Research on hardness and tensile properties of A390 alloy with tin addition

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Abstract. The effect of tin content on hardness and tensile properties of A390 alloys has been discussed. The microstructure of the A390 alloy with tin addition has been surveyed by OM and investigated by SEM. Research showed that β-Sn in the alloy precipitation forms were mainly small blocks and thin strips, particles within the Al2Cu network or large blocks consisting of β-Sn and Al2Cu on Al/Si interfaces or α-Al grain boundaries. Spheroidization of the primary and eutectic silicon was improved due to Sn accretion. With the augment of element tin, hardness of casting alloy is much higher than that of alloy after heat treatment. The elongation and ultimate tensile strength (UTS) were increased in Sn addition from 0 to 1%, which is attributed to the multiple action of Sn.

1. Introduction
Due to wearability, corrosion resistance, light resistance, aluminum silicon alloy has attracted many researchers' attention. The low curing rate results in a large number of segregation and rough microstructure in the casting of high silicon aluminum alloy. The problem of high eutectic aluminum silicon alloy ingot casting could be managed, through rapid solidification processing such as spraying, welding and cooling[1]. These alloys containing Al, Cu, Si, Zr, Mg, Ni and Fe were produced by rapid solidification, and melt spinning is one of effective rapid solidification methods[2].

At present scientists studied friction characteristics of aluminum silicon and tin alloys through the inject method. Research showed that wear resistance property of the alloy was related with Sn addition in Al-12.5Si-Sn. Homogeneous distribution of silicon particles in aluminum silicon alloys contributed to microstructural refinement. Tin and silicon particles homogeneous distributed in the regular array α-Al phase of aluminum silicon and tin alloys[3-4].

It was undertaken to special research on hardness and tensile properties by Sn additions. The existence form and distribution of Sn in the alloys were further discovered, and then maybe achieve a feasible measure to increase the machinability and abrasive resistance of aluminum silicon and tin alloys.

2. Experiment process
Composition of the alloy was demonstrated in the table 1 below. Firstly part of pure silicon and pure aluminum were heated in graphite oven. The second Step was to add the remaining silicon to the melt and fully melted. The third step is to add pure magnesium to the melt. After the melt was preheated at 200 °C, and mixed, the flux was casted into a grinding apparatus and made 25mm metal round rod. After sample was casted, heat treated temperature was 490 °C and treat time was 8h, and then the sample was quenched into 75°C water and thermal insulationat kept 200 °C for 8h.
Table 1. Alloy composition

| Elements | Silicon | Iron | Copper | Manganese | Magnesium | Zinc |
|----------|---------|------|--------|-----------|-----------|------|
| Percentage/wt.% | 16.0-18.0 | <0.5 | 4.0-5.0 | <0.2 | 0.45-0.65 | <0.1 |

3. Discussion and analysis

3.1. Microstructures

Fig. 1 displayed optical microstructures of as-cast alloys in various amounts of Sn. The microtissue of the alloys were slightly changed on aluminium silicon copper magnesium alloys with tin addition. Disintegrating and spheroidization in eutectic were promoted by addition of Sn.

Fig. 2 showed optical microstructures of heat-treated alloys in various amounts of Sn. In Fig. 2a, Without Sn, silicon particles in initial long acicular phases became thicker after the process of casting. However, after addition Sn, primary silicon and eutectic silicon disintegrated and spheroidized (Fig. 2b,c,d), especially for the heat-treated alloy added 3 and 5% Sn, the sharp angles of some polyhedral or primary silicon disappeared and most of the eutectic silicon and some of the primary silicon became spherical (Fig. 2c and d). This demonstrated that adding Sn facilitated spheroidization of eutectic and proved the formation of primary silicon in alloy sample after heat-treated.

![Fig. 1. Optical microstructures of as-cast alloys in different amounts of Sn: (a) 0%; (b) 1%; (c) 3% and (d) 5%](image1)

![Fig. 2. Optical microstructures of heat-treated alloys in different amounts of Sn: (a) 0%; (b) 1%; (c) 3% and (d) 5%](image2)

