Effect of Solution Treatment on Microstructure and Properties of Al-20Si-1.5Mg Cast Aluminum Alloy

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Abstract. The effects of the main process factors such as temperature and time on the microstructure and properties of hypereutectic Al-20Si-1.5Mg alloy were analyzed. The results show that when the solution treatment process is 510 °C × 6h, the primary silicon, eutectic silicon and Mg2Si in the sample structure have been solution maximized, and the morphology distribution has been optimized, which is related to the passivation effect of solution treatment on silicon phase, etc.; At the same time, the hardness decreases first and then increases with the extension of solution time, and the inflection point appears at 6h. Compared with the as cast structure, the hardness is reduced by more than 15%. At this time, the super saturation of the alloy is the largest, which is conducive to obtain the best aging strengthening effect.

Keywords: High Silicon Aluminum Alloy, hypereutectic, Al-20Si-1.5Mg, Solid Solution, Super Saturation, Structure, Hardness

1 Introduction
In recent years, with the development of vehicle, ship and other equipment lightweight, hypereutectic high silicon aluminum alloy with high silicon content as casting alloy has attracted more and more attention in the field of high power engine and supercharged internal combustion engine. Compared with the hypereutectic and eutectic Al-Si alloy with low silicon content, a large amount of super solid solution silicon in the form of primary silicon and eutectic silicon in the matrix can greatly reduce the density and thermal expansion coefficient of the alloy, reduce the casting cost, and improve the volume stability and process performance of the casting [1-3].

However, with the increase of silicon content, the primary and eutectic silicon phases in the structure gradually become coarse and disordered, the difficulty of refinement and modification increases, and the damage to the mechanical properties of the material becomes more and more serious, especially the deterioration of its strength, plasticity and wear resistance [4-5]. Modification and alloying can refine the microstructure and improve the mechanical properties of the alloy. However, these methods can not completely eliminate the sharp corners of the edge of primary silicon and the needle like tips of eutectic silicon, which are harmful to the properties. In addition, with the increasing
requirements of modern industry for material properties, it is necessary to further tap the potential of alloy structure and properties by other means, and the most effective method is heat treatment.

The heat treatment of Al-Si alloy is mainly carried out under the condition of T6 (solid solution + artificial aging), which is mainly strengthened by aging precipitation. In the solution treatment stage, increasing the solid solubility can increase the super saturation of the alloy and obtain the unstable supersaturated α-Al solid solution, thus increasing the number of aging precipitates, helping to maximize the precipitation strengthening effect, optimizing the solution temperature and time, helping to improve the production efficiency and reduce the manufacturing cost [6-7]. Obtaining the best solution treatment process has become the focus and difficulty of heat treatment of high silicon aluminum alloy, and is also the main purpose of this experiment.

2 Test materials and methods

The cast Al-Si alloy selected in this experiment is hypereutectic Al-20Si-1.5Mg alloy after modification. The main alloying elements are Mg, including Mn, Ti, Cu, etc., see Table 1 for the specific alloy composition.

**Table 1** chemical composition of Al-20Si-1.5Mg alloy (wt. %)

| Elements | Si   | Mg  | Mn  | Ti  | Cu  | P     | Al  |
|----------|------|-----|-----|-----|-----|-------|-----|
| Composition (wt.%) | 20.36 | 1.62 | 0.80 | 0.47 | 0.26 | 0.03  | Bal.|

During the experiment, four groups of as cast Al-20Si-1.5Mg alloy samples of the same composition and size were taken first. Under the same conditions, when the furnace temperature of the heat treatment furnace rises to 300 °C, the four groups of samples were put in, and then the temperature was raised to 510 °C to start timing. The holding time was 3h, 4.5H, 6h and 7.5h respectively. After the completion of heat preservation of each sample, take out and close the furnace quickly, quench it in 60 ~ 90 °C water to room temperature, and the transfer time shall not exceed 6S. The SX2-10-13 type heat treatment furnace is selected, the microstructure is analyzed by metallographic microscope, and HB-3000A type hardness tester is used for hardness measurement.

![Fig. 1 Size diagram of Al-20Si-1.5Mg alloy solution treated sample](image)

3 Test results and analysis

3.1 Effect of solution treatment on Microstructure of alloy

The solution temperature should be below the solid phase line temperature of the alloy, which must be lower than the eutectic temperature or the temperature when the solubility of alloy components is the maximum. High temperature may lead to over burning of the structure, melting or local oxidation of the grain boundary, and coarsening of the alloy structure. However, if it is too low, the super saturation of alloy elements in the matrix will not be increased to the maximum extent, the aging effect will be weakened, and the homogenization of microstructure will not be realized. At the same time, the solution time will be too long, the heat treatment cycle will be prolonged, and the energy consumption will be increased. According to the literature [8], the over burning temperature of ternary eutectic (Si + α-Al + Mg2Si) with low melting point in Al-20Si-1.5Mg alloy is 558 °C, the over burning temperature of Quaternary eutectic (Si + α-Al + Mg2Si + Al2Cu) is 517 °C, in order to prevent the over burning of eutectic with low melting point in solution stage, the solution temperature should be 5 ~ 10 °C at the lowest over burning temperature, so the solution temperature of Al-20Si-1.5Mg alloy is 510 C.

