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Influence of Purity on Tensile Property of Al–Si Hypo-Eutectic Alloy Castings

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Influence of alloy purity on the tensile properties of Al–Si eutectic alloy castings has been investigated by using two kinds of the melted alloys: L-Alloy of 99.89 mass% purity and H-Alloy of 99.98 mass% purity. Although the base structure in both of alloys was composed of proeutectic α-phase and eutectic structure, the eutectic structure of H-Alloy was finer than that of L-Alloy. Coarse crystals of plate-like silicon were observed in L-Alloy, while were not observed in H-Alloy. Based on the results of Brinell Hardness Test on the solidification structure, it was found that there was little difference of the hardness between the both alloys. Tensile tests were also performed in an atmosphere at room temperature. The elongation of H-Alloy was twice as large as that of L-Alloy, though the tensile strength of L-Alloy and H-Alloy were almost the same.

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1. Introduction

Aluminum alloys have been used positively for the parts of automobile and transport vehicles to increase energy-saving and to reduce exhaust-emissions by means of the weight reduction. Impact absorption parts, suspension parts have been replaced by aluminum alloy castings for further weight reduction. To perform the replacement, it is important to develop the aluminum alloy castings possessing a high quality and a high reliability. To meet these demands, many investigations on the mechanical properties of aluminum alloy castings have been performed, which have examined the effects of casting condition,[1)] cooling rate,[2)] heat treatment,[3–5)] modification,[6)] impurity elements,[7)] structure or cast defect,[8)] inclusion,[9)] content of hydrogen or oxygen.[10)] However, few investigations have been made on the mechanical properties of aluminum alloy castings by making the best use of the reduction of impurities. In the future, the metallic materials which have simple compositions can be easily recycled and should be developed. The present authors reported that there was a possibility of improving the elongation by purification without remarkable decreasing of the tensile strength for AC4CH.[7)] However, the cause of large elongation has not been clarified yet. Also it was reported that the mechanical properties of Al–Si system alloy are affected by eutectic solidification structure.[11)]

In the present work, the influence of alloy purity on the tensile property was investigated by using two kinds of Al–Si eutectic alloy castings with different levels of purity.

2. Experimental Procedure

Two kinds of Al–Si hypo-eutectic alloys, L-Alloy and H-Alloy, were prepared. L-alloy was made from 99.7 mass% Al and 99.999 mass% Si. H-Alloy was made from 99.99 mass% Al and 99.999 mass% Si. These alloys were melted by means of high frequency induction heating using a cold-copper-crucible. There is no impurity contamination from the crucible into the molten metal. Before the melting, the chamber of the furnace was evacuated to 1×10^{-1} Pa by a rotary pump and replaced with the high purity argon gas to the atmospheric pressure, so few gaseous impurities from the atmosphere permeated the molten metal. As a result, it became possible to make an ingot which keeps the purity of raw material. The weight of an ingot was 500 g. The melting was performed under conditions where all of raw materials were set in the crucible. For such melting condition, a maximum out-put power was set at 80 kW, and the total melting time was 1200 s. After the out-put power was reduced, the molten metal was solidified in the cold-crucible. The ingot was an acorn-shape which was 60 mm in diameter and 90 mm in length.

The test pieces, for chemical composition analysis, metallographic examination, hardness test and tensile test, were cut out from regions having homogeneous structure of the ingot, and regions around the shrinkage cavity and the ingot surface were not used for the tests. The eleven elements provided by JIS H 5202 and modification elements which were calcium, sodium, phosphorus, antimony and strontium were analyzed to estimate the purity of the ingot. A hardness test was performed to examine the effects of the purity to hardness. A tensile test was performed by $1.4 \times 10^{-3}\,s^{-1}$ of strain rate. After this test, a fractured surface was observed by means of a scanning electron microscopy (SEM).

3. Results and Discussion

3.1 Comparison of Composition and Purity

Table 1 shows the results of chemical analysis. Silicon was analyzed by a gravimetric method and other elements were analyzed by methods for inductively coupled plasma emission spectrometric analysis where the quantitative limit was 10 mass ppm. The contents of silicon in L-Alloy and H-Alloy were almost the same and both melted alloys were confirmed to be a hypo-eutectic alloy. The contents of cupper and iron in L-Alloy were more than that in H-Alloy. Modification element of calcium was contained in both alloys by 10 mass ppm, but other modification elements were contained under the quantitative limit. The elements except for aluminum and silicon were regarded as impurity elements and the purity of the each alloy was estimated. The purity of L-Alloy was 99.89 mass% and H-Alloy was 99.98 mass%.

Table 1 Chemical composition of alloys.

