EFFECT OF MICROSTRUCTURAL VARIATION ON MECHANICAL PROPERTIES OF HYPEREUTECTIC Al-Si CASTING ALLOYS

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ABSTRACT The effects of the addition of phosphorus and the spheroidization of primary silicon particles on mechanical properties such as tensile strength and both static and impact fracture toughness were investigated in hypereutectic Al-Si casting alloys with several silicon concentration. The mechanical properties decrease with increasing silicon concentration. Minute primary silicon particles with round corners are obtained by applying modification, and they are spheroidized by adding spheroidization treatment. The modification by adding phosphorus contributes to the improvement in mechanical properties. The spheroidized alloys exhibit more obvious improvement, except for the static fracture toughness.

Keywords: *hypereutectic Al-Si casting alloys, microstructure, tensile properties, impact toughness, fracture toughness*

1. INTRODUCTION

Hypereutectic aluminium-silicon casting alloys are utilized for engineering applications, e.g. piston and cylinder block in combustion engine. These applications generally need low thermal expansion coefficient and high wear resistance as material properties.

The mechanical properties of these alloys are largely dependent on the configuration of primary silicon particles. Generally, the primary silicon particles in the aluminium matrix are coarse and irregular when cooling rate during solidification is not so high. Such particles often act as crack initiation sites due to stress concentration and low fracture strength, which causes the degradation of mechanical properties. The modification of primary silicon particles is usually performed by adding phosphorus, sulfur or arsenic [1,2]. The addition of these elements makes the shape of primary silicon particles finer and round, thereby improving the mechanical properties [3].

However, there are few quantitative information on the effect of microstructures on the mechanical properties, especially fracture toughness, in hypereutectic Al-Si casting alloys. Therefore, in the present study, the effect of microstructural variation by the addition of phosphorus and/or the spheroidization of primary silicon particles on tensile properties, impact toughness and static fracture toughness was investigated in hypereutectic Al-Si casting alloys with varying silicon concentration.

2. EXPERIMENTAL PROCEDURE

The hypereutectic Al-Si casting alloys used in this study was prepared using 99.9% pure Al, Al-25%Si master alloy, Al-30%Cu master alloy and 99.9% pure Mg. Their chemical compositions are shown in Table 1. The phosphorus concentrations, which were controlled by adding Al-1.2%P master alloy are also shown in Table 1. Nonmodified alloys contains 0.0006-0.0007%P. Molten alloys were held at 1033K, and then poured into a metal mold preheated at 423K. Also the combination of modification and spheroidization was applied to a series of alloys in Table 1. The heat treatment conditions are given in Table 2.

Table 1 Chemical composition (mass%)

	Si	Fe	Cu	Mg	P	Al
Al-11Si	11.0	0.08	4.46	0.66	0.0007	bal.
Al-15Si	14.7	0.09	4.61	0.66	0.0060	bal.
Al-17Si	16.5	0.10	4.68	0.66	0.0084	bal.
Al-19Si	18.3	0.10	4.70	0.64	0.012	bal.
Al-21Si	21.4	0.11	4.72	0.64	0.0092	bal.

Table 2 Heat treatment conditions in each alloy

	Spheroidization treatment	Solution treatment	Aging treatment
Nonmodified and P modified alloys	———	773K×14.4ks W.Q.*	453K×21.6ks A.C.**
Spheroidized alloys	773K×360ks W.Q.	773K×14.4ks W.Q.	453K×21.6ks A.C.

* W.Q. : Water quenching
** A.C. : Air cooling

The geometry of tensile specimens were determined according to JIS Z 2201 standard. Tensile tests were conducted at room temperature using an Instron testing machine at the cross head speed of $8.3\times10^{-6}ms^{-1}$. Impact tests were carried out using a Computer Aided Instrumented Charpy impact testing system [4] with the impact velocity of $1.4ms^{-1}$ at room temperature. The maximum load, crack initiation energy, Ei, crack propagation energy, Ep, and total absorbed energy until fracture, Et (=Ei+Ep), were measured using V-notched specimens. The specimens of static fracture toughness tests were machined according to JSME S001. Static fracture toughness tests were carried out using an Instron testing machine at the cross head speed of $5.0\times10^{-6}ms^{-1}$ at room temperature. Three-point bending specimens with fatigue precrack were used.

