Experimental Studies of the Corrosion Resistance for Q235 and Q235NH in the Outdoor High-voltage Disconnector

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Abstract. Aiming at the corrosion failure question of the outdoor high-voltage isolation switch, accelerated corrosion tests using 5% (mass fraction) NaCl salt spray for materials of Q235 and Q235NH were carried out. By means of the controlled trials method, samples were divided into two groups, and each group contains four specimens. After that, neutral-salt-spray corrosion tests with 60h, 100h, 130h, and 160h were conducted. Finally, the rust layer was observed by a microscope, and the corrosion rate was calculated according to the weight loss method. Experimental results indicated that the rust layer in Q235NH was more compact after being corroded. As a result, it provide more protection for the substrate.

1. Introduction

In the power plant and the substation electrical system, the high voltage disconnector is the most widely used device[1]. The main function of the disconnector is to cut down circuit steadily for safety when servicing high voltage device. However, the corrosion of the disconnector is one of the most easily happening deficiency[2], which will directly cause jam fault of the transmission process and resulted in the operation failure. Meanwhile, the mechanical strength of the parts will lower, and will cause deformation and damage further. Seriously, the safe operation of the power grid would be threatened.

The reason for disconnector corrosion primarily arose from the designing deficiency, the improper material selection, the substandard surface treatment and the unqualified plating procedure, etc[3]. As a result, the material selection problem of the disconnector was discussed in the research. In comparison with the ordinary steel, a special one named weathering resistant steel has been widely used to avoid atmosphere corrosion. The main difference between the weathering resistant steel and the ordinary one is the element content and the corrosion product composition. In special, the weathering resistant steel has a stable and protective inside rust layer whereas the ordinary one does not have. The rust layer can prevent corrosion medium contact with the substrate effectively[4].

As a kind of ordinary steel, the Q235 is widely used in transmission links of the disconnector. Moreover, the Q235NH is one of the weathering resistant steel. The element content of the Q235 and the Q235NH is shown in Table 1.

Table 1. The element content of Q235 and Q235NH.

| Steel type | C   | Si   | Mn   | S     | P    | Cr   | Cu    | Ni    |
|------------|-----|------|------|-------|------|------|-------|-------|
| Q235       | 0.18| 0.25 | 0.5  | 0.018 | 0.016|      |       |       |
| Q235NH     | ≤0.13| 0.10–0.30| 0.20–0.6| ≤0.03 | ≤0.03| 0.4–0.8| 0.25–0.55| ≤0.65 |
For the early stage of corrosion, the composition of the rust layer in both the Q235 and the Q235NH is $\alpha$-FeOOH, which hardly protect the substrate. Then, some of $\alpha$-FeOOH transform to $\gamma$-FeOOH, which is more stable and has a better protection to the substrate[6]. The essential reason why the Q235NH has a better protection for the substrate is that the element of Ni is in the form of NiFe2O4. It has a high electrochemical stability, and resulted in a better protection ability in the rust layer of the Q235NH[8].

In order to evaluate the corrosion resistance of the metal, the corrosion test with artificial acceleration is a good choice. The commonly used methods involves the salt spray test, the gas corrosion test, the field corrosion test and the cyclic-immersion-corrosion test[9]. Although the field corrosion test is a common way to evaluate the property of weathering resistant steel, it has a very long test cycle. Moreover, the cyclic-immersion-corrosion test can simulate an alternate wetting and drying status, but it also cost too much time[10]. In particular, the salt spray test was used to compare the corrosion resistance of the Q235 and the Q235NH in the outdoor high-voltage disconnector.

1.1 Weight loss analysis
The weight loss analysis is a reliable, effective and widely used quantitative test method to calculate the corrosion rate. It compare the weight of samples before and after they suffer from corrosion[11]. In case of uniform corrosion, the average corrosion rate can be calculated using the weight loss, the area and the test time. Due to the similar density of materials used in the test, the corrosion rate can be calculated according to the follow equation[12]:

$$V = \frac{m_0 - m_1}{At}$$

(1)

Where $V$ is the corrosion rate, the unit is g/(m2·h); $m_0$ denotes the weight before corrosion; $m_1$ presents the weight after the remove of the corrosion product; $A$ is the surface area that exposed in corrosive environment of samples; $t$ is the test time.

2. Experiments

2.1 Test samples set
Test samples were metal cylindrical tubes, whose parameters are given in Table 2.

| Serial number | Material | Outer diameter (mm) | Length (mm) | Wall thickness (mm) | Surface area (mm²) |
|---------------|----------|---------------------|-------------|---------------------|--------------------|
| 1~4           | Q235     | 30                  | 50          | 3.1                 | 4712.3889          |
| 9~12          | Q235NH   | 40                  | 50          | 2.7                 | 6283.1852          |

2.2 Sample processing
Samples were polished by 150, 240, 400, 800 mesh sandpaper successively, then immersed in the acetone solution. After that, samples were degreased by the ultrasonic cleaner, followed by a dehydration process with ethyl alcohol and then they were put in drying oven. After 2h, samples were marked 1~4, 9~12 by an oily pen.

The analytical balance was demarcated with calibration weights, and then each sample was weighed for three times by the analytical balance. The average of the three values was set to be the initial weight.

The samples’ inside space was filled with some material like foam after weighed. Afterwards, the two end of samples was sealed by neutral silicone sealant. These processes made the metal surface exposed in the salt spray environment only with the outside surface. After being sealed, samples were put into the drying oven again for about 8h, and taken out until the sealant was completely dried out.
2.3 Solution configuration
This experiment was performed according to GB/T 10125-2012, four kinds of parameters need to be controlled.

