Microstructure and properties of ZL205 alloy

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High strength aluminum alloy castings used in automobile, aerospace and domestic mechanical components can be classified into two types: (1) the solid solution alloy, such as Al-5Cu; and (2) the eutectic-ferrous alloy based on Al-7Si. Since the 20th century, cast Al-Cu alloy has been widely used because of its excellent properties at both room and elevated temperatures. However, the characteristic broad range of solidification temperature associated with this type of alloy restricted it from further applications. The wide temperature range usually results in hot tear in foundry practice because of the stresses near the hot spot [1]. The microstructure and properties of materials are correlatively linked to each other. Any change in size and distribution of phase structures will lead to significantly different properties. For a given component, controlling the microstructure is critical in materials design. Subsequent heat treatment of the materials also impacts the materials microstructure, thus influences the final properties. In order to improve the properties of an Al-Cu alloy, it is important to analyze the microstructure of the alloy [2]. In this paper, the relationship between microstructure and properties of the Al-Cu alloy were investigated.

1 Experiment

Industrial high purity aluminum, electrolytic copper, Zr, Ti, B, V and Mn were used for preparing the master alloys. Cadmium was added into alloy directly, forming a composition of the ZL205 alloy of w(Cu)=5%, w(Mn)=0.4%, w(V)=0.15%, w(Cd)=0.2%, w(Ti)=0.7% and w(B)=0.14%, balanced by aluminum. The alloy was melted in a 12 kW electrical resistance furnace with circumgyrating spray method (99.9%Ar) for degassing.

The alloys were cast in a metal mould, SiC sand mould, Cr-ore sand mould, and resin bonded sand mould, respectively. The mass fraction of both nobake furan resin and binders are 0.8wt% of the raw sand. A 4018 data acquisition module was used to collect the data from 4 pairs of thermal couples, and a 4520 data transition module transferred the data to the computer via a RS232 serial interface. The temperature-time curves was then recorded simultaneously, with an interval of 0.1 s. Then the liquidus, cooling rate, solidification time and concrystalloid equilibrium curves can be calculated from the data. The influence of moulds on cooling rate of the alloy, as well as the microstructure, were studied quantitatively. The samples were then solution-treated in a salt bath for 12 h and 15 h at 536 °C, then aged for 4, 6, 10, and 15 h at 175 °C, respectively.

Samples for optical microscopy observation were grinded, mechanically polished, then dipped into a mixed acid (75 ml HCl + 25 ml HNO3 + 5ml HF + 100 ml distilled water) for 30 s, and washed by distilled water, and then wiped up by alcohol, and finally air blow-dried. Samples for transmission electron microscopy observation followed a standard electropolish process. Room temperature tensile tests were carried out on an Instron 1186 universal electronic tensile testing machine, and the load-offset curves were recorded using a tensiometer. The crosshead speed was 1 mm/min.

2 Results and discussion

2.1 Effects of mould types on the as-cast microstructure

Temperature-time curves during solidification in different moulds can be plotted by normalizing the time axis, as shown in Fig.1. Figure 1 shows that the cooling rate of the alloy in metal mould...
which is governed by both the compositions and the solidification conditions. The solidification condition is highly depending on the mould material employed. Materials vary in their thermal and physical properties, and moulds made of different materials result in various chilling capacity and thermal conductivity. The microstructure of solidified alloy in different moulds was shown in Fig.2. Figure 2 shows that the grain structure varies with the mold used, which indicates that the effects of casting moulds on the as-cast microstructures are great. The cooling rate of alloy poured in metal mould was the highest, and the solidification time was the shortest, thus the grain structure was the most refined. On the contrary, the average grain size in the sand mould was larger than those in the metal mould. The microstructure of alloy in SiC mould and Cr-ore mould is similar, but the grain size of alloy in SiC mould is slightly bigger than that in the Cr-ore mould. Therefore, it is expected that the mechanical properties of a casting would be improved by using metal mould instead of common sand mould due to the increased cooling rate.

In addition, the influence of mould on the cooling rate was closely related to the spacing between the casting and the mould after solidification. The larger the linear expansion coefficient between mold material and casting, the bigger the air space of an alloy under the given conditions, and the bigger the thermal resistance between casting and mould, this makes the thermal energy difficult to conduct. The lower the cooling rate of casting, and the smaller the supercooling degree of solidification, the wider the region that liquid and solid coexist. Consequently, the tendency that the grains grow towards opposite direction of the thermal transmission is obvious after the melt contacted with the sand mould wall and nucleated. It is easy to induce the formation of large grain, and the liquid-solid coexist among these large grains. As a result, the flow of remaining liquid was blocked. Meanwhile, the volume reduction due to the shrinkage of the liquid-solid conversion cannot be refilled, leading to shrinkage porosities. The linear expansibility of quartz sand is the largest, therefore the grains of samples in sand mould were the largest. The thermal storage and chilling capacity of metal mould is the highest. Its chilling effect makes the thermal distribution within some particular parts or even the entire casting more uniform, and accelerates the cooling rate of the thermal center and refines the grains.