3. RESULTS AND DISCUSSION

The representative microstructures of the present alloys are shown in Fig.1. Needle-like eutectic silicon particles are observed in the nonmodified alloys, while fine and round particles are obtained by the spheroidization treatment as shown in Fig.1 (b). The addition of phosphorus makes the shape of the primary silicon particles finer and round as shown in Fig.1 (d). More spherical primary silicon particles are attributed to subsequent spheroidization treatment as shown in Fig.1 (e).

The effects of the Si content, phosphorus modification and spheroidization on the tensile strength are depicted in Fig.2. The tensile strengths of all the alloys decrease with increasing the silicon content. Modification and spheroidization are much more effective in the 21%Si alloys. 11%Si alloys exhibit elongation of about 1% in average, while 15-21%Si alloys don't show any noticeable ductility.

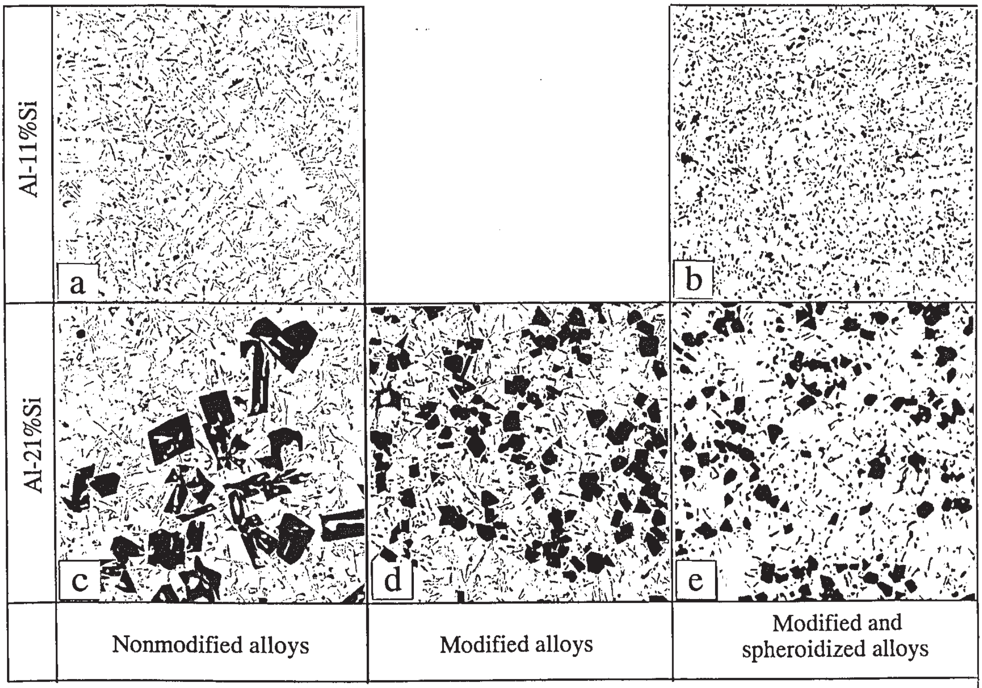

Fig.1 Optical microstructures.

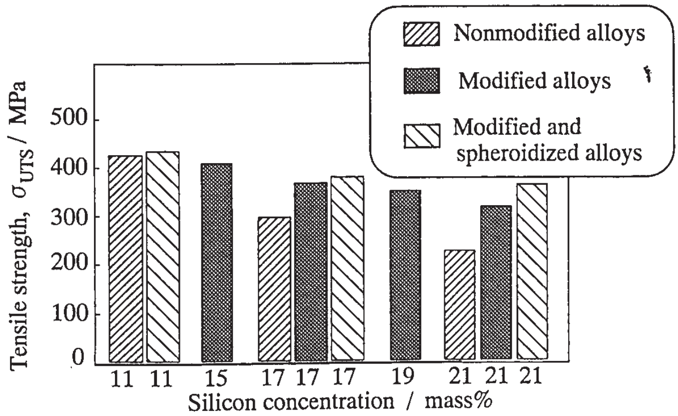

Fig.2 Tensile strength.

