SEMI-SOLID SOLIDIFICATION STRUCTURE IN GRAIN-REFINED AL-7%SI-3%CU ALLOY

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ABSTRACT The change in the morphology of the dendritic primary α-Al crystals heated at the semi-solid temperatures was examined in Al-7%Si-3%Cu alloy containing 0.1～1.0% Fe. Dendritic α-Al crystals, which were refined by Ti-B addition and solidified with higher cooling rate than 10K/s, spheroidize only by heating up to the semi-solid state without stirring. The size of the spheroidized primary α-Al crystals is about 100 μm in diameter. The elongation of the as-semi-solid cast materials is superior to that of the conventional gravity diecast materials, causing 9% of elongation even in the alloy containing 1% Fe. The tensile properties of the alloy materials containing small amount of Mn are further improved by changing morphology of Fe intermetallic compounds from needle-like form to Chinese script one.

Keyword: *semi-solid solidification, morphology, grain-refinement, mechanical property, Al-Si-Cu alloy*

1. INTRODUCTION

The semi-solid squeeze casting is a near-net-shape process that alloy billet are heated to the solid-liquid coexisting state and cast by high pressure. Though in the conventional casting from complete liquid state, the structure of primary α-Al crystals is the dendritic morphology, in semi-solid casting that is the spherical one. Therefore, the semi-solid cast materials with high tensile strength and high toughness can be obtained [(1)~(4)]. In this process, the structural control of billets and the sever temperature control in semi-solid stages are necessary due to the good fluidity in the semi-solid state. In the past, the refinement and the spheloidization of primary α-Al crystals have been achieved by shearing dendrite arms with mechanical or electric stirring in the semi-solid state [(5)~(7)]. However, it is difficult to spread such methods that need the large-scale equipment and the high production cost. So it is important to realize the simple production process of billets that make easily the spheloidization of primary α-Al crystals possible only by heating to the semi-solid state.

On the other hand, in the recent recycle and reuse of cast and wrought Al alloy materials, it is difficult to purify them owing to the mixture of impurities, especially Fe intermetallic compounds. The iron is the most deleterious large amount of impurities element in aluminum alloy casting, since it forms large needle-like brittle compound. In the semi-solid process, impurities are gathered in the liquid region, and solidified under rapid cooling rates by pressure casting. Therefore, even if the semi-solid cast materials contain some amounts of Fe, it is expected that the mechanical properties of the casting are improved comparing with those of conventional cast materials. It has been well known that the addition of certain elements such as Mn and Cr can change the morphology of the Fe compounds from needle-like form to less harmful Chinese script one [9]. Mn is the most common addition element that is used to modify the morphology and type of Fe compounds.

The purposes of this study are to investigate the solidification structure and the production condition of the alloy ingots that α-Al crystals will easily spheloidize only by heating to semi-solid temperature, to control the morphology of Fe intermetallic compounds by the addition of Mn on in the semi-solid casting, and to improve mechanical properties of high Fe contained Al-7%Si-3%Cu-1%Fe alloy by means of semi-solid processing.

2.EXPERIMENTAL PROCEDURE

Al-7%Si-3%Cu alloy ingots with various amount of Fe and Mn were prepared by melting Al-25%Si, Al-35%Cu and Al-7%Fe master alloys and 99.9% purity aluminum, and pouring into metallic mold. In this study, 0.2%Ti and 200ppmSr were added for the refinement of primary α-Al crystals and eutectic Si phase. The cooling rate during solidification was about 10K/s, the pouring temperature was 917K above 30K from liquidus temperature. Sectioned ingot specimens were reheated at a semi-solid temperature of 860K for 0.6ks, then cast and solidified under the pressure of 50MPa. Some cast specimens were solution heat-treated at 773K for 86.4ks. The microstructures of cast specimens were examined by an optical microscope. Specimens for the tensile test were machined to a gage diameter of 3.6mm and a gage length of 12mm. Tensile tests were conducted at a constant strain rate of 7×10^{-4} s^{-1} at room temperature. The microstructures of near fractured surfaces for each specimen were examined.