1) Salt need to be dissolved in the distilled water or the deionized water with the temperature of 25±2°C and the conductivity below 20 μs/cm. Moreover, the concentration needs to be controlled to be 50g/L±5g/L.

2) The pH value of the solution that used in the salt spray test requires to be between 6.5 and 7.2, the diluted hydrochloric acid or sodium hydroxide is allowed to adjust the pH value of the solution.

3) For the collector at any spot of the effective space in this test, the continuous spray collection time is at least 16h, and the average salt spray settlement is 1.2mL at a horizon collecting area of 80cm² per hour

4) The temperature of salt spray environment is set to be 35°C.

2.4 Experimental procedure
The experimental procedures are listed below:

(1) Check samples’ appearance, take photos.

(2) Before the test, turn on the salt spray test chamber, make it continuous spray for 24h to ensure the stability of the test chamber.

(3) Test the pH value of the salt solution, to guarantee the pH value is within the range of the standard.

(4) The nozzle of the salt spray test chamber is in the middle of the chamber with an umbrella spray, so that when the samples are placed, they are avoided to get too close to the nozzle. Samples are placed at a rigid plastic support, and the salt spray can be freely deposited on the surface of each sample.

(5) When the test comes to 62h, take out sample 1 and 9. Firstly, observe the corrosion morphology and take photos. Secondly, pickle samples in a solution of 500ml hydrochloric acid, 500ml distilled water, and 20g hexamethylenetetramine. After the product of corrosion have been cleaned completely, clean the samples with ethyl alcohol. Then put them into the drying oven for 2h and weigh them at last.

(6) When the test comes to 112h, take out sample 2 and 10, do the same operation as step (5).

(7) When the test comes to 162h, take out sample 3 and 11, do the same operation as step (5).

(8) When the test comes to 212h, take out sample 4 and 12, do the same operation as step (5).

(9) Calculate the weight loss data and draw a weight loss curve.

3. Results and discussions

3.1 Corrosion result
The morphology photos of sample 2 and sample 10 are shown in Figure 1, it can be seen from which is as follows:

The Q235 corroded seriously, and was completely wrapped by the rust layer. The surface of the rust layer appeared to be yellow and the inside appeared to be dark brown. After removing the rust layer by descaling liquid, the surface of the metal appeared to be gully-shaped.

Similarly, the Q235NH was wrapped by two rust layers after corrosion, and the surface of the metal after being descaled appeared to be gully-shaped too. Note that the difference between the Q235 and the Q235 NH is that the rust layer in the Q235 NH was more compact.
3.2 Component analysis

Figure 2 shows micrographs of two kinds of material’s corrosion surface.

As can be seen from Figure 2, the rust layer of the Q235 after corrosion is powder-shaped and loose. Therefore, it has a poor protective effect on the base material. On the other hand, the Q235NH is flake-shaped, and more compact than its counterpart. Consequently, it has a stronger protective effect on the base material.

3.3 Weight-loss analysis

The weight loss analysis was performed according to GB/T 16545-1996. Table 3 shows the weight loss data of the Q235, the Q235NH and other parameters according to experiment records. The corrosion weight loss curves of the Q235 and the Q235NH are shown in Figure 3.

| NO. | Corrosion time (h) | Initial weight (g) | Final weight (g) | Weight Loss (g) | Weight loss ratio (%) | Surface area (m²) | Corrosion rate (g·m⁻²·h⁻¹) |
|-----|-------------------|--------------------|------------------|----------------|-----------------------|------------------|-----------------------------|
| 1#  | 62                | 92.3458            | 91.9420          | 0.4038         | 0.4373                | 4.7124E-03       | 1.38                        |
| 2#  | 112               | 93.5709            | 92.9506          | 0.6203         | 0.6629                | 4.7124E-03       | 1.18                        |
| 3#  | 162               | 91.4036            | 90.3074          | 1.0962         | 1.1993                | 4.7124E-03       | 1.44                        |
| 4#  | 212               | 94.4836            | 92.8973          | 1.5863         | 1.6790                | 4.7124E-03       | 1.59                        |
| 9#  | 62                | 116.5849           | 116.1047         | 0.4802         | 0.4119                | 6.2832E-03       | 1.23                        |
| 10# | 112               | 113.1401           | 112.3063         | 0.8338         | 0.7369                | 6.2832E-03       | 1.18                        |
| 11# | 162               | 113.9638           | 112.4459         | 1.5179         | 1.3319                | 6.2832E-03       | 1.49                        |
| 12# | 212               | 117.2886           | 115.5608         | 1.7278         | 1.4731                | 6.2832E-03       | 1.30                        |
Figure 2. Micrographs of Q235 and Q235NH. Figure 3. Corrosion weight loss curves. (a) Q235, (b) Q235NH.

Results show that few difference between the Q235 and the Q235NH occurred in the early stage of the neutral-salt-spray test. The Q235NH has a certain advantage of corrosion resistance over its counterpart in the later stage. However, the difference is not as good as the data (2-8 times) from related literature. These facts illustrate that the corrosion resistance of the Q235NH is slightly better than that of the Q235 in the neutral-salt-spray test in a short time, and it is necessary to do a longer test to further study the differences between them.

4. Conclusions
a) The rust layer in Q235NH after corrosion is more compact than that of Q235, and leads to a stronger protective effect for the base material.

b) In the early stage of the neutral-salt-spray test, the difference between the Q235NH and the Q235 in is not obvious. However, the Q235NH has a certain advantage of corrosion resistance in the later stage. Accordingly, the Q235NH is a more suitable material for the outdoor high-voltage disconnector.

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6. Reference
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