Separate tensile tests of ACSR at high and low temperatures

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Abstract. In order to ensure the accuracy of the test and avoid the errors caused by the slip between the steel and aluminum materials, the mechanical properties of ACSR at different temperatures were studied by the method of separate experiment of steel strand and aluminum strand. The test results show that with the increase of temperature, the elastic modulus of aluminum strand and steel strand decreases, but the elastic modulus of steel strand decreases more. There is no obvious strengthening stage and yield stage for aluminum strand, but obvious elastic stage, yield stage, strengthening stage and local necking stage for steel strand. The failure parts of aluminum strands are concentrated in the position of 1/2 ~ 1/3 of the samples, and the failure parts of each strand tend to develop along the twisting direction. The failure position of the steel strand is basically in the same cross section of the middle area of the sample. The experimental results of steel and aluminum strands are basically consistent with the results of the whole steel reinforced aluminum strand, which proves that the experimental method is feasible.

1. Introduction

The tensile performance of conductor is an important parameter to study the sag, wind deflection and galloping of transmission lines [1]. Especially, the temperature of conductor will affect the change of elastic modulus and mechanical properties of conductor. He Weibin [2] studied the mechanical properties and sag characteristics of ACSR in heavy ice area, and showed that the tensile performance and economy of ACSR in freezing weather were better than those at normal temperature, and the corresponding safety factor was also greater. Liu Yang [3] and others studied the mechanical properties of ACSR at low temperature by means of test. Through the tests of breaking, twisting of a single wire, it is shown that the breaking force and tensile capacity of single steel wire and aluminum wire at low temperature are improved compared with that at room temperature. Ren Yan [4] show that the yield strength and tensile strength of aluminum alloy increase with the decrease of temperature at low temperature. Zhou haunting [5] made relevant research on the change of mechanical properties of steel strand under high temperature by experimental method, obtained the relationship expression of yield strength, elastic modulus with temperature.

With the progress of UHV technology, the cross section of ACSR is becoming larger and larger [6]. Under the action of large tensile loads, the large diameter conductor is easy to slip on the testing machine. It is difficult to realize the traditional single stranded ACSR clamping experiment. In addition, because
the ACSR is composed of different materials, the separate tensile test of ACSR the high and low temperature tests of the steel core and the aluminum strand at high and low temperature were carried out. Finally, the mechanical properties of the large section diameter at high and low temperature were obtained.

2. Separate tensile tests of ACSR

2.1. Test scheme
The test was carried out in the 59th Research Institute of China Ordnance Industry. The model type is ACSR-300/25, and the temperature was -50 ℃ -70 ℃. The test equipment is shown in Fig.1. MTS322 universal testing machine and the matched heat preservation box MTS651 are adopted, which has good thermal insulation performance. It create high temperature environment by its own resistance wire. The size is 700mm × 760mm × 500mm, and the temperature range is -129 ℃ ~ 316 ℃.

![Figure 1. Picture of tensile sample of aluminum strand](image)

2.2. Test process
The tensile test procedures of steel and aluminum strands are as follows:

(1) Connect the control cabinet, testing machine and computer control software and turn on the power for preheating;

(2) Install the incubator, connect the liquid nitrogen tank, and ensure that there is no air leakage and the tightness of the incubator during the transportation of liquid nitrogen;

(3) The specimen is installed in the center of the incubator, and the extensometer is installed in the middle of the specimen;

(4) Adjust the temperature in the incubator to the desired value and start the test after the temperature is stable for five minutes;

(5) Start the program operation button to start the test and observe the phenomenon of strand test until the system stops automatically when it is broken;

(6) Repeat the test twice for each temperature value of the same specimen to verify the accuracy of the test, and then repeat the above steps 3-7 with a different temperature. Finally, the most reasonable curve is selected to obtain the stress-strain curve within the elastic range of different temperatures.

3. Test results
The tensile tests of the aluminum stranded wires show that there is no obvious strengthening stage and yield stage for the aluminum stranded wire. When the elastic modulus approaches zero, it immediately enters the local necking failure stage, and the whole aluminum strand rapidly loses its bearing capacity. The fracture of the outer layer of the aluminum strand occurs firstly, and then develops to the inner layer gradually. The failure parts of aluminum strands are concentrated in the position of 1/2 ~ 1/3 of the sample. The failure parts of each strand are not in the same cross section, but show the development trend along the stranding direction. The fracture shape of all aluminum strand wires is a typical conical...
tensile fracture, with obvious necking phenomenon. The aluminum wires in the fracture area are obviously softer than other parts, as shown in Fig. 2 (a).

