Study on Corrosion Resistance of Modified Concrete Grounding Materials

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Abstract. Steel is widely used as a grounding material in power system, but it is easily corroded in the soil. To resolve the problem a new type of modified concrete composite has been developed. The modified concrete, added with carbon fiber, wrapped around carbon steel to form a composite to reduce the steel corrosion. Three corrosion comparison tests had been taken out. The corrosion test under three different pH soils show that the composite’s internal carbon steel’s corrosion rate is better than zinc-clad steel's rate in all pH soils, and better than copper's in soil with pH=5, also better than copper-clad steel's in soil with pH=9. The typical area soil corrosion test shows that modified concrete can protect carbon steel in saline-alkali soil area and acid red soil area. The results of site-buried test show that modified concrete material can effectively reduce the corrosion of carbon steel in Tianjin saline soil. Those test results show that modified concrete, as external component, can protect internal carbon steel in various environments. The composite's anti-corrosion effect is better other metals regularly used in grounding. The composite can be used in power system grounding, especially in corrosive areas such as saline-alkali area and acid red area.

1. Introduction

The operating experience of China’s power system shows that most transmission line trips are caused by lightning strike the lines or towers. According to the statistics of grid faults, in the area with high tripping rate, the total number of trips of high-voltage line is about 60% caused by lightning strike [1]. The tower’s excessive grounding resistance is an important reason for the transmission line lightning trips. The experience and theoretical analysis show that effectively reducing the tower grounding resistance is an important method to reduce the lightning trip rate of transmission lines [2-5].

China’s power transmission tower grounding mainly uses carbon steel and zinc-clad steel as grounding materials, both are easily corroded. Corroded metal grounding will increase grounding resistance and threaten transmission lines safety. Copper has good corrosion resistance, but its high price makes it difficult to use on a large scale. The corrosion resistance of copper-clad steel is good, but the thickness of copper plating should be greater than 0.25mm to have better protection performance. Once the copper coating is broken, it will accelerate the corrosion of internal steel.

To solve those problems of grounding metals, some non-metallic grounding materials have emerged, such as flexible graphite grounding material, conductive anti-corrosive coatings, grounding modules, etc[7-10]. However, these materials have their own defects in application. If the grounding
module is infiltrated by moisture, it's internal metal will corrode fast; conductive anti-corrosive coatings are difficult to be applied and vulnerable to get damaged; flexible graphite grounding material have yet to be verified due to their short use time.

In this paper, a new type of grounding material, modified concrete, is designed to improve corrosion resistance of steel. The concrete wrapped around the steel to form a composite material, the internal steel is used for a current channel, and the outer concrete used for corrosion prevention. This structure improves contact between metal and soil, increases discharge radius. This composite grounding material have good conductivity, corrosion resistance and grounding resistance reduction effect as for the power system grounding device.

2. Modified concrete material

The modified concrete materials are mainly composed of concrete cement, bentonite, coal ash, silicon powder, polyacrylonitrile-based carbon fiber, humectant, etc. Carbon fiber is a key raw material for modifying concrete materials, it has good self-lubricity and electrical conductivity. The reinforced concrete added of carbon fiber has high compressive strength and tensile strength. In general, more carbon fiber content, the better conductivity of concrete. When the amount of carbon fiber in concrete is fixed, the better dispersion of carbon fiber, the easier to form a conductive network.

The microscopic morphology of carbon fibers extends along the axial direction of the fibers, as shown in Figure 1. Figure 2 shows that the modified concrete hydrates are tightly bonded with few gaps. After carbon fibers added, the carbon fibers are evenly distributed, and tight bonding between the carbon fibers and the modified concrete hydration products can be observed clearly.

![Microscopic morphology of concrete added carbon fiber](image)

Figure 1. Microscopic morphology of concrete added carbon fiber

Modified concrete materials have good corrosion protection for carbon steel, mainly because the material can resist chloride ion penetration. The modified concrete cement is a hydraulic cementitious material made by grinding active mineral materials such as coal ash and silica fume, and the cement is pulverized by the volcanic ash effect and fine filling effect of finely ground mineral materials such as slag powder and coal ash. The hydration product and pore structure are optimized, and the chemical combination and physical adsorption of chloride ions are enhanced to achieve strong resistance to chloride ion penetration.

