Effect of Sr Modifier on Microstructure and Mechanical Properties of ZL102 Casting Suspension Clamp

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Abstract. In this thesis, the microstructure and mechanical properties of the suspension clamp made of ZL102 material modified with different amounts of Sr added are studied, and the grip strength and damage load of the suspension clamp as well as the tensile testing properties at room temperature, hardness and impact toughness of the material are tested. The results show that with the increase of Sr addition, α solid solution gradually changes into dendrite, while coarse strip eutectic silicon and bulk primary crystal silicon gradually change into granular and short-rod shapes. With the addition of Sr modifier, the tensile strength, elongation, expansion and impact toughness of ZL102 material increased significantly, and the hardness value decreased slightly but with a smaller range. The grip strength test of suspension clamp modified with different added amounts of Sr meets the standard requirements, and the damage load test of suspension clamp modified without Sr does not meet the requirements. When the added amount of Sr is 0.0250%, the type test index of suspension clamp is stable and dispersive.

1. Introduction

The suspension clamp is used to hang the conductor on the overhead transmission line, which is connected with the cross arm of the tower through the suspension insulator string. The suspension clamp is a fulcrum for the conductor. It is easily damaged if it bears all the load transmitted from the conductor. The performance of the clamp directly affects the service life and line loss of the overhead transmission line [1].

When the armour clamps in direct contact with the conductor are made of ferromagnetic materials, there will be loss of hysteresis and eddy current under the alternating magnetic field [2]. With the increase of load and voltage level of the transmission line, the power loss caused by suspension clamp cannot be ignored. The manufacturing material of the suspension clamp gradually changes from the original malleable cast iron to the cast aluminium alloy [3,4].

Cast Al-Si alloy ZL102 is provided with excellent casting properties, corrosion resistance and electrical properties, without the tendency of hot tearing and looseness. Besides, it is provided with weak strengthening effect of heat treatment and moderate mechanical properties. The eutectic silicon in ZL102 is in the shape of coarse needle-like or plate, which will significantly reduce the strength and plasticity of the alloy. Generally, modification is required to improve the morphology and refined grain of eutectic silicon and primary crystal silicon, so as to improve the performance of the alloy [5-7]. This thesis mainly studies the effect of different added amounts of Sr modifier on the microstructure of suspension clamp during the smelting of ZL102, and explores the influence on the mechanical properties of ZL102 material and the type test items of casting suspension clamp.
2. Trial-manufacture and Test

2.1. Test materials and process

The material used in the test is ZL102, and the chemical composition is shown in Table 1. The modifier is Sr rod, with an addition amount of 0%, 0.0125%, 0.0250% respectively. Casting process: smelting preparation - filling - melting and refining - modification (modifier: Sr rod modifier, 730 ~ 750°C, 15 ~ 18min) - gravity casting - pouring riser. Six suspension clamps (model: XGA-10040) and four tensile samples are poured simultaneously with metal mold for each addition amount. The dimension of tensile sample is in accordance with GB1173, and the suspension clamp is shown in Figure 1.

| Si   | Fe  | Cu  | Mn  | Mg  | Zn  | Ti  | Al  |
|------|-----|-----|-----|-----|-----|-----|-----|
| 10.0-13.0 | ≤1 | ≤0.3 | ≤0.5 | ≤0.1 | ≤0.1 | ≤0.20 | rest |

Figure 1. Physical picture of XGA-10040 suspension clamp

2.2. Material test method

The samples for metallographic analysis, hardness test and impact test of ZL102 material are all cut from the tested suspension clamp body. The samples are etched by 0.5% hydrofluoric acid solution and observed by a Leica DMI 3000M optical microscope, with the magnification of 100 × and 400 × respectively; the HBE-3000 electronic Brinell hardness tester is used for hardness tests, and the average value is measured three times at different positions of the sample; The U-notch sample is used for impact tests, with the notch depth of 2 mm, and the ZBC2302 metal pendulum impact testing machine is used for the test; The CMT5305 microcomputer control electronic universal testing machine is used for tensile tests.

2.3. Suspension clamp test

The type test items for suspension clamp are mainly grip strength and damage load tests, and the test method shall refer to GB/T 2317.1. The conductor model used for the XGA-10040 suspension clamp test is JL/G1A-630/45-45/7. The test is carried out on a 1000 kN screen display hydraulic universal testing machine and horizontal tensile machine.

