Effects of progressive solution treatment on microstructure and property of the aluminium alloy electrical round rod

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Abstract. This paper aims to research the effects of progressive solution treatment on property of aluminium alloy electrical round rod, we mainly research the influences of different temperature on tensile strength and electrical conductivity of the aluminium alloy electrician round rod. The component and phase constitution of the aluminium alloy was analysed by means of OLYMPUSPMG-3 horizontal metallurgical microscope, SUPRA40 scanning electron microscope, APOLLO-10Xenergy spectrometer, tensile strength and conductivity of aluminium alloy electrical round rod under various progressive solution treatment. The results show that: comprehensive performance of specimen is optimal by means of scheme(350℃×1h+510℃×6h), the conductivity is 56.6%IACS and the tensile strength is 103MPa.

1. Introduction
Transmit the electricity from western areas to East China, north-south power exchange, intelligent networking have become the focus of the national power grid construction strategy. Although the annual output of China's cable ranks in the forefront of the world, technology content is not high, especially with the power cable distribution [1]. The use of annealed copper wire is more than 90% and the proportion of aluminium or aluminium alloy wire is very small. After the Second World War, the world's copper resources are generally in short supply, and the price is expensive, but the aluminium resources are abundant[2-4]. Therefore, it has important economic significance to replace copper wire with aluminium wire as soon as possible[5-6]. This paper is to study the effect of the progressive solution and the single-stage solid solution on the microstructure and properties of the aluminium alloy round rod so that we can improve the mechanical properties and electrical conductivity. Laying the foundation for researching and developing the processing technology of high performance electrician round aluminium alloy rod.
2. Experimental

2.1. Experimental materials
The composition of raw materials in the experiment is listed in Table 1. In order to guarantee the experimental accuracy, there are three samples of each state, and the experimental data was obtained by average when testing the performance of the sample.

| Element | Al  | B  | Si  | Fe  | Mg  | Cr  | Ni  | Ti  | Others |
|---------|-----|----|-----|-----|-----|-----|-----|-----|--------|
| Content | 99.685 | 0.020 | 0.067 | 0.111 | 0.005 | 0.001 | 0.007 | 0.033 | 0.071 |

2.2. Experimental processing technology
The experiments were carried out to compare the progressive solution with the single-stage solid solution to determine the best experimental processing technology. Concrete parameters of the progressive solution are 250°C × 2h+530°C × 8h, 300°C × 2h+530°C × 8h, 350°C × 2h+530°C × 8h, 400°C × 2h+530°C × 8h, 450°C × 2h+530°C × 8h, Concrete parameters of the single-stage solid solution is 530°C × 8h.

2.3. Analysis and test methods
Rolling process was conducted by the F50-150 type rolling round machine at room temperature; Intron - 8501 materials tensile tester with the stretching rate of 2 mm/min was used to test the tensile strength and elongation of the specimens. QJ57 Arms Bridge was performed to analyse the electrical conductivity of specimens; Microstructure and element distribution of the specimens were observed by Olympus-BH2 optical microscope (OM), SUPRA40 field emission scanning electron microscope (SEM) and APOLLO-10X spectrometer; Phases were analysed by X’ Pert PRO X ray polycrystalline diffraction (XRD).