Solution time plays an important role in increasing super saturation of solute atoms in matrix. The
aging strengthening effect can be exerted to a greater extent by prolonging solution treatment time properly. Fig. 2 shows the microstructure of as cast Al-20Si-1.5Mg alloy at 510 °C and different solution time.

![Microstructures of Al-20Si-1.5Mg alloy after different heat-retaining time at 510°C](image)

**Fig.2** The microstructures of Al-20Si-1.5Mg alloy after different heat-retaining time at 510°C  
(a)510°C×0h; (b)510°C×3h; (c)510°C×4.5h; (d)510°C×6h; (e)510°C×7.5h

It can be seen that, before solution treatment (Fig. 2 (a)), due to the effect of modification treatment, although the dimensions of primary silicon (Mark a) and eutectic silicon (Mark b) are relatively small, there are many sharp corners along the edge of primary silicon, eutectic silicon is needle like, and Mg2Si (Mark C) is mostly small bone like, all of which are easy to produce stress concentration and damage the properties of alloy. After solution for 3h (Fig. 2 (b)), the structure changes little, and there is almost no passivation on the surface of primary silicon. Eutectic silicon is short rod-shaped or needle shaped, and Mg2Si fails to fuse or dissolve into the matrix. With the extension of time, the surface of primary silicon is passivated gradually, and the sharp angle decreases or disappears gradually. Eutectic silicon is transformed into granular or short rod shape as shown in Fig. 2 (d), which is mainly granular. The quantity of Mg2Si is significantly reduced, the solution effect is good, and the distribution of each phase is relatively uniform. However, with the further extension of solution time, as shown in Fig. 2 (E), the microstructure shows obvious over solution phenomenon, the eutectic silicon is re coarsened, the quantity is reduced, the matrix is seriously burned, and the color is blackened. It can be seen that the best solution treatment effect can be obtained when the solution time is 6h.

### 3.2 Effect of solution treatment on mechanical properties of alloy

The effect of solution time on the hardness of Al-20Si-1.5Mg alloy at 510 °C is shown in Fig. 3. The hardness of the alloy reached 116.5hb before solution treatment, and then decreased to 99hb after solution for 6h, with a decrease of more than 15%. It is proved that the hard strengthening phase which can improve the bearing capacity of the matrix in the experimental alloy after solution treatment has obtained a large solid solubility, such as primary silicon, eutectic silicon and Mg2Si. However, with the appearance of super solution, some of the hard strengthening phases which have been solid dissolved into the matrix are re precipitated, and the hardness is increased.
3.3 Discussion
For primary silicon, in the solution treatment stage, with the increase of temperature and the extension of solution time, the sharp corner of the edge gradually melts and covers the surface of the solid phase, accelerates the liquefaction of the solid phase under the action of diffusion movement, and finally makes the sharp corner of the solid phase gradually disappear. The primary silicon is passivated and rounded, the granulation effect is obvious, the sphereidization rate is increased, and the size is slightly reduced compared with as cast silicon.

For eutectic silicon and Mg2Si, with the increase of solution time, the smaller eutectic silicon and Mg2Si phase will gradually dissolve into α-Al matrix, resulting in the decrease of the number of them to some extent. However, the supersaturated α-Al solid solution formed after solution is an unstable structure. In the aging stage, under the action of material migration and homogenization of heat treatment, it will gradually precipitate in fine form and grow into particles. Some of the rod-shaped eutectic silicon and the small skeletal Mg2Si which are not completely solid solution are fused due to the shape instability of Rayleigh [9] under the action of proper heat treatment, and are transformed into granular or short rod-shaped, mainly granular.

In this experiment, the solution effect is maximized, and primary silicon, eutectic silicon and Mg2Si all have the maximum solution amount. As the hardness of α-Al phase is only 60-100hv, that of primary silicon and eutectic silicon is about 1150hv, and that of Mg2Si phase is 460hv, all of them are hard strengthening phases. With the increase of their solid solution content, the hardness of the alloy will gradually decrease and reach the minimum value when the solid solution process is 510 ℃× 6h, as shown in Fig. 3. At this time, the obtained α-Al matrix is a solid solution with high super saturation, so as to maximize the subsequent aging strengthening effect [10]. At the same time, the process effectively optimizes the morphology and distribution of the main phases of the alloy, and these microstructures can be well preserved after aging treatment, which is conducive to the improvement of performance.

4 Conclusions
1) In the solid solution treatment of Al-20Si-1.5Mg alloy, with the extension of time, the surface of primary silicon in the structure is gradually passivated, eutectic silicon is transformed into granular or short rod shape, Mg2Si is fused into granular or solid solution into the matrix, the size and quantity are reduced, and the distribution of each phase tends to be uniform; however, if the time is too long, the phenomenon of over solid solution appears, and the structure is coarsened.

2) The hardness of the alloy decreased first and then increased with the increase of solution time, and the inflexion point appeared at 510 ℃ solution for 6h. Compared with the as cast structure, the
hardness decreased by more than 15%, indicating that the solution effect was the best.

3) In this experiment, the excellent solution treatment process of hypereutectic high silicon aluminum alloy can make the maximum amount of solid solution of each phase in the structure, and obtain supersaturated α-Al solid solution, which is conducive to the best aging strengthening effect of the alloy.

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