Effects of Pretension Test on the Microstructure and Mechanical Properties of Steel Wire Rope

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Abstract. Due to the breaking force of Ф14-1770, the three pre-tensioning process was designed and the wire rope was pre-tensioned. The result shows that the wire rope has different degrees of elongation and the elastic modulus increases by 60% breaking force pre-tension test. However, there is no change in the diameter of steel wire, indicating that the steel wire has no plastic deformation. The wire rope has different degrees of elongation, and the elastic modulus decreases by 80% breaking tension pretension test, indicating that the steel wire produces plastic deformation.

1. Introduction

Wire rope has good softness, high tensile strength, fatigue strength, impact toughness in high speed working conditions and many other advantages. It has been widely used in mine production, engineering machinery, aeronautics and astronautics and other industries as a major component for the use of load bearing, elevating and so on. However, the wire rope produces elongation due to loading and dead-weight, causing harm to the user. So far, the most effective way to eliminate the extension of the structure is to pretension the wire rope. In the developed countries, the pre tension technology of wire rope has been studied in 1970, in order to improve the quality of the wire rope and the market competitiveness. The relevant data show that more than 50% of the high added value wire ropes for important using are imported from abroad in our country [1-2]. At present, the research of wire rope pre-tensioning technology is in the beginning stage in our country, so it is of great significance to study the technology of wire rope pre-tensioning.

2. Material and Experimental Procedures

The material of the pre-tension test is 10 meters Ф14-1770 wire rope and is carried out with LNH-3000 microcomputer controlled electro-hydraulic servo horizontal tension tester. The length change of wire rope is measured by meter stick, the rope diameter change of wire rope is measured by SATA 91511 vernier caliper, the diameter and microstructure change of the steel wire is measured by Olympus PME3 optical microscope and the micro-hardness is tested by HXD-1000 Vivtorinox hardness tester. The breaking tension of Ф14-1770 wire rope is 176kN tested by WAW-1000B microcomputer controlled electro-hydraulic servo universal testing machine. The pre-tensioning technology is shown in Table 1 [3].
Table 1. The Pretension technology of the steel wire rope.

| Number | Pre-tensioning technology                                      |
|--------|-----------------------------------------------------------------|
| 1      | 42.2kN×5min+73.9kN×10min+105.6kN×5min                           |
| 2      | 42.2kN×5min+73.9kN×10min+105.6kN×10min                          |
| 3      | 42.2kN×5min+73.9kN×10min+105.6kN×20min                          |
| 4      | 42.2kN×5min+73.9kN×10min+140.9kN×5min                           |
| 5      | 42.2kN×5min+73.9kN×10min+140.9kN×10min                          |
| 6      | 42.2kN×5min+73.9kN×10min+140.9kN×20min                          |

In order to gauge the result of wire rope pretension, according to GB/T24191-2009, GB/T8358-2014 and GB/T8918-2006, the actual elastic modulus E and the elongation ratio of the wire rope after pretension are measured [4].

3. Results and discussion

3.1. The Elongation of Wire Rope and the Change of Elastic Modulus

The pre-tensioning test of the wire rope is carried out according to the technology shown in Table 1. The elongation of the wire rope and the change of the elastic modulus after pre-tensioning are shown in Table 2.

Table 2. The elongation and of the steel wire rope.

| Number | Original length /mm | Pretension length /mm | Elongation /% | E1/MPa | E2/MPa | ΔE /% |
|--------|---------------------|-----------------------|---------------|--------|--------|-------|
| 1      | 9927                | 9957                  | 0.30          | 60400  | 71200  | 18    |
| 2      | 9926                | 9963                  | 0.37          | 60200  | 74380  | 24    |
| 3      | 9928                | 9975                  | 0.47          | 60400  | 82100  | 36    |
| 4      | 9925                | 10096                 | 0.72          | 60200  | 52300  | -13   |
| 5      | 9927                | 10215                 | 1.35          | 60400  | 48280  | -20   |
| 6      | 9925                | 10439                 | 2.68          | 60400  | 43600  | -28   |

From table 2, it can be seen that the wire rope has different elongation, and the elastic modulus increases by processing 1-3 treatment. And with the increasing of the loading time, the elongation and elastic modulus of the wire rope also increase. The elongation of wire rope treated by processing 1-3 treatment is 0.47%, and the modulus of elasticity is increased by 36%. After processing 4-6 treatment, the elongation of wire rope increased significantly and the highest elongation can reach 2.68%, but its elastic modulus decreased, and the maximum descending amount reached 28%. This is due to the excessive pretension force that makes the wire rope under the necking of the pretension force, and produces a large contact stress between the strand and steel wire in the rope, resulting in steel wire damage, resulting in the decrease of elastic modulus. The wire rope has little amplitude of swing after processing 1-3 treatment, while it has great amplitude of swing after processing 4-6 treatment.

3.2. The Diameter Change of Wire Rope

As can be seen from table 3, the diameter of the wire rope has been reduced by 0.17 to 0.31mm after 1-3 processing treatment, and the diameter of the wire rope has been reduced by 1.09 to 1.37mm after 4-6 processing treatment. According to the relevant data, the reduction of the wire rope diameter is generally 0.2~1.0mm after pre-tensioning [5]. The decrease of wire rope diameter indicates that the clearance between wire and strand is reduced, or the diameter of steel wire decreases, or the interaction between them.
Table 3. The diameter of the wire rope after pretension test.

| Number | Diameter /mm | Average Value /mm |
|--------|--------------|-------------------|
| 0      | 14.13        | 14.08             | 14.05             | 14.11             | 14.07             | 14.09             |
| 1      | 13.92        | 13.89             | 13.91             | 13.96             | 13.93             | 13.92             |
| 2      | 13.86        | 13.91             | 13.86             | 13.87             | 13.85             | 13.87             |
| 3      | 13.78        | 13.75             | 13.76             | 13.77             | 13.81             | 13.77             |
| 4      | 13.02        | 12.99             | 13.05             | 12.98             | 12.97             | 13.00             |
| 5      | 12.89        | 12.92             | 12.87             | 12.93             | 12.91             | 12.90             |
| 6      | 12.75        | 12.72             | 12.69             | 12.73             | 12.71             | 12.72             |

Note: No.0 is a wire rope without pre-tensioning.

