Study on Manufacturing Technologies of LHA5 Aluminum Alloy wire

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Keywords: aluminum alloy wire, overhead conductor, manufacturing technologies

Abstract. Through the analysis of aluminum alloy characteristics, material control research and manufacturing process, the aluminum alloy formulation optimization and aluminum alloy wire with 55% IACS and strength of 295MPa were completed. The aluminum alloy wire with conductivity of 55% IACS and strength of 295 MPa developed in this paper is named LHA5 type high conductivity aluminum alloy wire, by the GB/T 23308-2009 and NB/T 42042-2014 [1-3].

Introduction

The transmission line loss is mainly composed of corona loss and resistance loss. When the corona loss is nearly the same, the line loss is mainly determined by the resistance loss. China's total social electricity consumption in 2008 increased from 2.1 trillion kWh to 5.55 trillion kWh in 2015. According to China's transmission loss rate of 6% to 7%, it means that China's annual line loss of electricity exceeds 385 billion dry watt hours.

At present, the main application of aluminum alloy products in China is high-strength aluminum alloy \(lha_1, lha_2\). The conductivity of \(lha_1\) aluminum alloy is 52.5% \(iacs\), while 53% \(iacs\) of \(lha_2\). In the EU standard EN 50183, The strength of the AL5, AL6 aluminum alloy is similar to that of \(lha_1\) and \(lha_2\), but the conductivity of the AL5 is 55.25% \(iacs\), while 56% \(iacs\) of AL6. Therefore, research on performance improvement in aluminum alloy lines is required.

"Aluminum-magnesium-silicon alloy round wire for overhead stranding wire" of GB/T23308-2009 specifies the performance parameters of \(lha_1\) and \(lha_2\). The "medium-strength aluminum alloy wire for overhead stranded wire" of NB/T 42042-2014 follows its naming scheme and specifies the performance parameters of \(lha_3\) and \(lha_4\). The aluminum alloy wire with conductivity of 55% \(iacs\) and strength of 295 MPa developed in this paper is named as \(lha_5\) high conductivity aluminum alloy wire \[4-6\].

By analyzing the \(lha_5\) aluminum alloy characteristic, researching material control and manufacturing process, this paper completed the trial production of \(lha_5\) aluminum alloy wire with optimization of aluminum alloy formulation and conductivity of 55% \(iacs\) and strength of 295 MPa,

Analysis of characteristics of LHA5 aluminum alloy

Effect of Magnesium-Silica Ratio on Microhardness of AlMgSi Alloy Rods

The aluminum alloy wire is superior to the magnesium-rich aluminum alloy wire in both electrical conductivity and micro hardness. Taking the alloying element content of 1.28%wt as an example, when the conductivity of the different magnesium-silicon alloys in the 150 °C, the conductivity is the best when the ratio of magnesium to silicon is 1.40. The micro hardness shown increases with the decrease of the ratio of magnesium to silicon, and the effect of age hardening is best when the ratio of magnesium to silicon is 1.11.

Differential Scanning Calorimetric Analysis

The aluminum-magnesium-silicon alloy-based aluminum alloy is a typical age-hardening aluminum alloy. During the aging process, a series of precipitation phases are produced, and different precipitation has different effects on the performance of the aluminum alloy rod. Different heating rates also have an important influence on the precipitation transition temperature of each precipitate.
Generally, at a higher heating rate, the precipitation transition temperature of each precipitate is increased. As the heating rate increasing, the phase precipitation transition temperature shows a different degree of improvement, and the test curve also becomes much smoother. When the heating rate reaches 20K/min and above, the exothermic peak of the GP zone and β' phase is masked off, so the proper heating rate can more accurately reflect the phase precipitation transition of the sample during heating. Nevertheless, the exothermic peaks produced by the β" phase and the β phase transition at a relatively fast heating rate are still very obvious. Therefore, for the aluminum-magnesium-silicon-based aluminum alloy, the β" phase and the β phase are the two main precipitation phases in the heating process. The nucleation and growth of these two precipitation phases have a very important influence on the performance of aluminum alloy wires.