3. Results and discussion

3.1. Effect of progressive solution on electrical conductivity and tensile strength
As shown in Fig.1, with the increase of the primary solution temperature, the conductivity first decreases and then increases while the tensile strength first increases and then decreases when the secondary solution temperature parameters is 530°C × 8h. When the parameters of the progressive solution is 250°C × 2h+530°C × 8h, the electrical conductivity is 56%IACS and the tensile strength is 95MPa; Comprehensive performance of specimen is optimal by means of scheme(350°C × 2h+530°C × 8h), the conductivity is 55.7%IACS and the tensile strength is 103MPa. The conductivity of the progressive solution decreased slowly and the tensile strength improved obviously compared with the single-stage solid solution (the conductivity is 55.8%IACS and the tensile strength is 99MPa), indicating that the progressive solution is better.
3.2. Microstructure of specimens
Figure 3 shows the metallographic structure of specimens with different of the progressive solution treatment. With the increase of the primary solution temperature, the grains become refining and then become coarse. The grain boundary of specimens was coarse (Fig.2a). The grain boundary of specimens was slender and distributed in grain boundary evenly (Fig.2b). The alloy elements are solid solution adequately, the grain is slender, the microstructure is uniform and the grain boundaries are clean because the temperature of the primary solution is low, there is a part of Sub-grain and smaller grain boundary, the grain boundary migration rate is lower, so that the specimen can obtain smaller grain boundary microstructure in high temperature stage (Fig.2c). The grain is refining and have a small amount of second phase (Fig.2d). The grain is coarse relatively (Fig.2e).

Figure 2. Microstructure of specimens on different the primary solution temperature.
### 3.3. SEM and EDS analysis of specimens

Figure 3 demonstrates the SEM and EDS analysis of specimens by means of scheme (350 °C ×2h+530 °C ×8h). As shown in Fig. 3, the grain boundary and the crystal are relatively clean, almost no white particles in the crystal, only a very small amount of white particles precipitation on the grain boundaries. It is pointed out that a large number of the alloy element is too late to precipitate in the temperature, and the precipitate phase is too late to grow up, the size is small and the solid solution is sufficient [7-10].

![Figure 3. SEM of sample under different multiples](image)

Component analysis was performed at positions 1, 2, 3 and 4 in Figure 3 (b). As can be seen from the results in Table 2: there are a mass of Al and few Cu by analysing the precipitates of point 1. The copper content of point 2 is much more than point 1, and the content of Y element is relatively small, which may be the result of the formation of Cu elements in the solution process. Point 3 at the grain boundaries, the main components are Al, Cu, La, Ce, Y. Point 4 is white particles, and the content of alloying elements are higher, it may be mixed precipitation of Al, Cu, La, Ce, and Y elements. It can be seen that the distribution of Cu, Ce, La, Y elements is more uniform after progressive solution treatment, and these elements exist in the grain and grain boundaries, which shows that the alloying elements are completely solid solution [11-13].

| Elements | Al  | Cu  | La  | Ce  | Y  |
|----------|-----|-----|-----|-----|----|
| Wt.%     |     |     |     |     |    |
| 1        | 99.12 | 0.88 | -   | -   | -  |
| 2        | 93.37 | 5.84 | -   | -   | 0.79 |
| 3        | 92.82 | 2.13 | 2.78| 1.69| 0.59 |
| 4        | 85.26 | 5.29 | 4.82| 4.25| 0.38 |

### 3.4. XRD analysis of specimens

Figure 4 shows the XRD analysis of the specimens by means of scheme(350°C×2h+530°C×8h). From the diffraction peak in Fig.4, the main phases of the specimens are Al, Al9Si, Cu3Si, Al3Y, Al0.3Fe3Si0.7 and so on. The main phases of the strongest diffraction peaks are Al, Al9Si. There is no Ce phase in each peak, the reason may be that the Ce phase has been fully melted into the matrix, indicating that Ce phase are completely solid solution after the progressive solution treatment [14-15].
4. Conclusion

(1) The grain boundary and the crystal of the specimens are relatively clean, almost no white particles in the crystal, only a very small amount of white particles precipitation on the grain boundaries, metallurgical structure is uniform and the alloy elements are solid solution adequately by means of scheme (350 °C × 1h + 510 °C × 6h).

(2) Comprehensive performance of specimens is optimal by means of scheme (350 °C × 1h + 510 °C × 6h), the conductivity is 56.6% IACS and the tensile strength is 103MPa. Compared with the single-stage solution treatment (530 °C × 8h), the tensile strength of the progressive solution treatment is improved obviously and the conductivity of the sample is reduced very little.

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