Influence of solution temperature on microstructure and mechanical properties of wrought Al-Si-Mg alloy

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Abstract. The microstructure and mechanical properties of wrought Al-12.7Si-0.7Mg alloy were investigated aiming at understanding the influence of the solution treatment. The result show that the Si particles were gradually rounded and the grain size increase with increasing the solution temperature from 500°C to 540°C. The alloy in T4 condition changed due to the grain size, Si particles and the super saturation level of Mg ans Si solute atoms. With higher solution temperature, the volume fraction of the precipitate becomes more which result in good manchannical properties.

Keywords: Wrought Al-Si-Mg alloy, Solution treatment, Microstructure, Mechanical property

1. Introduction
The main alloying elements in 6xxx Al-Mg-Si aluminum alloys and wrought Al-Si-Mg alloys are Si and Mg, which form Mg2Si phase in the equilibrium state and a series of transient phases as precipitation during aging treatment following solution treatment [1-4]. Al-Si alloys with addition of Mg make a big group of cast aluminum alloys for structural purpose.

The fact that the mechanical properties of the Mg bearing Al-Si alloys can be made comparable or even superior to that of the 6000 series alloys through traditional metallurgical process is attractive from the viewpoint of industrial application of the Al-Si alloys [5]. The strengthening mechanisms are from precipitation, grain boundary and particulate strengthening. The main feature of wrought Al-Si-Mg alloy is that it contains uniformly distributed silicon particles in the Al matrix of fine equiaxed grains.

During heat treatment process, the normal grain growth of Al matrix and the coarsening of the Si particles at high temperature might be restrained by mutual reactions. In this paper, The microstructure and mechanical properties of the alloy were investigated aiming at elucidating the impact of the solution treatment.

2. Material and methods
DC cast Al-12.7Si-0.7Mg billet without chemical modification in Ref. [5] was used in this study. After pre-heat-treatment at 480°C for 3 hours, the billets were extruded into a profile of 4 mm in thickness at the same temperature.

The extruded samples were solution-treated at 500°C, 520°C and 540°C for 30 min, and subsequently quenched into water. The quenched samples were artificial aged at 180°C for 3 h in a Muffle furnace. The tensile specimens and wear test specimens were prepared from extruded profile along the extruding direction. Specimens were tensile-tested at a cross-head speed of 1 mm/min on a SANS testing machine.
An optical microscope (Leica DMI 5000M) and a FEI Tecnai F20 transmission electron microscope (TEM) were used to observe the microstructures of samples. Image-Pro Plus image analysis software was used for investigation of the Si particle size distribution in the alloy and the grain size of the Al matrix.

3. Results and discussion

Fig. 1 show the microstructure of longitudinal (along the extrusion direction) of Al-12.7Si-0.7Mg alloy in T4 (solution treatment+natural aging) and T6(solution treatment+artificial aging), respectively. It can be seen that a number of Si particles distributed in Al matrix and the size of Si particle increase by varying the solution temperature. Aging at 180℃, the size of Si particle is not changed by the aging treatment. The Si particles and the grain sizes were obtained by measuring as shown in Table 1. It is noticed that the Si particles were gradually rounded and their aspect ratio were decreased in average. It is worthy to notice that the Al matrix grains increased to 5.5μm increasing solution treatment temperature to 540℃ which result in the decrease of YS and UTS.

![Figure 1. Optical micrographs of extruded alloy in different conditions](image)

500℃×30min, (b)520℃×30min, (c)540℃×30min, (d) 500℃×30min+180℃×3h, (e) 520℃×30min+180℃×3h, (f) 540℃×30min+180℃×3h.
Table 1. The size of the Si particle and grain of the alloy in different condition.

| Alloy statements                  | Si particles size (μm) | Aspect ratio | Grain size (μm) |
|----------------------------------|------------------------|--------------|-----------------|
| 500℃×30min+180℃×3h               | 2.8                    | 1.91         | 5.1             |
| 520℃×30min+180℃×3h               | 3.1                    | 1.70         | 5.2             |
| 540℃×30min+180℃×3h               | 3.0                    | 1.57         | 5.5             |

Table 2 lists the mechanical properties of the Al-12.7Si-0.7Mg alloy treated in different conditions. As shown in Table 1, yield strength (YS), ultimate tensile strength (UTS) and Elongation of the alloy in T4 and T6 tempers are much higher than that in T1 (as extruded). The optical microstructures shown in Fig.1 indicate that there are merely differences between that in T4 condition and that in T6 conditions. On the other hand, it is thus clear that precipitation hardening makes contribution to the increased YS and UTS in T6 treated alloy[6-8].

After solution treatment, the solubility of Mg2Si phase increases with increasing of solution temperature from 500℃ to 540℃. The Mg2Si phase is in the form of solute atoms into the matrix which act as solid-solution strengthening. The YS and UTS varies directly with introducing Mg and Si solute atoms. With more Mg and Si solute atoms into the matrix, and the strength of the alloy is higher[9]. Compared to 520℃, YS and UTS of the alloy decrease when heat treated at 540℃ because the equiaxed Al grain size increase to from 5.1 to 5.5μm.

Fig. 2 shows the bright-field TEM micrograph (B=[001] Al) of the alloy in T6 condition. The TEM images of the T6 condition alloy are characterized by very fine dot and needle precipitates. The needle-shaped precipitates are oriented along [010]Al and [100]Al directions. It can be seen that volume fraction of the precipitates is higher in Fig. 2(c) due to the more solute atoms in the matrix to form the precipitates.

Table 2. Mechanical properties of the Al-12.7Si-0.7Mg alloy in T1, T4 and T6.

| Alloy statement                  | YS (MPa) | UTS(MPa) | Elongation(%) |
|----------------------------------|----------|----------|---------------|
| T1(as extruded)                  | 108      | 190      | 15.0          |
| 500℃×30min                       | 136      | 263      | 16.2          |
| 520℃×30min                       | 162      | 292      | 13.7          |
| 540℃×30min                       | 148      | 285      | 15.9          |
| 500℃×30min+180℃×3h               | 250      | 313      | 7.4           |
| 520℃×30min+180℃×3h               | 270      | 333      | 7.3           |
| 540℃×30min+180℃×3h               | 293      | 358      | 6.7           |
4. Conclusion
(1) The Si particles were gradually rounded and their aspect ratio were decreased in average and the grain size increase with increasing the solution temperature from $500^\circ\text{C}$ to $540^\circ\text{C}$.
(2) Wrought Al-12.7Si-0.7Mg alloy in T4 condition have good mechanical properties due to solid-solution strengthening.
(3) Elevating the solution treatment temperature can effectively enhance the volume fraction precipitation phase.

5. References
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