and thin hard particles generated by corrosion moved along the crack, resulting in crack propagation. Peng et al. studied the friction and wear performance of mine hoisting wire rope by using a special test rig. The influence of different contact load, cross angle and displacement on the friction and wear of wire rope was studied [3]. Wang et al. [4] studied the dynamic wear evolution and crack growth behavior of steel wire during fretting fatigue. The wear trace and wear depth of steel wire were quantitatively analyzed by three-dimensional white light interferometer, and the theoretical model of the maximum wear depth and wear coefficient of parabolic wear trace was established. Wang et al. studied the mechanical behaviors of hoisting rope, who indicated the elliptical strand rope more suitable for coal mine hoisting by the finite element analyses [5]. In view of the fretting friction and wear of steel wire rope, Cruzado, a Spanish scholar, had studied the influence of contact load and cross angle between wires on the friction and wear performance of steel wire rope [6]. Pavel et al. [7] determined the cause of wire rope failure from the perspective of metallographic analysis. Despite the progress made in wire ropes research, no study has thus far been devoted to investigating the friction and wear behavior of braided wire rope. In the present study, due to the traction with braided wire ropes under tension stringing is too complex to study through experimental research and simulation of real hard reactions under actual conditions of loading state. Therefore, this study, through scrap wire braided rope collection, specimen preparation, and the macroscopic and microscopic morphology observation, analyzes the wear mechanisms to take targeted measures to reduce wear and prolong service life.

2. Working condition analysis
In the process of not passing through the traction wheel, the straight-line braided wire rope mainly bears the tensile load. At the same time, both ends of the braided wire rope are free, which leads to the mutual rotation between the strands of wire. After the braided wire rope is pulled through the traction wheel, the traction tension is effectively attenuated and the recovery wheel is wound at the outlet end. The traction machine is the only power equipment for the whole stringing operation. The core component of the equipment, the traction drum, uses the friction winding of the braided wire rope to realize the traction erection of the conductor. In the process of stringing, the "winding in - winding out" winding process of the hauling wire rope body of the hauling machine experiences three states of "straight line - transition - bending" in turn. During the hauling process, the rope body is subject to the combined action of pulling, bending, twisting, pressing and other forces, as shown in figure 2.
Under the action of axial load, because there is no mutual sliding between the contact points of steel wire, the influence of friction between the wires on its performance is usually small. While, for many steel wire ropes wound on the roller (or drum), due to the mutual sliding between the contact points of steel wire, the friction between the wires cannot be ignored. For the wire rope repeatedly wound on the roller or drum, the periodic bending load will cause the friction and sliding between the steel wires inside the rope strand, and the long-term service will lead to the wear of the steel wire, which will cause the stress concentration and accelerate the crack initiation. In serious cases, it will also cause the failure phenomena such as broken wire and rope.

The research object of this paper is YS 9-8×19 galvanized braided wire rope for tension stringing guidance of power grid construction. The strand track on its cross section can be approximately distributed on two intersecting ellipses, and the strand lay direction on the same ellipse is the same. It is defined that the right braided strands are woven by four right-hand twisted strands in the anticlockwise direction of the ellipse, and the left braided strands are woven by four left-hand twisted strands in the clockwise direction of the ellipse, and each strand is cross braided at a certain initial position at the same time to form a wire rope. The relative initial position angles of the four strands 1, 2, 3 and 4 are 0, 3π/4, π, 7π/4 respectively; the relative initial position angles of the four strands 1′, 2′, 3′, 4′ are 0, π/4, π, 5π/4 respectively. Because of the different initial position, the movement track of eight strands on the elliptic cylinder is not the same. As shown in figure 3.

In this definition, the contact between the wire rope and the traction wheel is defined as the "rope-wheel" contact, called Nick type A, the contact between the wires between the strands is Nick type B, and the contact within the strands is Nick type C, as shown in figure 3b.

Further, in order to ensure the safe operation of the hoisting system, the static strength design theory is adopted for the selection of the braided steel wire rope for traction, that is, based on the static tensile strength, according to the different traction purposes, different static safety factors are selected for the braided steel wire rope, and the allowable bearing capacity of the steel wire rope is obtained. According to the inspection and discard standard of steel wire rope in China, when the number of visible broken wires of steel wire rope reaches 10 in 6d or 19 in 30d (d is the diameter of steel wire rope), the steel wire rope reaches the discard standard.

However, in the actual working condition, the static strength design theory also fails to take into account the impact of friction and wear during the use of the lifting wire rope, so it is impossible to make accurate prediction and evaluation of the safety status of the service wire rope. Therefore, as shown in figure 4, the scrapped wire rope collected from the construction site is analyzed for the friction and
wear behavior of the scrapped wire rope, so as to improve the selection standard of the braided wire rope Provide theoretical basis.

3. Friction and wear analysis

3.1. Wear depth
It can be seen that there is a large amount of black oil deposited between the rope strands. The stock observation shows that the surface of the rope is rough, there are a large number of elliptical wear scars, and that there are obvious signs of "rust". The severely worn wire rope is intercepted and disassembled. Then, it is cleaned with an ultrasonic oscillator, observation samples are prepared.