	L-Alloy	H-Alloy
Cu	0.024	—
Si	11.2	11.1
Mg	0.002	0.004
Zn	<0.001	—
Fe	0.074	0.013
Mn	0.001	<0.001
Ni	—	—
Ti	0.003	<0.001
Pb	—	—
Sn	—	—
Cr	<0.001	<0.001
Ca	0.001	0.001
Na	<0.001	<0.001
P	<0.001	<0.001
Sb	<0.001	<0.001
Sr	<0.001	<0.001
Al	bal.	bal.

(unit: mass%)

3.2 Comparison of Solidification Structure

Figure 1 shows the solidification structure of the alloys. As shown in Figs. 1(a) and (c), the base structure of the alloys consisted of α aluminum dendrite and eutectic structure. The α aluminum dendrite in L-Alloy was thicker than that in H-Alloy. As shown in Figs. 1(b) and (d), the eutectic structure in H-Alloy was finer than that in L-Alloy. A coarse crystal of plate-like silicon, which is shown in Fig. 1(b), was observed in L-Alloy, but none was observed in H-Alloy. The solidification structure of casting is affected by the following conditions: casting temperature, cooling rate and so on. Both L-Alloy and H-Alloy were made in the same conditions, so it is not thought that these conditions brought about the difference of the solidification structures between L-Alloy and H-Alloy. It was found generally that the morphology of eutectic silicon in Al–Si alloy changes due to various modification elements.[12] It is reported that the eutectic silicon in AC4CH alloy was refined by addition of 11 mass ppm calcium.[13] As shown in Table 1, both L-Alloy and H-Alloy contained 10 mass ppm calcium, so the morphology of eutectic silicon may have changed because of calcium content. But it is not considered to be the cause of the difference of eutectic structure, because the calcium content of the both alloys was same. It is reported that the minute amounts of phosphorus in Al–Si eutectic alloy affected the solidification structure, and the phosphorus existed in the coarse crystal of plate-like silicon.[14] Phosphorus in L-Alloy was analyzed by electron probe micro analysis (EPMA). Figure 2 shows a result of analyses for the α aluminum dendrite and the coarse crystal of plate-like silicon. The intensity level of phosphorus in Fig. 2(a) is constant, while in Fig. 2(b) it is somewhat high in the field of the coarse crystal of plate-like silicon. As a result, it was found that there were minute amounts of phosphorus in the coarse crystal of plate-like silicon. From these findings, we concluded that the minute amounts of phosphorus are one of the causes which brought about the difference of the eutectic structure between L-Alloy and H-Alloy. To understand more clearly what causes the difference of the solidification structure between L-Alloy and H-Alloy, it is necessary to conduct certain quantitative analysis of the modification elements which were under quantitative limit, and to examine the interaction between modification elements and impurity elements such as iron and copper.

3.3 Effect of Purity on Hardness and Tensile Property

To examine the effect of alloy purity on the hardness of Al–Si hypo-eutectic alloy, Brinell Hardness Tests were performed for L-Alloy and H-Alloy. The hardness of L-Alloy was BHW:55 and H-Alloy was BHW:52. Little difference between the hardness of the both alloys was found.

Figure 3 shows the results of tensile tests for L-Alloy and

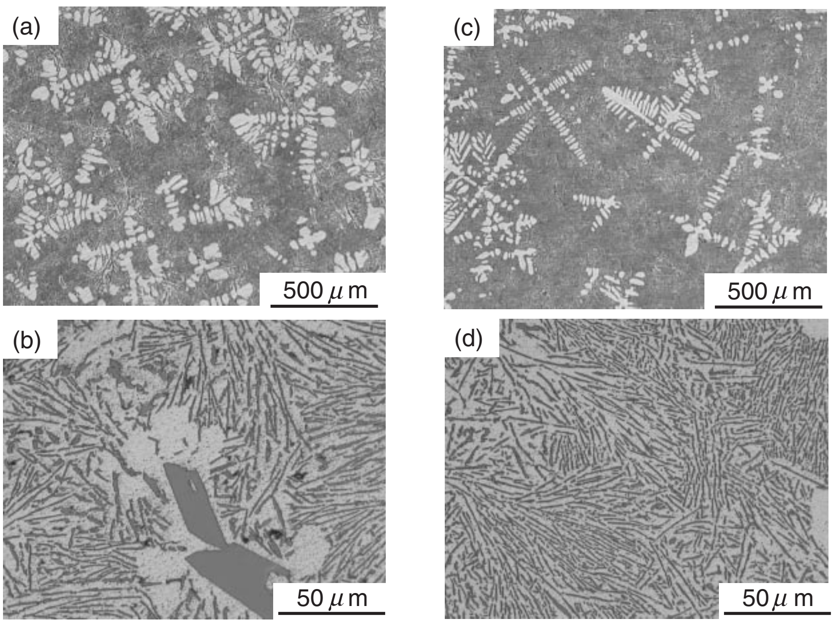

Fig. 1 Optical microscope images of solidification structure, (a) and (b): L-Alloy, (c) and (d): H-Alloy.