3. Results and Discussion

3.1. Effect of Sr addition on ZL102 casting alloy microstructure

Figure 2 shows the morphology at low magnification of ZL102 casting alloy after adding different amounts of Sr modifier. With the addition of Sr modifier, α solid solution gradually changes into dendrite. α solid solution dendrite is coarse in 0.0125%, and the quantity of α solid solution dendrite increases in 0.0250%, with short-rod shape as well as smaller and more uniform dendrite. Figure 3 shows the eutectic morphology at high magnification of ZL102 casting alloy after adding different amounts of Sr modifier. When Sr is not added, silicon exists in the form of coarse needle-like and flake eutectic silicon and block primary crystal silicon, as shown in Figure 3 (a). With the addition of Sr, the block primary crystal silicon decreases, and the needle-like eutectic silicon gradually changes into short-rod and granular shapes with smaller sizes. When the added Sr is 0.0250%, the granular
eutectic silicon is evenly distributed, and the morphology of short-rod eutectic silicon is less. Compared with the 0.0125% Sr addition, the microstructure is fine and uniform with good modification.

![Figure 2](image-url)  
**Figure 2.** Effect of Sr addition on microstructure of ZL102 cast aluminium alloy (100 ×)

![Figure 3](image-url)  
**Figure 3.** Effect of Sr addition on microstructure of ZL102 cast aluminium alloy (400 ×)

### 3.2. Effect of Sr Addition on Mechanical Property Test of ZL102

Table 2 shows the comparison of tensile properties of ZL102 alloy with different amounts of Sr addition. According to Table 2, the tensile strength and elongation of ZL102 without modifier are 146 MPa and 3.5% respectively. With the increase of Sr addition, the tensile strength and elongation increase. When the added Sr is 0.0125%, the tensile strength and elongation are 172.00 MPa and 8.17% respectively; when the added Sr is 0.0250%, the tensile strength and elongation increase to 189.50 MPa and 8.33% respectively. With the increase of Sr addition, the reduction of area also increased, which was 90% higher than that of without Sr.

| Sr addition (%) | Yield strength σ₀.₂ (Mpa) | Tensile strength σₘ (Mpa) | Elongation A (%) | Reduction of area Z (%) |
|-----------------|--------------------------|--------------------------|-----------------|------------------------|
| 0               | 78.00                    | 160.00                   | 3.50            | 6.67                   |
| 0.0125          | 80.00                    | 181.00                   | 8.17            | 12.33                  |
| 0.0250          | 82.67                    | 189.50                   | 8.33            | 12.67                  |

Table 3 shows the Brinell hardness and impact test values of ZL102 alloy modified with different amounts of Sr addition. It can be seen from the table that the impact toughness of the modified material is higher. The impact toughness of 0.0125% Sr sample is 3.50 J / cm², which is 100% higher than that of the unmodified sample. The Brinell hardness of ZL102 alloy is slightly different with the increase of Sr modifier.

| Sr addition (%) | Brinell hardness (HB) | Impact test (J/cm²) |
|-----------------|-----------------------|---------------------|
| 0               | 59.22                 | 1.75                |
| 0.0125          | 56.47                 | 3.50                |
| 0.0250          | 57.65                 | 5.13                |
The mechanical properties of ZL102 materials are closely related to the microstructure of eutectic silicon and α solid solution [5]. The microstructures in Figure 2 (a) and Figure 3 (a) show that coarse strip eutectic silicon and bulk primary crystal silicon are distributed in the α solid solution, and the strip eutectic silicon is arranged in a disorderly manner, which seriously cuts the continuity of α solid solution matrix. The properties of α solid solution and Al are similar, and the microhardness and brittleness of the silicon phase are high. It is easy to cause stress concentration [9] at the tip or corner of the strip eutectic silicon, and crack along the grain boundary or the bulk silicon itself. Therefore, the tensile strength and elongation of ZL102 alloy are lower, the mechanical properties (especially the elongation) are significantly reduced, and the impact toughness is lower due to the presence of coarse eutectic silicon and bulk primary crystal silicon when there is no added Sr modifier. Moreover, the coarse strip eutectic silicon is provided with high brittleness and low strength, and the tensile strength and elongation of ZL102 alloy are low, so the impact toughness and plasticity are significantly reduced.