In order to observe the three-dimensional shape of wear rope directly, the samples of different wear types are observed and analyzed by VHX-5000 super depth of field three-dimensional microscope, and the wear depth is used to characterize the wear severity. figure 5a, 5b and 5c show the wear morphology of "rope-wheel" contact rope (type A), inter strand rope (type B) and intra strand rope (type C), respectively.

Figure 5d shows the maximum wear scar depth of three kinds of wear observed by the super field microscope. It is found that the maximum wear depth of type B is about twice that of type A. That is to say, in the service process of braided wire rope, the most serious wear is between strands, followed by the "rope-wheel" contact rope, while the rope in strand is only slightly worn.

The reason is that the braided structure of the braided wire rope leads to a much larger gap between the strands than that of the twisted wire rope, showing a significant point contact state. During the winding process, the uneven stress of the rope leads to the relative sliding between the different strands of rope, so the wear is the most serious; because there is lubricating oil on the contact surface between the rope and the wheel in the actual working condition, the wear of the outer side wire of the braided wire rope is slowed down. However, the contact state between the core wire and the rope wire in the strand is wire contact, so only slight wear occurs.

![Figure 5. Three-dimensional wear morphology](image-url)
3.2. Wear type
In order to explore the type of rope wear, the surface morphology of the most seriously worn "rope-wheel" contact rope and strand rope are observed by means of COXEMEM-30 scanning electron microscope.

As shown in figure 6a,"rope-wheel" contact rope wire shows that the surface of rope wire is stratified and deformed, the small cracks gradually expand to form large cracks, and a large number of large pits are formed due to the peeling off of material fragments around the cracks. There are many scale-shaped warping after work hardening in the severe wear position, and many pits formed when the hardening material breaks and falls off, which makes the rope surface rough and generate many pockmarks.

Combined with the working condition of wire rope pulling and erecting cable, the analysis shows that the galvanized layer on the surface of the rope body will bond during contact extrusion and plastic flow of the material of the rope body, and the surface will be torn to form cracks. In addition, the electrochemical corrosion between the moisture and sulfur in the air and the zinc on the rope surface accelerates the damage of the zinc coating on the rope surface.

Under the repeated action of corrosion medium and periodic load, the hardened layer produces by corrosion products and alternating stress disintegrates and becomes flaky and warped. Therefore, according to the principle of tribology, the wear type of "rope-wheel" contact rope is mainly composed of fatigue wear and corrosion wear.

Figure 6b shows that a large number of pits formed by peeling are distributed around the abrasion mark of the rope between strands, and a large number of cracks are distributed on the surface. The serious cracks formed by crack propagation at the place of severe wear, a large number of pits formed by tearing off of the base material around the cracks, and the accumulation of materials formed by adhesion.

Combined with the working condition analysis, it is considered that in the process of winding, the ropes and wires are squeezed mutually, and the fallen debris migrates to the surface of another rope and forms a surface pit after repeatedly loading and unloading the material adhered to the rope and the metal matrix falling off. Furthermore, the fallen debris slides between the strand and forms a scratch along the sliding direction. Therefore, according to the principle of tribology, it can be judged that the type of wear between strands is adhesive wear.

4. Conclusion
1) In this paper, the braided wire rope used for traction is taken as the research object. It is found that the wear between the strands of the braided wire rope is the most serious through the ultra-depth of field microscope, and the maximum wear depth is twice that of the "rope-wheel" contact rope. And because the contact form of the rope in the strand is wire contact, the rope in the strand is only slightly worn.
2) Based on the SEM analysis and the actual working conditions of the braided wire rope for traction, the main wear types of the braided wire rope for traction are adhesive wear and composite wear caused by fatigue wear and corrosion wear.

Acknowledgments
This work was supported by the Shandong natural fund project: Research on mechanical properties of braided wire rope for traction under tension-torsion composite load. Grant No. ZR2019MEE062.

References
[1] Wang D, Song D, Wang X, et al. Tribo-fatigue behaviors of steel wires under coupled tension-torsion in different environmental media[J]. Wear, 2019, 420: 38-53.
[2] Singh R P, Mallick M, Verma M K. Studies on failure behaviour of wire rope used in underground coal mines[J]. Engineering failure analysis, 2016, 70: 290-304.
[3] Yu-xing P, Xiang-dong C, Zhen-cai Z, et al. Sliding friction and wear behavior of winding hoisting rope in ultra-deep coal mine under different conditions[J]. Wear, 2016, 368: 423-434.
[4] Wang D, Li X, Wang X, et al. Dynamic wear evolution and crack propagation behaviors of steel wires during fretting-fatigue[J]. Tribology International, 2016, 101: 348-355.
[5] Wang D, Zhang J, Ge S, et al. Mechanical behavior of hoisting rope in 2 km ultra deep coal mine[J]. Engineering Failure Analysis, 2019, 106: 104185.
[6] Cruzado A, Hartelt M, Wäsche R, et al. Fretting wear of thin steel wires. Part 2: Influence of crossing angle[J]. Wear, 2011, 273(1): 60-69.
[7] Peterka P, Krešák J, Kropuch S, et al. Failure analysis of hoisting steel wire rope[J]. Engineering Failure Analysis, 2014, 45: 96-105.