3.3. Diameter Change of Steel Wire in Wire Rope

For many wire ropes, because of uneven twisting stress and loss of twisting strength [6], when the pulling force reached above 85%, the steel wire rope is pulled off. The maximum load of this pretension is 80% of the tensile strength of the wire rope. It is necessary to study whether steel wire in wire rope produces the plastic deformation or not. In the same wire rope, the stress in the wire rope from the lateral wire to the core is reduced in turn [7]. The wire rope is cut and its lateral rope is inserted. The diameter of the 8 steel wires in the wire rope is measured using the method shown in Figure 1, and the change of the diameter of the wire rope is observed by metallurgical microscope, and the result is shown in Table 4.

Figure 1. Measuring the diameter of wire.

Table 4. The diameter of wire in the wire rope.

| Number | Diameter /μm | Average Value /μm |
|--------|--------------|-------------------|
| 0      | 360.82       | 504.91            | 502.25            | 508.76            | 509.35            | 500.27            | 623.38            | 495.18            | 500.62            |
| 1      | 361.46       | 509.78            | 508.55            | 507.32            | 510.91            | 501.47            | 606.03            | 495.70            | 500.15            |
| 2      | 361.32       | 506.53            | 503.83            | 506.82            | 506.77            | 502.76            | 620.68            | 496.38            | 500.64            |
| 3      | 362.35       | 507.36            | 505.19            | 504.83            | 509.92            | 502.16            | 618.57            | 493.97            | 500.54            |
| 4      | 350.86       | 489.62            | 490.36            | 491.82            | 489.86            | 486.28            | 607.63            | 480.27            | 485.84            |
| 5      | 338.18       | 475.38            | 476.81            | 474.18            | 472.68            | 478.91            | 592.38            | 468.92            | 472.18            |
| 6      | 325.57       | 459.61            | 460.97            | 458.57            | 460.26            | 463.65            | 573.92            | 455.63            | 457.27            |

Note: No.0 is a wire rope without pre-tensioning.

From table 4, the diameter of the steel wire without pre-tensioning is 500.62μm and the diameter deviation of the steel wire is ±0.47μm after 1-3 processing treatment. After 4-6 processing treatment,
the diameter of the wire rope has been greatly reduced and the maximum decrease is 43.35μm, which indicates that the plastic deformation of the wire rope has occurred after 4-6 processing treatment.

3.4. Research on Microstructure and Micro-hardness of steel wire

The microstructure of steel wire treated by 1-3 processing treatment is no direction tempered sorbite, and its hardness is within a reasonable range of change from table 5 and figure 2. The microstructure of steel wire treated by process 4-6 is elongated tempered sorbite, and its micro-hardness is larger than that of the original wire rope. This is due to the plastic deformation of steel wire treated by 4-6 processing treatment, and the work-harden of the steel leads to the increase of hardness.

Figure 2. Microstructure of steel wire after different pre-tensioning.

Table 5. Micro-hardness of steel wire after different pre-tensioning.

| Number | Hardness/HV1 | Average Value /HV1 |
|--------|--------------|--------------------|
| 0      | 656 659 648 646 647 649 653 650 646 668 530 535 | 632 |
| 1      | 656 651 648 650 642 650 647 650 643 670 537 550 | 633 |
| 2      | 652 652 643 656 645 646 650 646 648 669 545 547 | 633 |
| 3      | 655 658 645 647 650 653 648 651 649 672 547 546 | 634 |
| 2      | 663 668 655 652 658 656 657 658 653 673 542 549 | 640 |
| 3      | 680 678 648 642 668 658 658 665 660 669 560 558 | 645 |
| 4      | 689 682 656 658 652 656 679 665 668 580 586 652 | 652 |

Each steel wire in the wire rope is processed by cold drawing, and the residual tensile stress will be produced during the drawing process. In the process of twisting the strands, the steel wire will further produce the twisting stress. The residual tensile stress and twisting stress are the main factors affecting the structural elongation of the wire rope [8]. The pre-tensioning treatment can partially or completely eliminate the residual stress and twisting stress, so the length of the wire rope becomes longer and the elastic modulus increases after pre-tensioning treatment. The high pretension will make the wire rope produce plastic deformation, although the elongation increases, the elastic modulus decrease greatly, which leads to the decrease of steel wire performance. In addition, the reason that the length of the wire rope is longer from microcosmic angle is analyzed, and it is found that the diameter of the steel wire has not changed after 1-3 processing treatment. That is because the gap between wire rope and
rope, the gap between wires and wire in the strand increasing, the residual stress eliminating and the structure more compact.

4. Conclusion
(1) The wire rope has different degrees of elongation, and the elastic modulus increases by 1-3 processing treatment; the elastic modulus of the wire rope after is reduced by 4-6 processing treatment.
(2) Through pretension test, the plastic deformation of Ф14-1770 types of wire rope cannot happen after 60% breaking force loading.
(3) Through pretension test, the plastic deformation of Ф14-1770 types of wire rope can happen after 80% breaking force loading.

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