The components of the modified concrete material are as follows: concrete cement, bentonite, coal ash, silicon powder, polyacrylonitrile-based carbon fiber, polyacrylamide. The modified concrete material test sample is shown in Figure 2. Its volume resistivity was measured to be 0.07 MΩ according to the standards GB/T 21698-2008 [11] and DL/T 380-2010 [12], the concrete samples had taken impulse current withstand test and power frequency current withstand test. The sample resistance change rate was -5.4% to 12.9% and -34% to -25% [13] each after the impulse current test and power frequency current test respectively. Those test results meet the requirements of both standards.
3. Corrosion performance comparison tests

In order to verify the corrosion protection effect of modified concrete around carbon steel, some typical metals and the modified concrete are selected to take three corrosion performance comparison tests, including pH test, typical area soils test and site-buried corrosion test. The test samples include stainless steel, copper, copper-clad steel, zinc-clad steel, carbon steel and modified concrete composite. Each sample has three pieces. The first five kind metal samples’ dimensions are 50mm, test and the modified concrete composite’s dimensions is 110mm. Series are performed as follows:

3.1 pH test

The pH test set three different pH soils, pH=5, pH=7 and pH=9, to compare metals’ corrosion rate. The test temperature is 45 celsius degrees and test period is 720 hours. After test, metal samples just been dug out from soil(pH=9) before cleaning are shown in Figure 4, those samples were cleaned subsequently for weighting are shown in Figure 5.

![Metal samples before cleaning (pH=9)](image)

Figure 4. Metal samples before cleaning (pH=9)
Figure 5. Cleaned metal samples before weighting (pH = 9)

Table 1. Samples corrosion rate and corrosion rate ratio in 720 hours pH soil corrosion test.

| Test samples          | pH=5  | pH=7  | pH=9  |
|-----------------------|-------|-------|-------|
|                       | Corrosion rate (g/m²·h) | Corrosion rate ratio | Corrosion rate (g/m²·h) | Corrosion rate ratio | Corrosion rate (g/m²·h) | Corrosion rate ratio |
| stainless steel       | 0.00021 | 0.02 | 0.00028 | 0.03 | 0.00052 | 0.09 |
| copper                | 0.01267 | 1.07 | 0.00555 | 0.51 | 0.00562 | 0.95 |
| copper-clad steel     | 0.00451 | 0.38 | 0.00469 | 0.43 | 0.00809 | 1.37 |
| zinc-clad steel       | 0.23838 | 20.07 | 0.07890 | 7.21 | 0.09788 | 16.56 |
| carbon steel          | 0.28773 | 24.22 | 0.11977 | 10.94 | 0.20787 | 35.17 |
| concrete's internal steel | 0.01188 | 1 | 0.01095 | 1 | 0.00591 | 1 |

Corrosion rate ratio equals metal's corrosion rate devide by internal steel's corrosion rate, similarly hereinafter.

The corrosion rate and corrosion rate ratio of six metal samples in different pH soils are shown in Table 1. Corrosion rate ratio equals metal's corrosion rate devide by internal steel's corrosion rate which means if metal ratio is high, it is easier to corroded than internal steel. It can be seen that the carbon steel has the highest corrosion rate regardless of the pH. The highest value of carbon steel is 0.28773 g/m²·h in the soil of pH=5. In the same soil, the composite's internal carbon steel's corrosion rate is 0.01188 g/m²·h, that means carbon steel's corrosion rate is 24.22 times that of the internal steel, meanwhile corrosion rate ratio of zinc-clad steel and copper are 20.07 and 1.07 respectively.

In soil with pH=9, the carbon steel's ratio is 35.17, which is the largest in all pH soils too. In this soil, zinc-clad steel's ratio is 16.56, and copper-clad steel's ratio is 1.37. In soil with pH=7, carbon steel's ratio is 10.94, and zinc-clad steel's ratio is 7.2.

Those test results show that the modified concrete material, with carbon steel wrapped inside, can protect the carbon steel in different pH soils. Moreover, internal steel's corrosion rate is better than zinc-clad steel in all pH soils. The anti-corrosion effect of internal steel is better copper in pH=5 soil, and is better than copper-clad steel in pH=9 soil.

3.2 Typical area soil test

Typical area soil test is to compare metal's corrosion rate in three different areas. The soil samples were carried out from Jixian of Tianjin, Nanchang of Jiangxi, and Chengdu of Sichuan, which respectively represent coastal saline-alkali area, acid red soil area and inland low-resistance area.