The effects of tin addition and solid-solution aging treatment on microform and β-Sn and Al2Cu phases were detected. Fig. 3 demonstrated the SEM micrograph of aluminium silicon copper magnesium alloys in various amounts of Sn. The alloys with 1% Sn, there was β-Sn in small blocks and thin belts at the boundary between the α-Al phases and total crystal si. (Fig. 3a); In 3% Sn alloy, β-Sn existed in particle forms on the Al2Cu neshwork (Fig. 3c). Increasing Sn to 5%, β-Sn and Al2Cu phases comprised large block (Fig. 3e), In the Sn addition alloys, fine strips, blocks and many particles on the Al2Cu neshwork gathered and merged after solid solution-aging treatment. When adding a small amount of Sn (1%), thin Sn layers were formed around Si particles and Sn as shown in Fig. 3(b). In the alloy with 5%Sn addition, there are some spheroidized Si particles in Sn layers forming peritectic structure (Fig. 3d). After adding the high concentration of Sn (5%), scattered and fine β-Sn phase
further gathered into large blocks around the grain boundaries and the interface of eutectic silicon as shown (Fig. 4f). On the other hand, it is noted that the as-heat-treated and cast samples various amounts Sn levels exhibit some porosity, especially for the alloys with high content of Sn (5wt.%), the pores in approximately 20μm have been observed. This result indicates that a large quantity of voids were developed as Sn additions in excess of a lower limit. According to binary phase diagrams, all Al-Si, Al-Sn and Si-Sn binary alloy systems are eutectic type ones and their eutectic reactions take place at 577 °C, 229 °C and 232 °C, respectively. The Sn contents at the eutectic points of Al-Sn and Si-Sn binary eutectic systems are nearly or more than 99.8% and very high, so Sn and Al, Sn and Si have mutual solid insolubility. On the other hand, any compounds are not formed between Al, Sn and Si.

Analysing the above data, it can be inferred that the Al-18Si–xSn (x = 1, 3 and 5) system is ternary eutectic system. The intermetallic phases, Al2Cu(θ), Cu2Mg5Si6Al5(Q), Al5FeSi(β) and Mg2Si, would precipitate during solidification. Therefore, the crystallization process of Sn-containing hypereutectic A390 alloy is as follows: Sn segregated in the form of a droplet in the alloy melt during the cooling process of the alloy melt as it has a low melting point, and mutual solid insolubility with Al and do not react with other elements. Then, Si atoms enriched around Sn droplets. Once the temperature of the melt approached to the liquidus temperature of the alloy, the primary silicon phase nucleated and grew. After that, the intermetallic phases such as Al2Cu precipitated one by one. When the temperature of the alloy melt reached eutectic one, binary eutectic reaction L→α(Al)+Si occurred and Sn droplets by oneself or with Al2Cu were pushed and squeezed into the phase by the growing eutectic silicon and α-Al until the eutectic reaction finished. With the temperature further decreasing, Sn concentration of the melt became higher, finally ternary eutectic reaction happened in melt with nearly pure Sn. Therefore, the Sn phases solidified in the cast state exist alone or coexist with the Al2Cu precipitated on the phase mainly in small particles, thin strips and large blocks (Figs. 3, a, c and e).

3.2. Hardness

Variations of hardness values are shown in Fig. 4. Under the as-cast, hardness value was 104 HB and hardness value was 138HB. 1% Sn addition, the hardness value reduced to 89,126HB respectively under the same condition. The hardness values reduced slightly with 3%Sn. However, hardness decreases sharply with 5%Sn.

Fig. 3. SEM (a) 1%Sn as cast alloy; (b) 1%Sn heat treated alloy; (c) 3%Sn as cast alloy; (d) 3%Sn heat treated alloy; (e) 5%Sn as cast alloy and (f) 5%Sn heat treated alloy
3.3. Tensile properties
Variations of tensile properties are shown in Fig. 5. The value of UST of the as-cast alloys decreased with the addition of Sn, and the influence trend was similar to that of the hardness value. With Sn content from 1, 3 to 5% the UTS values reduced 6.6, 23.7 and 31.1% comparing representative Ultimate tensile strength of the foundry alloy was 241MPa.

4. Conclusion
The conclusions that Sn content effected on hardness and tensile properties of hypereutectic aluminium silicon magnesium copper alloys can be concluded:

1) There was slightly change on the microtissue of hypereutectic alloys with Sn addition. Primary silicon and eutectic silicon disintegrated and spheroidized, and eutectic Si phase in acicular -like became shortish.

2) β-Sn in alloys precipitation forms were mainly small blocks and thin strips, particles within the Al12Cu network or large blocks consisting of β-Sn and Al12Cu on Al/Si interfaces or α-Al grain boundaries. Spheroidization of the eutectic and primary silicon of the Al-Si-Mg-Cu alloy was improved by Sn addition.

3) With the augment of element tin, hardness of casting alloy is much higher than that of alloy after heat treatment.

4) The elongation and ultimate tensile strength (UTS) were increased in Sn addition from 0 to 1%, which is attributed to the multiple action of Sn.

5) The impression of the Sn addition on the mechanical properties of hypereutectic Al-Si-Mg-Cu alloys are rooted in by a combination of the promotion role of Sn in the precipitation hardening and spheroidization. Adding content of Sn depends on the Sn softening and the cracking of the porosity produced, which effect hardness and tensile properties of the alloys [7].
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