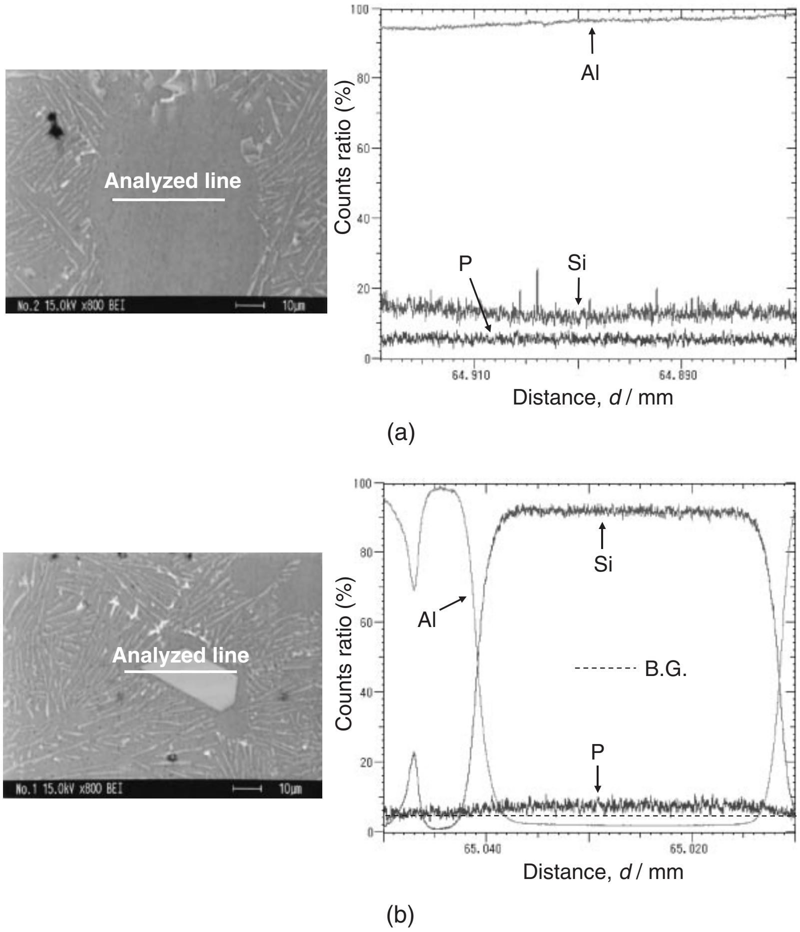

Fig. 2 (a) Results of SEM observation and EPMA for α aluminum in L-Alloy. (b) Results of SEM observation and EPMA for coarse crystal of plate-like silicon in L-Alloy.

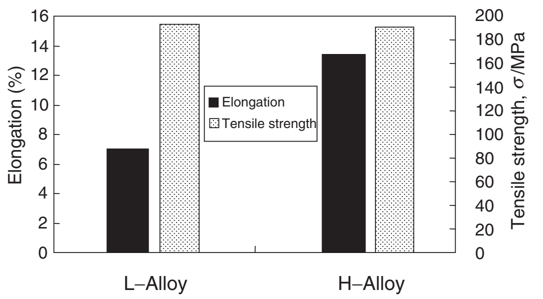

Fig. 3 Results of tensile test.

H-Alloy, where the tensile strength and the elongation were obtained by averaging three measurements. The tensile strength of L-Alloy was 193 MPa and H-Alloy was 191 MPa, so the tensile strength of the both alloys was almost the same. On the other hand, the elongation of L-Alloy was 7.0% and H-Alloy was 13.4%, so the elongation of H-Alloy was twice as large as the L-Alloy. It is well known that the elongation of metallic material becomes larger with the decreasing of its hardness. In this case, however, elongations of L-Alloy and H-Alloy were markedly different from one another, in spite of the fact that they had nearly same strength and hardness. From these results, on Al–Si eutectic alloy casting, it can be proved that there is a possibility of improving the elongation by purification without any remarkable decrease in tensile strength.