The metal samples are still stainless steel, copper, copper-clad steel, zinc-clad steel, carbon steel and carbon steel wrapped in composite. The sample amounts, dimensions, test temperature, test period are same as the pH test. Pictures of metal samples before cleaning and before weighting are shown in Figure 6 and Figure 7.
It can be seen from Table 2 that carbon steel's corrosion rate in the soil from Jixian reaches the highest, 0.44752 g/m²·h, and internal steel's corrosion rate is 0.18020 g/m²·h in the same soil, carbon steel's corrosion rate is 2.48 times that of internal steel. In soil from Chengdu, the corrosion rate ratio of carbon steel is the largest 1400.9. In soil from Nanchang, the ratio of carbon steel is 15.15. Obviously the modified concrete, as external component, protect the internal carbon steel quite well in the saline soil and the acid red soil.

Table 2 also shows internal steel's corrosion rate is better than zinc-clad steel in the soil from Jixian and the soil from Nanchang. In the soil from Chengdu, the internal steel's corrosion rate is better than other five metals.

3.3 Site-buried corrosion test
Five samples, including stainless steel, copper, zinc-clad steel, carbon steel and modified concrete composite, are buried respectively in four Tianjin areas, such as Jixian, Binhai, Jinnan and Jinghai. Each sample has three pieces and dimensions are the same as the previous test. The site-buried test
period is 317 days. Figure 8 shows situation of one test site. Pictures of metal samples before cleaning and before weighting are shown in Figure 9 and Figure 10.

![Figure 8. Site-buried corrosion test](image)

![Figure 9. Metal samples before been cleaned (samples buried in Jixian, Tianjin)](image)

![Figure 10. Cleaned metal samples had been cleaned (samples buried in Jixian, Tianjin)](image)

### Table 3. Samples corrosion rate and corrosion rate ratio in site-buried corrosion test.

| Test samples | Jixian, Tianjin | Binhai, Tianjin | Jinnan, Tianjin | Jinghai, Tianjin |
|--------------|-----------------|-----------------|-----------------|-----------------|
| Corrosion rate (g/(dm²·a)) | 0.44 | 0.52 | 0.52 | 0.48 |
| Corrosion rate ratio | 0.79 | 1.18 | 1.18 | 0.60 |
The composite made of internal steel and external concrete has excellent anti-corrosion performance in various environments. The modified concrete and carbon steel have better performance than other five metal's rates in sites of Binhai and Jinnan, and better than zinc-clad steel's rate in Chengdu. Carbon steel's corrosion rate in Jinnan is up to 8.25 g/(dm²·a), internal steel's corrosion rate in the same site is 0.44 g/(dm²·a), the corrosion rate ratio of carbon steel is 18.75. In Jixian, Binhai, Jinghai, the ratio of carbon steel is 4.98, 6.91 and 6.41 respectively. Those results show that because of the resistance of chloride ion penetration, the modified concrete material can effectively reduce the corrosion of carbon steel in Tianjin saline-alkali soil.

4. Conclusion

Based on the corrosion problem of grounding metal materials in power system, a new grounding composite is developed with modified concrete and carbon steel. The modified concrete and its corrosion comparison tests are described. The main conclusions are as follows:

1. The results of pH corrosion test show that the modified concrete material can protect carbon steel in different pH soils. Carbon steel sealed into the concrete has better anti-corrosion effect than zinc-clad steel, also better than copper in pH=5 soil, better than copper-clad steel in pH=9 soil.

2. Typical soils test results show that the modified concrete can protect its internal carbon steel quite well in the saline soil and the acid red soil. The internal steel's corrosion rate is better than zinc-clad steel's rate in three areas and better than other five metal's rates in soil from Chengdu.

3. The results of site-buried test show that the modified concrete can effectively reduce the corrosion of carbon steel in Tianjin saline-alkali soil. The composite's internal steel's corrosion rate is better than other five metal's rates in sites of Binhai and Jinnan, and better than zinc-clad steel in Jixian and Jinghai.

4. The corrosion comparison tests show that modified concrete can protect carbon steel under various environments. The composite made of internal steel and external concrete has excellent anti-corrosion effect than metals usually used in power system grounding. The composite is suitable for high corrosion areas like saline-alkali area and acid red area.

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