After the ZL102 alloy is modified with Sr, the structure distribution of eutectic silicon and α solid solution is changed. α solid solution is dendritic, eutectic silicon is granular and short strip-shaped, and the microstructure is gradually refined with the addition of modifier. The fine and uniform microstructure can not only improve the strength but also improve the plasticity of the material significantly [9]. When the added Sr is 0.0125%, the tensile strength of the alloy increases by 12%, the elongation and impact toughness value increase by more than 50%, the hardness slightly decreases with small amplitude; when the added Sr is 0.0250%, the tensile strength and elongation increase with small amplitude.

3.3. Effect of Sr modifier addition on the properties of ZL102 casting suspension clamp
Table 4 shows the test results of grip strength and damage load of suspension clamp. XGA-10040 suspension clamp, the suitable conductor is JL/G1A-630/45-45/7, the required grip strength is 36.11 kN, and the nominal damage load is 100 kN. It can be seen from the table that when the added Sr is 0.0125% and 0.0250%, the damage load of suspension clamp is greater than the nominal damage load, and the grip strength test meets the requirements; when the added Sr is 0.0250%, the mean value of damage load of suspension clamp is 153.9 kN. Compared to the 0.0125% Sr addition, the mean value of damage load is increased by 22%, and the maximum dispersion rate of three samples is 1%. At this time, the suspension clamp is in the state of stable damage load value and small dispersion. The damage load of two suspension clamps without Sr is lower than the required value, so the casting suspension clamp of this process does not meet the standard requirements.

| Sr addition (%) | Damage load (kN) | Grip strength (kN) |
|----------------|-----------------|--------------------|
| 0              | 100.4           | 137.0              | 98.0              | 43.4(No slip) |
| 0.0125         | 132.4           | 145.7              | 139.4             | 43.4(No slip) |
| 0.0250         | 153.5           | 156.2              | 152.0             | 43.4(No slip) |

In this thesis, the damage load tests of suspension clamps are all carried out in single hole or double hole at the hanger. When the suspension clamp is in normal use, it mainly bears the total load composed of the vertical load and horizontal load of the conductor. When the conductor is disconnected, the tensile direction of the conductor is in a straight line with the hanging hole. The hull of the suspension clamp bears a large bending moment. Since the hanger of the suspension clamp is weak, the clamp is easily damaged at the hanger.

When the suspension clamp is under stress, the stress and strain at the interface between α solid solution and silicon phase suddenly change, and the degree of stress concentration is related to the shape and distribution of silicon. In the suspension clamp without Sr modifier, coarse strip eutectic silicon and bulk primary crystal silicon are disorderly arranged in the α solid solution, with sharp tips or corners. When the suspension clamp is under stress, it is easy to cause stress concentration to a
large degree, and crack and expand along the grain boundary or the bulk silicon itself. If the suspension clamp produced by this process is squeezed and impacted in production, transportation and use, it is easy to produce microcracks at the corners of coarse strip eutectic silicon and bulk primary crystal silicon, which will lead to the clamp cracking.

When Sr modifier is added, the eutectic silicon is granular and round and short rod-shaped. The dendrite structure of α solid solution is fine and uniform, and the stress concentration is minimized, which is conducive to improving the tensile resistance of castings and improving the strength and plasticity of materials. It can be seen that when the added Sr is 0.025%, the tensile strength, elongation and impact test value are significantly improved, and the average value of damage load of suspension clamp is also significantly increased, 56.4% higher than that without modifier.

4. Conclusions

(1) The addition of Sr modifier changes the eutectic silicon morphology of ZL102 alloy, and the solid solution changes into dendrite, with fine grains and uniform structure.

(2) The suspension clamp made of ZL102 and the addition of Sr modifier can improve the strength, impact toughness and plasticity of the alloy.

(3) The grip strength and damage load of the suspension clamp made of ZL102 alloy with Sr modifier meet the requirements of product load. It should be noted that when the added Sr is 0.0250%, the mechanical properties of the suspension clamp are stable and the dispersion is small.

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