**Transmission Electron Microscopy Analysis**

In the peak aging state, the precipitate phase in the matrix of the aluminum-magnesium-silicon-based aluminum alloy is a needle-like β" phase (Mg₅Si₆), and the dispersed needle-like Mg₅Si₆ can significantly increase the strength of the matrix, and the dissolution of magnesium atoms and silicon atoms in the matrix improves the conductivity performance. In the study, the transmission time electron microscopy analysis was carried out for the magnesium-silicon ratio of 1.40 and 2.40 aluminum alloy rods after aging for 10 hours. It can be seen from the comparison that the two types of aluminum alloy rods with a magnesium-to-silicon ratio of 1.40 and magnesium-silicon ratio of 2.40 are aged at 190 °C for 10 hours, and the morphology, size and arrangement of the precipitated phases in the matrix are similar. The main difference between the two is the number of precipitated phases. The number of precipitated phases in the aluminum alloy rod matrix with magnesium to silicon ratio of 1.40 is significantly higher than that of the magnesium-rich aluminum alloy rod with magnesium to silicon ratio of 2.40. Under the premise that the total amount of alloying elements is the same, the more the number of precipitated phases, the more the amount of solid solution atoms in the matrix is precipitated, the more the obvious the conductivity increases, and the higher the strength.

![Figure 1: TEM image of the precipitated phase near the grain boundary](image)

**X-ray diffraction (XRD) analysis**

The XRD analysis of magnesium-silicon to 1.40 and 2.40 aluminum alloy rods, which shows that in the peak aging state, the needle-like precipitates in the alloy rod matrix with a Mg/Si ratio of 1.70 and 2.4 is β" (Mg₅Si₆) phase. With the aging time prolonged, some β" (Mg₅Si₆) phase will gradually transform into β(Mg₂Si) phase, and the transition phase of aluminum-magnesium-silicon alloy with Mg/Si ratio of 2.40 will be more easily converted into equilibrium phase β (Mg₂Si).

Through aluminum-magnesium-silicon alloy researched, the alloy strengthening phase should be dominated by β"(Mg₅Si₆) phase, and the transition of β"(Mg₅Si₆) to β (Mg₂Si) phase is inhibited, by developing new LHA5-type aluminum alloy and optimizing formula and process. Under the premise of ensuring the strength of the alloy, the content of each alloy element is appropriately reduced to improve the electrical conductivity of the aluminum alloy.
LHA5 aluminum alloy material control

The LHA1 and LHA2 type aluminum-magnesium-silicon alloys are line-strengthened, mainly because the Mg2Si particles precipitated during the artificial aging process are dispersed in the matrix, thereby increasing the strength. The mass ratio of magnesium to silicon in Mg2Si particles is 1.73, but the mass ratio of magnesium to silicon used in the actual production process is generally less than 1.73, which is mainly because the influence of magnesium on conductivity is greater than that of silicon. The presence of silicon promotes the desolvation of magnesium. The presence of residual silicon can also interact with aluminum and the impurity elemental iron to form an aluminum-iron-silicon phase.

Through a large number of trial production and research analysis, it is necessary to obtain high-conductivity and high-strength aluminum alloy with conductivity of 55% IACS. In the control of aluminum alloy composition: iron 0.16%~0.22%, silicon 0.48%~0.54%, magnesium 0.62%~0.67 %, boron 0.01% to 0.02%, ytterbium 0.02% to 0.05%, and the balance is aluminum.

The optimization and time-effect treatment of yttrium (Yb) rare earth elements is a key process in production control. Firstly, it mainly promotes the desolvation of Mg, Fe, Si and other solid solution elements in aluminum alloy, and improves the electrical conductivity of aluminum alloy. Secondly, it can promote the spheroidization of the second phase and reduce the influence of the relative conductivity of the aluminum alloy. Thirdly, the microhardness of the aluminum alloy wire and the strength of the aluminum alloy wire can be improved. Fourthly, the precipitation of the strengthening phase of the Mg5Si6 alloy is more easily promoted during the artificial aging process. The addition of heavy rare earth lanthanum (Yb) element reduces the influence of alloying elements on the electrical conductivity of aluminum under the premise of ensuring the strengthening effect.