Impact properties obtained from the V-notched impact tests are shown in Fig.3. The alloys containing 17%Si exhibit the largest maximum loads and absorbed energies. The addition of phosphorus remarkably improves the maximum load and the absorbed energy. The improvement in impact properties by the phosphorus addition is considered to be caused by the fine and round

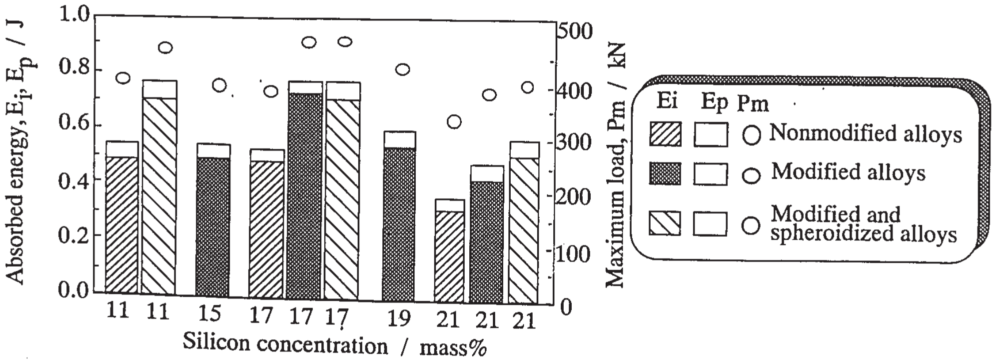

Fig. 3 Results of Charpy impact tests using V-noched Charpy specimens.

morphology of the primary silicon particles. The modification of primary silicon minimizes the stress concentration around a primary silicon particle, which contribute to the increase of crack initiation toughness by retarding microscopic damage initiation. The spheroidized alloys containing 11 and 21%Si show remarkable improvement in comparison to the other Si contents. The spheroidization brings more complete improvement in configuration of both the eutectic silicon and primary silicon particles, which contributes to the additional improvement of the impact properties.

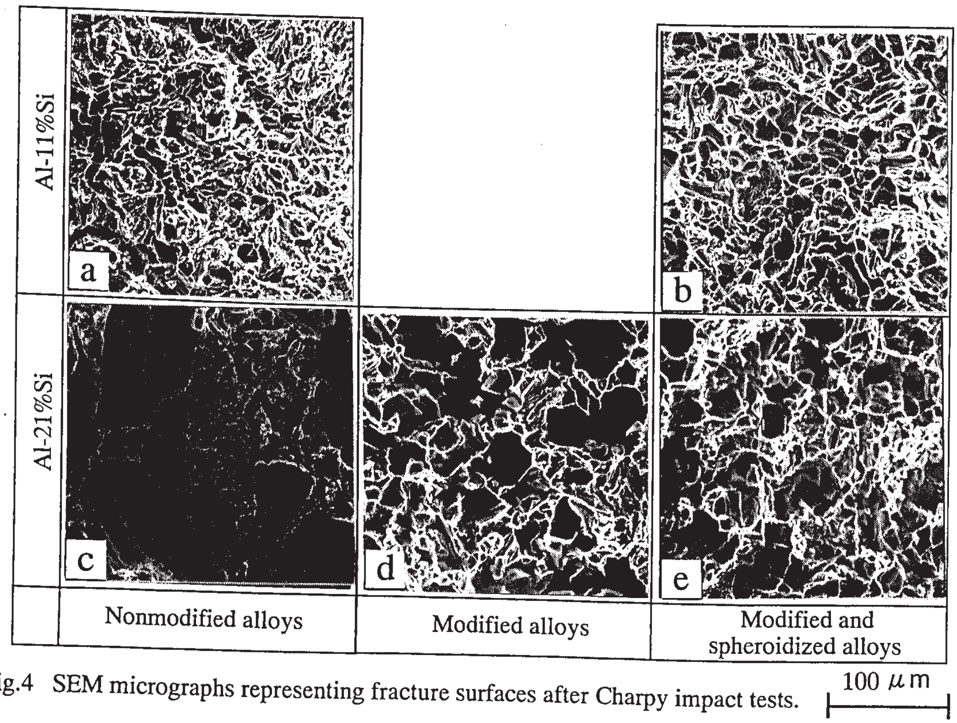

Fig.4 SEM micrographs representing fracture surfaces after Charpy impact tests.

The scanning electron micrographs of fracture surfaces after Charpy impact tests are shown in Fig.4. Ordinary dimple pattern is observed in 11%Si alloys as shown in Fig.4 (a),(b). Many of fractured Si particles appeared on the fracture surface of the nonmodified Al-21%Si alloys, which suggests the predominant fracture and linkage of the Si particles on fracture. On the other hand, the area fraction of Si particles on a fracture surface is much smaller in the modified (and spheroidized) Al-21%Si alloys. In the modified hypoeutectic alloy, conspicuous dimple pattern is observed due to its ductile nature.