3.RESULTS AND DISCUSSION

3.1 Microstructure of semi-solid cast Al-7%Si-3%Cu alloy

The microstructure of an as-gravity diecast Al-7%Si-3%Cu-1%Fe alloy ingot is shown in Fig.1(a) that contained 0.2%Ti and 200ppm Sr, was poured at 917K and solidified in the cooling

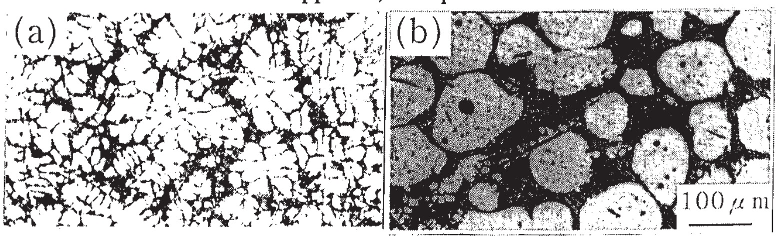

Fig.1 Microstructures of Al-7%Si-3%Cu-1%Fe alloys under (a) as-gravity diecast,(b) semi-solid cast at 860K.

rate of 10K/s. Primary α-Al crystals have dendritic morphology with short dendrite arms. The dendritic grain size is about 100 μm in diameter. This morphology results from the effects of high cooling rate and grain refiner,Ti. Eutectic Si phase and Fe intermetallic compounds, Al_5FeSi β phase, crystallized as needle-like phase. The length of this Fe compounds is about 50 μm.

The microstructure of semi-solid cast Al-7%Si-3%Cu-1%Fe alloy containing 0.2%Ti and 200ppm Sr is shown in Fig.1(b). The morphology of primary α-Al crystals changes from dendritic form to spherical one owing to only heating the alloy ingot to 860K. The size of primary α-Al crystals is the almost same, about 100~150 μm, as that of as-gravity diecast structure. In this case, it is considered that the following three phenomena occur at the same time during the heating to semi-solid temperature; first, the morphological change of primary α-Al crystals from dendritic form to spherical one, second, the coarsening of the α-Al crystal grain with Ostwald ripening, and third, the partial melting of α-Al crystals according to the equiliburium phase diagram. These phenomena are caused by diffusion of elements for decreasing interfacial energy of all system. This spheloidization of α-Al crystals has priority over other morphological change. This result shows that the materials with fine and spherical microstructure are easily obtained only by heating gravity diecast ingot. However, Fe intermetallic compounds still exist as needle-like form.

3.2 Microstructure of semi-solid cast Al-7%Si-3%Cu alloy solution treated

The microstructure of semi-solid cast Al-7%Si-3%Cu-1%Fe alloy solution heat- treated for 86.4ks at 773K is shown in Fig.2. No change in the size and morphology of spherical α-Al crystals and Fe intermetallic compounds can be observed, but the morphology of eutectic Si crystal changes from needle-like form to spherical one. This result takes place by the same reason as the spheloidization of primary α-Al crystal.

Fig.2 Microstructure of semi-solid cast Al-7%Si-3%Cu-1%Fe alloy solution treated at 773K for 86.4ks.

3.3 Effect of Mn in Al-7%Si-3%Cu-1%Fe alloy

The microstructures of as-gravity diecast Al-7%Si-3%Cu-1%Fe alloy containing 0.1~1.0%Mn is shown in Fig.3. In the high Mn content, Fe intermetallic compounds crystallize as Chinese script form (α phase) or disk shape (sludge, primary α phase), not as needle-like form (β phase). This result shows the change of the system itself owing to addition of Mn. The α phase sludge is very hard and brittle and will become the hard spots in machining. Therefore, the number and size of the α phase sludge should be decreased. In the low Mn content, less than 0.3%Mn, the α phase sludge is not observed, needle β phase and the small amount of Chinese script α phase exist, and the length of needle β phase decreases with increasing Mn content.

The microstructures of semi-solid cast Al-7%Si-3%Cu-1%Fe alloys containing Mn is shown in Fig.4. The needle β phase dissolves once by heating alloy these specimens to