LHA5 type aluminum alloy manufacturing process

High conductivity aluminum alloy rod rolling

The aluminum ingot is selected from AL99.70 aluminum ingot. The quality of AL99.70 aluminum ingot is stable. The auxiliary materials such as intermediate aluminum-iron alloy, aluminum-silicon alloy and rare earth aluminum alloy are selected to purchase high-quality Longxuan. The composition of Longxuan intermediate alloy is stable and fluctuating. In the process of rolling alloy aluminum rod, AL99.70 aluminum ingot is used. The quality of aluminum ingot is stable, the content of iron and silicon is small, and it is easy to adjust the distribution ratio. The content of manganese, titanium, tantalum and chromium is low, which is beneficial to improve the aluminum wire. Sampling analysis of aluminum ingot, iron content ≤ 0.20%, silicon content ≤ 0.16 %, copper content ≤ 0.01%, Mn + Ti + Cr + V ≤ 0.02%, other impurities content ≤ 0.03%, the rest is aluminum. According to the composition requirements of the high conductivity aluminum alloy gold element, when the aluminum ingot is melted, the aluminum-iron intermediate alloy, the aluminum-silicon intermediate alloy, the aluminum-boron intermediate alloy and the aluminum-cerium rare earth intermediate alloy are uniformly matched with the aluminum ingot except the magnesium ingot. After that, it is melted in a cupola.

When adding magnesium in batches, ensure that the amount of magnesium added to each position in the furnace is uniform. At the same time, ensure that the bell jar does not move along the bottom of the furnace, and move it at the bottom of the aluminum liquid at the bottom of the furnace to prevent the bottom of the furnace from being damaged. It cannot be moved on the upper part of the aluminum liquid to prevent the magnesium ingot from burning.

After the magnesium ingot is melted, it is evenly stirred to make the alloy composition in the aluminum liquid evenly distributed. Then degas, remove the slag, and cover the surface of the aluminum liquid with a solid covering agent. Rapid furnace pre-testing of aluminum liquid, adjusting the content of aluminum alloy to a suitable range, after that, the temperature of the aluminum liquid is controlled at 720-740 °C, and it is allowed to stand for more than 25 minutes. The tilting holding furnace is slowly raised, and the aluminum liquid is flowed into the degassing furnace through the
launder. High-purity argon gas is used in the degassing furnace to enter the aluminum liquid through the high-speed running graphite rotor impeller, which generates inert bubbles, takes out the hydrogen in the aluminum liquid, and floats the impurities on the surface. After heating the filter furnace, rolling is performed. By adjusting the flow rate of the cooling water of the crystallizing wheel, the rolling temperature is strictly controlled between 490 and 530 °C, and the finishing temperature and the strength of the aluminum rod are controlled by controlling the water temperature and flow rate of the saponification liquid. The rod temperature is controlled below 80 °C.

**Drawing of high conductivity aluminum alloy wire**

After 24 hours of natural aging, the aluminum alloy rod is drawn in a non-sliding wire drawing machine LFDL-450/9. This trial production specification Φ3.83 mm aluminum alloy wire, considering the process extension finished mold selection Φ3.85 mm mold, aluminum rod used Φ9.5 mm high conductivity aluminum alloy rod, selected 9 pull process. The specific matching conditions are shown in Table 1 below.

<table>
<thead>
<tr>
<th>Incoming line / mm</th>
<th>1way / mm</th>
<th>2 way / mm</th>
<th>3 way / mm</th>
<th>4 way / mm</th>
<th>5 way / mm</th>
<th>6 way / mm</th>
<th>7 way / mm</th>
<th>8 way / mm</th>
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<td>7.61</td>
<td>6.86</td>
<td>6.20</td>
<td>5.61</td>
<td>5.07</td>
<td>4.63</td>
<td>4.22</td>
<td>3.85</td>
</tr>
</tbody>
</table>

**Conclusions**

In this paper, the characteristics of LHA5 aluminum alloy, LHA5 aluminum alloy material control research and LHA5 aluminum alloy manufacturing process were studied, and the aluminum alloy formulation was optimized. The aluminum alloy wire LHA5 with conductivity of 55% IACS and strength of 295MPa was completed. The composition requirements of aluminum ingots and aluminum rods, the control ratio of alloying elements and the heat treatment requirements of aluminum alloy materials are proposed in the paper.

**References**


