Effect of heat treatment and shot peening technology on microstructure and properties of 7A04 aluminum alloy conductive rod

Yi Xie¹, Wenbo LI¹, Chao Feng¹, Hongjian Luo², Yaxia Qiao³, Hao Zhang³
¹State Grid Hunan Electric Power Company Limited Research Institute, Changsha 410007, China
²State Grid Zhejiang Electric Power Research Institute, Hangzhou 310014, China
³China Electric Power Research Institute, Beijing 100192, China

Abstract. In order to study the corrosion problem of 7A04 aluminum alloy conductive rod in humid environment and coastal area, the effects of heat treatment and shot peening technology on the microstructure and erosion resistance of 7A04 alloy were investigated by the optical microscope, scanning electron microscope, transmission electron microscope, portable Vickers hardness tester and peeling test. It was found that the microstructure of the 7A04 aluminum alloy was refined after heat treatment, and the surface hardness reached 170-185 HV. The resistance of aluminium alloy to spalling corrosion was also improved. After the shot peening treatment, the surface grain of the 7A04 aluminum alloy was further refined and the surface micro-hardness was elevated to 200-260 HV. In addition, the anti-flaking corrosion ability was further improved to the optimal PB level. Finally, the on-site detection method of heat treatment and shot peening of 7A04 aluminum alloy conductive rod was proposed.

1. Introduction
With the rapid development of power grid construction, more and more 7-series super-hard aluminum alloy conductive rods were used in the isolating switch. The operation and maintenance experience showed that this kind of super-hard aluminum alloy had the advantages of light weight, good electrical conductivity and low density, but there were still many problems of corrosion failure, especially in the humid environment and coastal areas in the south [1-2]. This straightly affected the splitting action and normal service of the high-voltage isolating switch, as shown in Figure 1.

Figure 1. 7A04 aluminum alloy conductive rod.
In order to solve the corrosion problem of super-hard aluminum alloy from the raw material, 7A04 alloy was selected as the object to study the effects of heat treatment and shot peening treatment on the microstructure and erosion resistance.

2. Experimental section
A certain type of isolating switch 7A04 aluminum alloy conductive rod was used as the experimental substrate. After removing the oxide scale and oil stain on the surface, three sets of samples were taken by a cutter, and each set had three samples, each of which possessed a size of 150 mm×50 mm×5 mm. The original sample of the conductive rod was set as the group A. Group B was packaged in a quartz tube and heat treated in a resistive annealing furnace. The specific heat treatment system was composed of solution treatment (temperature 480°C/insulation 24h/water quenching), low temperature aging (temperature 125°C/insulation 24h) and high temperature aging (temperature 175°C/insulation 24h). Group C was shot peened by a research institute on the basis of Group B.

Microstructure observation was performed using a Zeiss optical microscope. The second phase distribution of the matrix was analyzed by transmission electron microscopy. Surface hardness testing was performed using a portable Vickers hardness tester and corresponding fixtures.

The peeling test was carried out in accordance with the standard requirements of GB/T 22639-2008. 234 g of NaCl and 50 g of KNO₃ were dissolved in distilled water, then 6.3 ml of HNO₃ was added, and diluted to 1000 ml with distilled water as a test solution. The experimental temperature was set to 25 °C.

3. EXPERIMENTAL RESULTS

3.1 Microstructure analysis
The metallographic structure of Group A had large grain length-to-width ratio and obvious orientation. Usually, this orientation was the direction of the rolling force of the conductive rod raw material, and the second phase were also contained in the matrix. The grains of Group B was gradually spheroidized to form equiaxed grains, and the second phases were partially dissolved. The surface of Group C was shot peening, and the surface layer of the sample was slightly refined compared with the other two Groups.
3.2 Second phase detection
The TEM images of Group A were shown in Fig. 3a and Fig. 3b. There were many second phase particles in the matrix with quite different shapes, such as large rods and small spheres. The size of the large particle in Fig. 3b reached the order of 100 nm. Compared with the Group A, the second phase particles in the Group B were smaller in size and more diffusely distributed. The particles size was about the order of 10μm, as shown in Figure 3d.

3.3 Surface microhardness test
The trend of surface Vickers hardness of the Group A, B and C as a function of surface distance were shown in Figure 4. The surface hardness of the Group A and the hardness of the matrix did not change substantially. The hardness of the Group B increased slightly from 155-160 HV of the substrate to 170-185 HV on the surface. The surface microhardness of the Group C increased greatly from 180 HV to 260 HV, indicating that the surface layer of the 100 μm region hardening was obvious.
Figure 4. The trend of surface Vickers hardness of the A, B and C samples as a function of surface distance

3.4 Peeling test
The Group A, B and C were placed together in the peeling test etching solution, and the sample was taken out after 48 hours. The surface morphology of the samples after the test was shown in Fig. 5.

Figure 5. The surface morphology of Group A, B and C after peeling test

The Group A was in good shape with a regular bulging along the length of the sample, and there was a small amount of rupture in the bulge. It indicated that the flaking phenomenon was related to the processing mode of the material, and the corrosion rating was EB grade. The surface of Group B was flatter than that of Group A. Only corrosion pits and corrosion holes appeared, no surface metal stripping, and good anti-flaking corrosion performance, corrosion rating was EA grade. Compared with Group A and Group B, Group C had a flatter surface with a corrosion rating of PA and optimum erosion resistance.