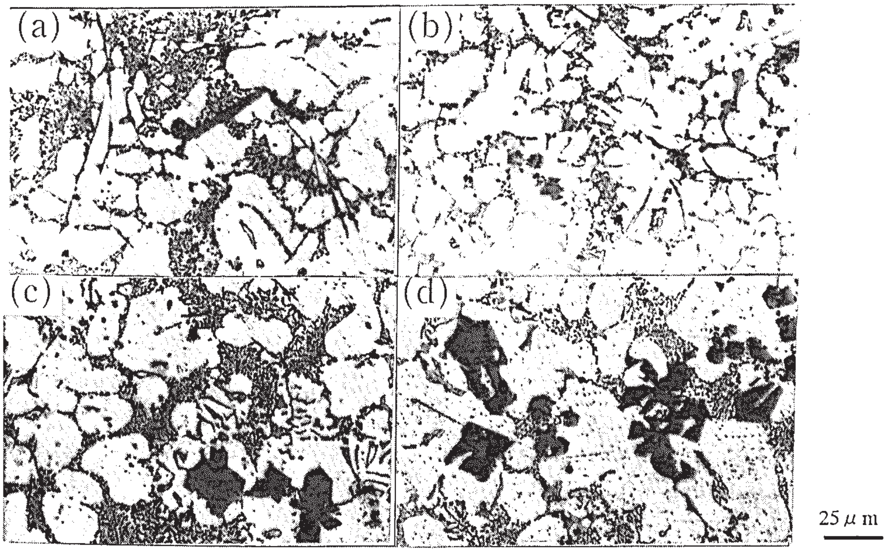

Fig.3 Influence of Mn contents on microstructure of as-cast Al-7%Si-3%Cu-1%Fe alloy, (a) 0.1%Mn (b) 0.3%Mn (c) 0.5%Mn (d) 1.0%Mn.

860K of semi-solid temperature, but the Chinese script α phase does not dissolve and exists in the liquid region. The dissolution of β phase results from the lowing of the melting point of β phase due to an addition of Mn. However, the α phase sludge do not change even after heating to 860K and exists as disk shape with a size of about 30

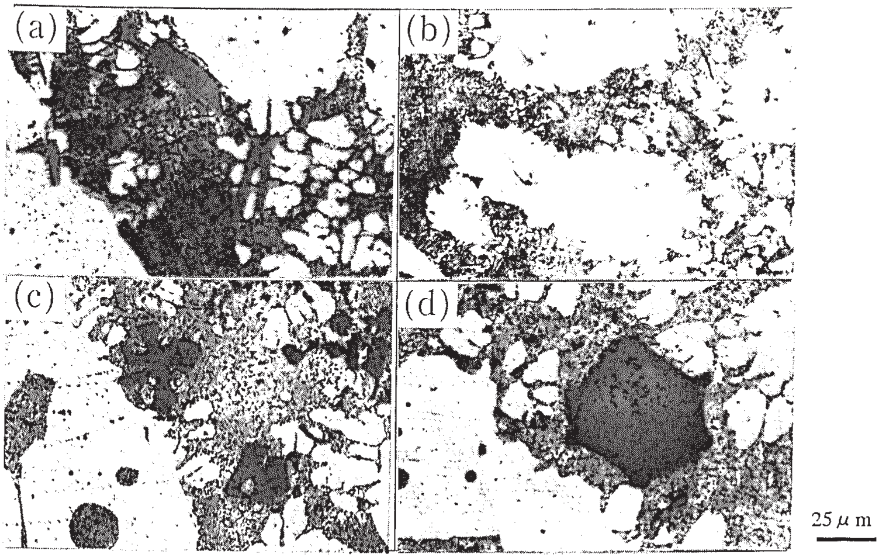

Fig.4 Influence of Mn content on microstructure of semi-solid cast Al-7%Si-3%Cu-1%Fe alloy.(a)0.1%Mn(b)0.3%Mn(c)0.5%Mn(d)1.0%Mn.

μm. Therefore, it is predicted that the addition of 0.3%Mn in which composition α phase sludge can not be observed is the most suitable composition for the dispersion and the refinement of Fe compounds.

3.4 Mechanical properties

Figure5 shows tensile properties of Al-7%Si-3%Cu-1%Fe alloy materials which were gravity diecast, semi-solid cast and semi-solid cast T4-treated. The higher Fe content is, the lower UTS and elongation are. It is to be pointed out that though the elongation of conventional iron mold cast material is very low, 2 ~3%, that in semi-solid cast material has high value about 9%, even in the alloy containing 1%Fe. This improvement results from the relaxation of the stress concentration at specific points due to the morphological change of primary α-Al crystals and extreme refinement of the structure of the remelted and resolidified region. By T4-treatment, the elongation further increases to 10~25%. This shows that the spheloidization of eutectic Si is the most effective. However, in the alloys with high Fe content of 0.8 ~ 1.0%, the negative effect due to crystallization of needle-like β phase appears firmly and then the positive effect obtained by T4-treatment remarkably decreases.