Longitudinal sections of fracture surfaces in the nonmodified alloys are shown in Fig.5. Longitudinal sections of fracture surfaces shows predominant crack growth through eutectic silicon particles in the nonmodified Al-11%Si alloys, while primary silicon particles are fractured, and fractured primary silicon particles are subsequently linked by matrix fracture in the nonmodified Al-21%Si alloy. Since the fracture of the primary silicon particles may be occurred when axial stress inside the particles exceed intrinsic fracture strength of the silicon particles, the fractured surface of the primary silicon always aligned perpendicular to the tensile axis. It brings the planar fracture surface as shown in Fig.5 (c).

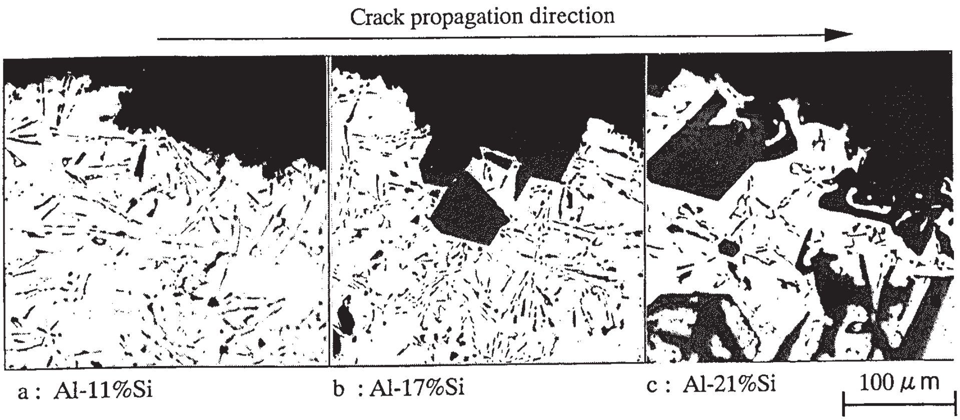

Fig.5 Longitudinal sections of fracture surfaces in the nonmodified alloys.

Figure 6 shows the static fracture toughness as a function of the silicon content. The fracture toughness of the spheroidized alloys slightly decreases with increasing silicon content. Why the modification and spheroidization treatment, which improves V-notched strength remarkably, do not have the same remarkable effects on the fracture toughness can not be explained. Further investigation on relationships between the size of crack-tip stress field and several microstructural dimensions such as primary silicon particle is necessary in a future study.

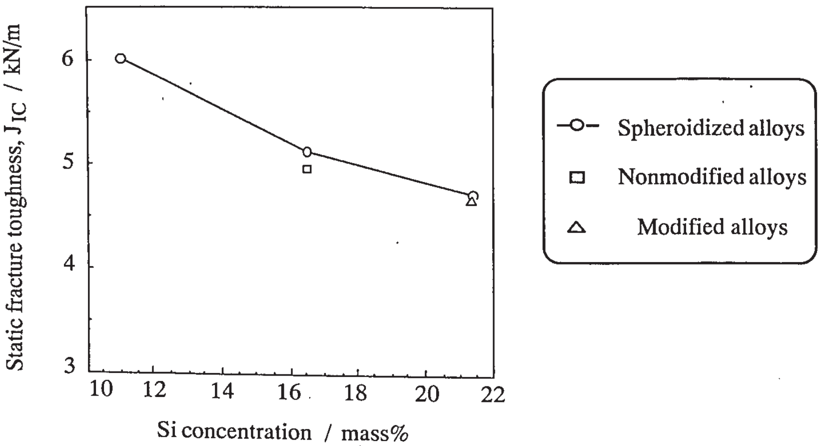

Fig. 6 Effects of Si content, modification and spheroidization treatment on static fracture toughness.

4. CONCLUSIONS

Effects of the modification treatment and/or spheroidization treatment of primary silicon on the mechanical properties of hypereutectic Al-Si casting alloys with various silicon contents yielded following conclusions.

(1) The addition of phosphorus makes the shape of the primary silicon particles finer and round, and more spherical primary silicon particles are attributed to subsequent spheroidization treatment.
(2) The tensile strengths of all the alloys decrease with increasing the silicon content. Modification and spheroidization treatment are much more effective in the 21%Si alloys.
(3) The alloys containing 17%Si exhibit the largest maximum loads and absorbed energies. The addition of phosphorus remarkably improves the maximum load and the absorbed energy. The spheroidized alloys containing 11 and 21%Si show remarkable improvement in comparison to the other Si contents.
(4) The fracture toughness of the spheroidized alloys slightly decreases with increasing silicon content. Modification and spheroidization treatment do not have the remarkable effects on the fracture toughness.

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