4. DISCUSSION
After the Group A was deformed by processing, a large number of dislocations were generated and the second phase particles were precipitated. It is known from the precipitation strengthening theory that the more the second phase particles act as strengthening, the greater the hindrance force that the dislocations are subjected to during the movement, thereby increasing the strength. This is also an important reason why the strength of the 7-series aluminum alloy is higher than that of other series of aluminum alloys. It is found from the TEM morphology in Fig. 3a that the second phase at the grain boundary is in a chain-like discontinuous distribution. According to the related literature, the second phase is a Mg(Zn,Cu,Al)₂ phase, which is an anodic phase during the corrosion of 7A04 alloy. Therefore, there is an active corrosion channel formed by the corrosion galvanic couple formed by the grain boundary anodic Mg(Zn, Cu, Al) 2 phase and its edge aluminum matrix in the 7A04 aluminum alloy, which results in a large peeling corrosion sensitivity. At the same time, the grain structure also has a great influence on the anti-flaking corrosion ability, and the alloy with a high aspect ratio is prone to ablate rather than forming pitting[3-5].

This study shows that the hardness of 7A04 aluminum alloy after two-stage aging treatment is about 170-185HV, and the surface micro-hardness after shot peening treatment is improved to 200-260HV.
The hardness characteristics can be tested in the field by a portable Vickers hardness tester and corresponding fixtures for easy supervision.

From the peeling test results in Fig. 5, it is known that the anti-flaking corrosion performance of the aluminum alloy in the Group B is greatly improved compared with the Group A. The main reason is that the Group B reduces the coarse second phase in the alloy, where the second phase acts as a source of corrosion during the corrosion process. Therefore, after the heat treatment, the pitting source in the alloy is reduced, the corrosion sensitivity of the material is lowered, and the performance of the anti-flaking corrosion is improved. At the same time, the aging treatment can change the structure of the crystal to a certain extent, reduce the aspect ratio of the grain, and improve the bonding energy of the grain interface.

Stress factor is one of the important conditions that affect the susceptibility of aluminum alloy erosion. Generally, tensile stress promotes the development of erosion, and compressive stress can alleviate the erosion[6-7]. It can be seen from Fig. 1c that the shot peening treatment refining the grain of the surface layer of the aluminum alloy treatment improves the hardness of the surface, as shown in Fig. 4, and can introduce surface residual compressive stress to reduce the electrochemical activity of atoms on the surface of the aluminum alloy and at the grain boundary and slow down selective corrosion in the product area. Therefore, shot peening treatment can improve the corrosion resistance of aluminum alloy. After the shot-peening treatment of the Group C, the highly oriented grains originally formed on the surface of the material are refined to form equiaxed crystals, thereby causing the active channels parallel to the surface of the material required for the occurrence of spalling corrosion to be blocked. The occurrence and development of erosion is delayed, and the performance against flaking corrosion is the strongest.

5. CONCLUSIONS

The 7A04 aluminum alloy conductive rod had high orientation after processing deformation, which is prone to exfoliation corrosion. In accordance with the standard GB/T 22639-2008, the corrosion rating is EB grade after 48h corrosion test.

After heat treatment, the second phase particles distribution of 7A04 aluminum alloy is more even and uniform, the surface hardness reached 170-185HV, and the anti-flaking corrosion ability is improved with EA grade corrosion rating after 48h corrosion test.

The shot peening treatment further refines the surface grain of the 7A04 aluminum alloy, enhances the surface micro-hardness to 200-260HV, and blocks the active channel on the surface of the material. The anti-flaking corrosion performance of the sample reaches the optimal PB level, which meets the service requirements. At the same time, on-site inspection and supervision can be carried out through a portable Vickers hardness tester and corresponding fixtures.

References

[1] H.L.Jiang, S.Y.Chen, K.H.Chen, P.J.Wang, G.Y.Hu, J.Cent. South Univ. Sci. Technol. 10, 2615 (2017)
[2] H.Zhao, F.Tian, Z.Q.Wang, Northeast Electric Power Technol. 2, 13 (2011)
[3] W.K.Hao, B.K.Yang, Y.Chen, G.Ma, X.L.Shen, D.Y.Lin, X.Chen, Y.X.Chen, Corros. Sci. Prot. Technol. 6, 633 (2017)
[4] W.K.Hao, B.K.Yang, G.Ma, Y.Chen, X.L.Shen, D.Y.Lin, X.Chen, Y.X.Chen, Mater. Mech. Eng. 12, 59 (2017)
[5] Y.B.Fang, J.Du, Q.C.Chen, H.Tian, Mater. Sci. Technol. 5, 85 (2017)
[6] S.X.Ji, L.Chi, F.Yan, J.Sun, R.L.Ji, Y.Li, H.X.Yin, Heat Treat. Metal. 11, 97 (2017)
[7] J.J.Zhuang, X.Y.Zhang, B.Sun, R.G.Song, H.Li, Heat Treat. Metal.. 10, 1532(2017)