The microstructure of the as-cast alloy shows that the matrix is $\alpha$-Al, and the dark continuous and discontinuous networks crossing the grains are eutectic of $\theta$ and $T$ phases (Fig.2). Because of the multiple elemental feature of the alloy, eutectic phases at the grain boundaries are commonly decorated with a small amount of TiAl$_3$, ZrAl$_3$, and Cd. The existence of such phases with low-melting points at the grain boundaries can split the matrix badly and reduce the overall mechanical properties, thus castings must be heat-treated to eliminate such defects [3].

### 2.2 Solution treatment effect on the microstructure

The microstructure of the samples (cast by sand mould) after salt bath treatment at 536°C for 15 h was shown in Fig.3. The eutectic phases at the grain boundaries have dissolved into $\alpha$-Al after the solution treatment, forming supersaturated solid solution. Another obvious characteristic change from the as-cast microstructure is that the $T$-phase near the grain boundary has disappeared, and the secondary $T$ ($A1_{12}CuMn_2$) phase dispersed homogeneously within the matrix. This effect would contribute to the mechanical properties of this alloy according to dispersion strengthening mechanism.
2.3 Ageing treatment

Figure 4 shows the microstructure of samples (cast by sand mould) after salt bath treatment at 536°C for 15 h and further ageing treatment at 175°C for 8 h.

The GP zone transition is slow during the ageing treatment. Its component and structure become similar to that of $\theta^\prime$ and $\theta^\prime\prime$ phases accompanied with the disappearance of the coherent relationship. Because the strengthening effects of $\theta^\prime$ phase is the strongest, it is important to choose appropriate ageing technique — a combination of temperature and time, in order to achieve the desired $\theta^\prime$ phase [4,5,6]. The aged alloy is made up of $\alpha$-Al phase and $\theta^\prime/\theta^\prime\prime$ phase. Figure 4(a) illustrates that a massive black needle-like phase $\theta^\prime$ precipitated from the supersaturated $\alpha$-Al solid solution during ageing treatment. Figure 4(b) shows that the fine distribution of the $\theta^\prime$ phase is homogeneous after ageing treatment. This structure is blocking the movement of dislocations, and as a result improving the mechanical property obviously.

2.4 Mechanical properties

Tensile test data of the metal mould samples under different ageing conditions (solution treatment at 536°C for 12 h and aged at 160°C for various length of time) are summarized in Table 1.

The tensile strength vs the ageing time is shown in Fig.5. As can be seen, the tensile strength increases gradually with the ageing time, and the improvement rate becomes slow after 12 h ageing. The elongation vs the ageing time was shown in Fig.6, which decreases with increasing ageing time.

Prolonged solution time to 15 h (536°C) and increased ageing temperature to 175°C, and T6 treatment were carried out for different time. As shown in Fig.7, the tensile strength increases first and then decreases with ageing time. The elongation vs ageing time is shown in Fig.8. The elongation decreases gradually with the increase of ageing time. After aged for 12 h, both the strength and the elongation are slightly lower than that of aged for 8 h, indicating an over-ageing effect for the 12 h treatment. The strength can indeed be improved to 488.2 MPa by means of

<table>
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<th>Ageing time (h)</th>
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<th>Maximum displacement (mm)</th>
<th>Maximum stress (MPa)</th>
<th>Elastic modulus (MPa)</th>
<th>Elongation (%)</th>
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 extends solution time and increasing ageing temperature, but the ductility decreases as a consequence.

3 Conclusions

(1) The cooling rate of alloy in metal mould, SiC mould, Cr-ore mould, and common sand mould decreased in turn. As a result, the microstructure of the as-cast alloy using metal mould is the finest, and the common sand mould samples the coarsest. High cooling rate and fine grain can be obtained by using of metal mould.

(2) The tensile strength of ZL205 alloy increases and then decreases with extended ageing time; the elongation decreases after peak-ageing at 175°C. Similar phenomenon was found in the prolonged solution treatment and subsequent ageing at 160°C.

(3) The optimal heat treatment parameters for ZL205 alloy are as follows: 536°C for 15 h solution treatment using salt bath + ageing at 175°C for 8 h.

References