3.4 Observation of Fractured Surface

Figure 4 shows SEM images of a fractured surface for L-Alloy and H-Alloy. The observation was performed from tensile axis direction. Figures 4(a) and (c) show low magnification images of the whole fractured surface. The fractured surface of L-Alloy was more rugged than that of H-Alloy. Figures 4(b) and (d) show high magnification images of the each alloy. It can be seen that there were more flat-planes on the fractured surface of L-Alloy than H-Alloy. On the fracture surface in L-Alloy, the flat-planes were analyzed by energy dispersive X-ray microanalysis. Figure 5 shows a result of analysis focused on the hexagonal flat-plane. The contents of silicon and aluminum were about 75 mass% and 25 mass% respectively, suggesting that the hexagonal flat-plane may be a silicon crystal. Aluminum could be the remains on the eutectic silicon after the interface fracture between α-phase and eutectic silicon. These findings reveal that a lot of the large-scale fracture occurred at the interface between α-phase and eutectic silicon in L-Alloy, and we surmised that the binding-strength of interface between α-phase and eutectic silicon in L-Alloy might be weaker than that in H-Alloy. In a previous investigation which the present authors have carried out,[7)] the improvements of elongation for α-phase and binding-strength of interface between α-phase and eutectic silicon in eutectic structure were thought to be the causes of large elongation for AC4CH-T6 by purification. The both alloys of this study extensively reveal

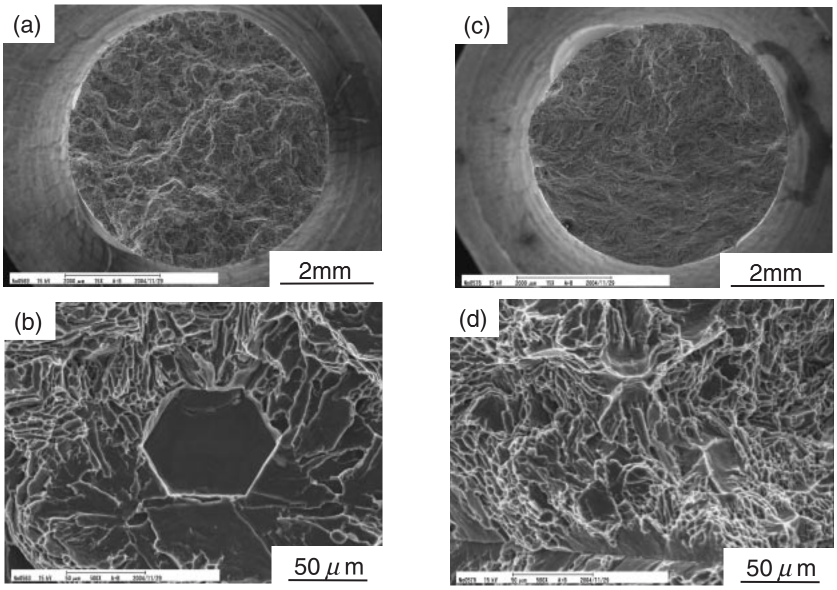

Fig. 4 SEM images of fractured surface, (a) and (b): L-Alloy, (c) and (d): H-Alloy.

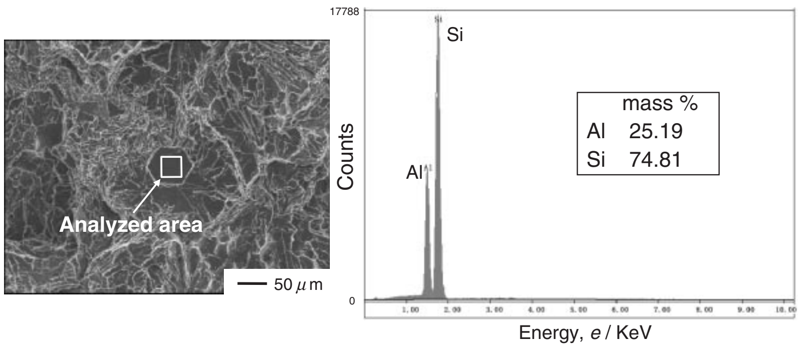

Fig. 5 Results of SEM observation and EDS analysis on the hexagonal flat-plane.

the eutectic structure and the eutectic structure exhibits an appreciable difference between them. Considering together with the results of analyses on fracture surface, the binding-strength of interface between α-phase and eutectic silicon may affect fracturing behavior and elongation through the effect of purifying.

4. Conclusion

Two kinds of Al–Si eutectic alloy castings which have different purities were melted in a cold-crucible furnace. Solidification structure, hardness and tensile property of the two alloys were compared. The results obtained in this investigation are as follows:

(1) No coarse crystal of plate-like silicon was observed and the eutectic structure was fine in the solidification structure of Al–Si hypo-eutectic alloy casting which is 99.98 mass% purity.

(2) It was found that there is a possibility of improving the elongation by purification without any remarkable decrease in tensile strength for Al–Si eutectic alloy casting.

(3) There are more flat-planes on the fractured surface of Al–Si hypo-eutectic alloy casting with 99.89 mass% purity rather than that with 99.98 mass% purity.

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