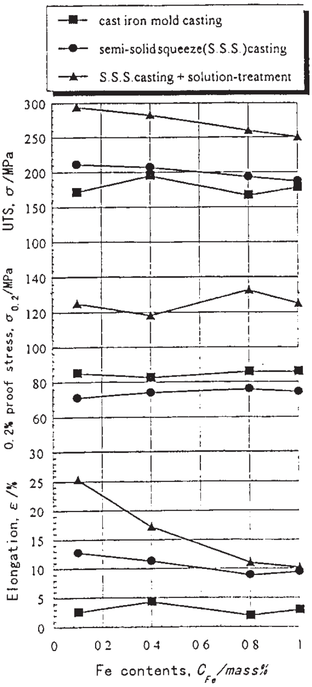

Fig.5 Mechanical properties of Al-7%Si-3%Cu alloy.

0.2% proof stress of the semi-solid cast materials is the least. Cu concentration in spherical α-Al grains of semi-solid cast materials is lower than that of conventional iron mold cast materials,

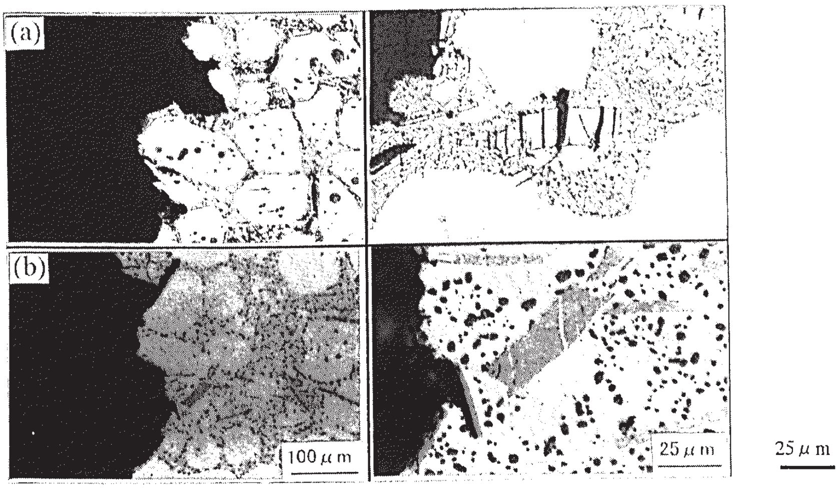

Fig.6 Microstructures near fractured surfaces in Al-7%Si-3%Cu-1%Fe alloys, (a) as-semi-solid cast and (b) solution heat-treated.

and the grain size of the semi-solid cast materials is larger than that of the iron mold cast materials. No influence of Fe contents on 0.2% proof stress can be seen because 0.2% proof stress depends on the strength of the α-Al matrix

Figure 6 shows the microstructure of near fractured surfaces of each material. Primary α-Al crystals careers deformation since the grains of spherical α-Al crystals have been deformed to tensile direction. Fractures take place at the interface between spherical primary α-Al crystal and eutectic region. In the alloys with high Fe content, many cracked Fe intermetallic compounds are observed. This result shows that Fe intermetallic compounds become the origin of the fracture and the path for the crack propagation, because the large stress concentration takes place on Fe intermetallic compounds with needle-like form. Similarly, in T4-treated materials, the cracked Fe intermetallic compounds are observed. However, the elongation and UTS in the alloys with high Fe content have high values comparing with those of conventional gravity diecast materials.

4.CONCLUSIONS

1. In Al-7%Si-3%Cu-0.1～1%Fe alloys, which were controlled the morphology as the refined equiaxed dendritic structure by the addition of grain refiner,Ti and the high cooling rate, primary α-Al crystals can be easily spheloidized only by heating to the semi-solid state.
2. The addition of Mn more than 0.3% changes the morphology and crystal structure of Fe intermetallic compound from needle β phase to Chinese script α phase or α phase sludge. By heating to semi-solid temperature, the Chinese script α phase is dispersed and β phase remelts in liquid region. However, no change in α phase sludge can be observed.
3. Even if Fe content is 1.0%, the elongation of the semi-solid cast materials is about 9%. This results from the positive effect of the spheloidization of primary α-Al crystals and extreme refinement of the structure of the remelted and resolidified region.
4. In T4-treated semi-solid cast materials, Cu concentration in primary α-Al crystals increases and eutectic Si crystals spheloidize, and then the elongation, UTS and 0.2% proof stress increase.

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