Study on Strengthening and Toughening Technology of Al-Cu-Mn Cast Aluminium Alloy

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Abstract. In order to reduce the segregation in Al-Cu-Mn cast aluminium alloy and improve the strengthening and toughening, the microstructure of the alloy during solution aging were studied. The strengthening and toughening technology of Al-Cu-Mn cast aluminium alloy was explored. The results show that the strengthening and toughening technology reduce macro-linear segregation and eutectic segregation in Al-Cu-Mn cast aluminium alloy. At the same time, tensile strength, yield strength and elongation of the alloy increase by more than 10%, 18% and 70% respectively.

In the field of equipment manufacturing, casting aluminium alloy plays an important role in realizing lightweight parts. As a kind of high strength aluminium alloy, Al-Cu-Mn casting aluminium alloys have good mechanical properties and machinability. They are used in aerospace, ships, weapons, machinery and other fields. They are mainly used as structural parts and heat-resistant parts under heavy loads. Al-Cu-Mn casting aluminium alloys have wide crystallization temperature range, paste solidification, poor fluidity and high tendency of thermal cracking. In the late solidification stage, it is difficult to compensate in time, and it is easy to produce defects such as shrinkage, shrinkage, oxidation inclusions, cracks and so on, which restricts its wide application in high-performance mechanical parts[1-2].

In this paper, the microstructure and properties of cast Al-Cu-Mn casting aluminium alloy in homogenization and deformation process are studied, and the forming process of cast Al-Cu-Mn casting aluminium alloy is optimized, which provides a basis for the wide application of high performance Al-Cu-Mn casting alloy in equipment manufacturing field, and expands the application of high strength cast aluminium alloy in complex thin-walled castings and precision forming field.

Problem Analysis

During the cooling crystallization process of Al-Cu-Mn alloy, the dendritic network skeleton was formed firstly due to the wide crystallization interval. The pore of the network skeleton was filled by eutectic liquid with low solubility in the later stage, and the distribution was uneven. Eutectic segregation was formed after cooling. At the same time, because of the difference of shape and size of castings or the large casting wall, the difference of local temperature during solidification is large in the process of casting, and the alloy itself solidifies in paste form, it is easy to produce defects such as shrinkage, shrinkage, oxidation inclusions, cracks and so on, which restricts its wide application in high-performance mechanical parts[1-2].

In this paper, the linear segregation structure and eutectic segregation region of the high strength and toughness cast aluminium alloy are sampled and analyzed, as shown in Fig.1. From the results of energy spectrum in Fig.1a), it can be seen that the linear segregation structure is mainly Al₃Cu and a small amount of Al₁₂CuMn₂ phase. It can be seen from figure Fig.1b) that eutectic segregation is mainly composed of θ-(Al₁₂Cu) phase with network distribution along grain boundaries[3].

In addition, the addition of Mn can strengthen the solid solution and produce new strengthening phases, which can improve the mechanical properties and corrosion resistance of the alloy. However, the diffusion rate of Mn in the alloy is very small. When solidified, part of Mn is supersaturated and part of Mn is T phase (Al₁₂CuMn₂), as shown in Fig.2. As-cast, the T phase
(Al\textsubscript{12}CuMn\textsubscript{2}) distributes in a continuous network on the grain boundary of the alpha phase. During the solid solution treatment, a part of T phase dissolves into alpha phase, and at the same time diffuse secondary T phase is precipitated in alpha phase. During the aging process after quenching, a large number of dispersed small particles of secondary T phase precipitated in the grain of alpha phase, while the unsolved T phase remained at the grain boundary in discontinuous form during solution treatment.

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<td>64.40</td>
<td>3.09</td>
<td>2.63</td>
<td>20.96</td>
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Figure 1. Scanning and energy spectrum analysis results of metallographic grinding surface

a) Linear segregation region  b) Eutectic segregation region.

Figure 2. T phase (Al\textsubscript{12}CuMn\textsubscript{2}) in alloy.

The segregated structure can be dissolved into the aluminum matrix as much as possible during solution treatment, but the larger T phase and Al\textsubscript{2}Cu cannot be completely dissolved in the actual situation. T phase will disperse and precipitate again during quenching. Fig. 3 shows the structure of the solution aging state of the high strength and toughness cast aluminum alloy material. After solution aging, the supersaturated solid solution of Al\textsubscript{2}Cu phase and alpha matrix is formed first, and then dispersed and precipitated. In the aging process, the enrichment zone of Cu atom is formed in the supersaturated alpha solid solution and further ordered, the forming a phase of theta(\theta) with composition close to that of Al\textsubscript{2}Cu and square lattice, resulting in strong distortion of the lattice, thus playing a role of dispersion strengthening. T (Al\textsubscript{12}Mn\textsubscript{2}Cu) phase can be formed by Mn element in Al-Cu alloy with dispersive particle distribution. The primary T phase and secondary T
phase can not only refine the grain size, but also improve the plasticity and toughness of the material. In addition, Ti, Zr, V and other elements in the alloy, their atoms and eutectic structure formed with the matrix can provide heterogeneous nucleation core, increase nucleation rate, and refine the matrix phase of alpha (Al).