In the tensile test of steel strands show that the steel strand has four distinct stages of elastic stage, yield stage, strengthening stage and local necking stage. The failure position of the steel strand is basically in the middle of the sample, and the fracture position of each steel wire is on the same cross section. With the gradual increase of load, the 7 strands have a large elongation, and the zinc coating on the steel wire surface gradually falls off, accompanied by obvious brittle fracture sound, the seven strands fracture at the same time. The fracture shape of the steel strand is a typical cup cone tensile fracture with obvious necking phenomenon, as shown in Fig. 2 (b).

![failure mode of aluminum strand](image1)

![failure mode of aluminum strand](image2)

**Figure 2.** Failure modes of steel and aluminum strands

![Relation diagram of elastic modulus and temperature of aluminum strand](image3)

**Figure 3.** Relation diagram of elastic modulus and temperature of aluminum strand

Fig. 3(a) shows that the stress less than 0.03Gpa is within the error range caused by the looseness of crimping terminal. The stress-strain curve begins to stabilize, and can be regarded as a straight line when the stress is greater than 0.03Gpa. The elastic force can be obtained by eliminating the end crimping error.
Fig.4(a) shows that the elastic modulus of the aluminum stranded wire decreases with the increase of temperature. The elastic modulus decreases greatly at range of the low temperature and high temperature, while the reduction range of the elastic modulus at from -30 ℃ to 20 ℃ is small. Fig.4(b) shows that the elastic modulus of steel strand decreases gradually with the increase of temperature, which is similar to that of aluminum strand, but the decreasing range is much larger.

4. Comprehensive elastic modulus

The calculation formula of comprehensive elastic modulus of ACSR is as follows:

\[ F = E_A = E_s A_s + E_a A_a \]  

where, \( F \) is the force that the whole ACSR can bear, \( E \) is the elastic modulus of the whole conductor, \( A \) is the area of the whole ACSR, \( E_s \) is the area of the steel core, \( E_a \) is the elastic modulus of the steel core, \( E_s \) is the elastic modulus of the aluminum strand, and \( A_a \) is the area of the aluminum strand. The force of the whole ACSR can be obtained by superimposing the forces on the ACSR and the ACSR. The tensile strain curves of steel core and aluminum strand at different temperatures are shown in Fig. 5.
Superimposing the forces on the steel core and aluminum strand, the superposed tension-strain curve is compared with the tension-strain curve obtained by finite element software simulation, as shown in Fig. 6.

![Comparison of tension-strain curve of ACSR-300/25](image)

**Figure 6. Comparison of tension-strain curve of ACSR-300/25**

Fig.6 shows that the superposition curve of ACSR after separate calculation is in good agreement with the tensile strain curve obtained by whole ACSR, especially the curve before 30% of yield strength is basically consistent. This proves that the experimental method of testing steel core and aluminum strand separately is feasible.

5. Conclusions

In order to ensure the accuracy of the test and avoid the error caused by the slip between different materials, the mechanical properties of ACSR at different temperatures were studied by the method of separate experiment of steel strand and aluminum strand. The main conclusions are as follows:

1. With the increase of temperature, the elastic modulus of steel strand and steel strand decreases obviously.

2. There is no obvious strengthening stage and yield stage for the aluminum strand. While the steel strand has four distinct stages of elastic stage, yield stage, strengthening stage and local necking stage.

3. The failure parts of aluminum strands are concentrated in the position of 1/2 ~ 1/3 of the sample. The failure parts of each strand are not in the same cross section, but show the development trend along the stranding direction. The failure position of the steel strand is basically in the middle of the sample, and the fracture position of each steel wire is on the same cross section. The fracture shape is a typical cup cone tensile fracture with obvious necking phenomenon.

4. The test results of steel and aluminum strands separately are basically consistent with the results of the whole ACSR, which proves that the experimental method of testing steel core and aluminum strand separately is feasible.

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