![Figure 3. The microstructure of conventional solution aging.](image)

**Strengthening and Toughening Process Plan**

The main alloying compositions (mass fraction, %) of the high strength and toughness aluminium alloy used in the experiment are 4.5-6.5Cu, 0.3-0.5Mn, 0.1-0.4Ti, 0.1-0.3Zr, 0.05-0.3V and the remaining amount is Al. The alloy is first used to cast round ingots with thickness of 30-40 mm, then homogenized, after deformation treatment, solution aging heat treatment is carried out.

**Result and Analysis of Strengthening and Toughening Process**

**Microstructure after Homogenization**

Due to the characteristics and the casting process of Al-Cu-Mn alloy, it is inevitable that the non-uniform composition of matrix solid solution, intragranular segregation and the precipitation of various non-equilibrium eutectic phases will occur in the initial as-cast alloy. These non-equilibrium microstructures will significantly reduce the formability of the alloy[4-5], seriously restricting the use of the alloy. Homogenization treatment can significantly reduce the dendritic segregation and element agglomeration of the alloy, and ensure that the alloy has good formability and service performance. The difference of alloying elements leads to different homogenization treatment processes of alloys, and the evolution of alloy microstructures during homogenization treatment also affects the formulation of homogenization treatment process.

In this paper, the homogenization treatment can eliminate or reduce the non-uniformity and deviation from the equilibrium structure in the actual crystallization conditions, so that the properties and component are uniform, and prepare for the subsequent processing[6]. Homogenization temperature and holding time are two main process parameters[7-8]. According to the diffusion law, increasing the homogenization temperature can accelerate the diffusion rate of elements and effectively eliminate the dendritic segregation structure in the alloy. However, excessive temperature will lead to the dissolution of low melting point non-equilibrium eutectic phase and the overburning of the alloy. The element distribution in the alloy can be dispersed by prolonging the holding time, but the grain growth will be caused by prolonging the holding time.

In this paper, three kinds of homogenization treatments, i.e. (450+5)°C×24h, (480+5)°C×24h,(500+5)°C×24h were carried out. From Fig.4, it can be seen that the Cu element at grain boundary after homogenization is basically dissolved by solid solution after holding at (500 + 5) °C for 24 hours.
Microstructure after Deformation

In general, the thick hard and brittle phase in aluminum alloy, such as Al$_2$Cu, the primary T will be broken into smaller particles by external force during deformation and distributed along the direction of extrusion deformation, the boundary is straight triangular or quadrilateral shape. It is possible that these tips will split the matrix at the deformation stage, resulting in a decrease in the mechanical properties.\(^{(9)}\)

![Figure 4. Microstructure of Al-Cu-Mn Alloy after Homogenization](image)

a) Homogenization at 450°C  \hspace{1cm} b) Homogenization at 480°C  \hspace{1cm} c) Homogenization at 500°C

Fig. 5 shows the deformation microstructure after homogenization treatment. As can be seen in Fig. 5, after homogenization treatment of the forming, the particles are crushed into smaller particles by external force, such as Al$_2$Cu and primary T phase, which are eliminated equally. At the same time, compared with figure 4c), segregation at grain boundary was further eliminated after homogenization treatment, and the grain size was refined from the original average of about 60 μm to an average of about 30μm.

Microstructure and Properties after Heat Treatment

Figure 6 shows the microstructure of the deformed after solution aging. It can be seen that there are dispersive fine second phase precipitation, and it is found that the small size of the insoluble phase does not exist basically. The larger size of the insoluble phase still exists and distributes along the direction of deformation, but the size decreases compared with that before the solution treatment. In addition, static recrystallization and grain growth may occur at the same time of solid solution.

![Figure 5. Microstructure after deformation](image)  \hspace{1cm} ![Figure 6. Microstructure of solution aging heat treatment.](image)

Table 1 is the mechanical properties of the alloy of conventional process and strengthening and toughening process, which makes the tensile strength of the material increase by more than 10%, the yield strength increases by about 18%, and the elongation increases by 70%.
Table 1. The mechanical properties of the alloy.

<table>
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<th>Rm(MPa)</th>
<th>Rp0.2(MPa)</th>
<th>A(%)</th>
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<tr>
<td>conventional process</td>
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<td>332</td>
<td>5</td>
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<td>strengthening and toughening process</td>
<td>474</td>
<td>392</td>
<td>8.5</td>
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**Conclusion**

After homogenization treatment, the segregation of the grain boundary is greatly reduced, the deformation process makes the internal organization evenly refined, and the segregation organization further eliminates. The toughening process makes the tensile strength of the material increase by more than 10%, the yield strength increases by about 18%, and the elongation increases by 70%.

**Reference**


[3] He Guoqiang, Doubal aging peaks phenomenon of Al-Si-Mg alloys and electrochemical characterization on age of Al-Cu alloys [D]. Guangxi; Guangxi University, 2008.


