Proc. 6th Japan International SAMPE
Symposium, Oct. 26-29, 1999

INFLUENCE OF SILICON CRYSTAL SIZE ON FATIGUE PROPERTY IN HYPER-EUTECTIC AL-SI ALLOY

H. Yokoyama*, O. Umezawa**, K. Nagai**, and K. Kokubo*

* Kogakuin University
1-24-2 Nishi-shinjuku, Shinjuku, Tokyo 163-8677, Japan
** National Research Institute for Metals
1-2-1 Sengen, Tsukuba, Ibaraki 305-0047, Japan

ABSTRACT

We have studied influence of silicon crystal size on tensile and high-cycle fatigue properties for hyper-eutectic Al-20.6 wt% Si materials at 77 K and 296 K. To control silicon crystal size, three kinds of materials, i.e. cast material, spray-formed (SF) one, and repeated thermomechanical treated (RTMT) one, were fabricated. Cracking of coarse primary Si crystal in the cast material led to early fracture under both tensile and fatigue tests. RTMT and SF materials showed much higher uniform elongation than cast one, and refinement of Si crystal was effective to improve the strength – ductility balance. However, fatigue strength of RTMT material was almost the same with that of cast one, although SF material showed higher fatigue strength.

KEY WORDS: High-cycle fatigue, Hyper-eutectic Al-Si alloy, Si crystal size.

1. INTRODUCTION

Generally microstructure affects mechanical properties such as brittle fracture, high-cycle fatigue and so on. Microstructure controlling by heat treatment, working, and/or transformation has been done to improve mechanical properties without changing chemical compositions. In hyper-eutectic Al-Si alloy, coarse primary Si crystal causes poor ductility and often gives an origin of fatigue crack initiation site as well as inclusion and defect, where Si crystal cracking and/or interface exfoliation between Si crystal and aluminium matrix occur [1]. To improve the mechanical properties, primary Si crystal must be refined to avoid sample fracture due to its cracking. Umezawa and Nagai [2] reported that the ductility of Al-Si cast alloy was improved by applying repeated thermomechanical treated (RTMT) method. Heavy working is available for the RTMT material, although the dispersion and size of Si crystals are not uniform. By spray forming method, fine dispersion of Si crystals in aluminum matrix is provided, which leads high strength and high ductility [3],[4]. However, few systematic studies have been done concerning effects of Si crystal on the tensile and fatigue strength in hyper-eutectic Al-Si alloy. We have studied the influence of Si crystal size and its distribution on both tensile and high-cycle fatigue properties for hyper-eutectic Al-20.6 wt% Si alloy.

2. EXPERIMENTAL

Test Materials

Three kinds of Al-20.6 wt% Si materials, namely cast material, RTMT one, and spray-formed (SF) one, were fabricated as mentioned below. Rods (φ39 mm) machined from 5.8 kg ingots and were hot-extruded at 673 K to extinguish pores. Reduction ratio in the section area is about 62 %. The extruded rods were annealed at 793 K for 3.6 ks. We call the heat treated rods as cast material. RTMT material was differently prepared. Ingots with 30 mm in diameter were annealed at 793 K for 3.6 ks. The rods were cooled in liquid nitrogen, and subsequently worked by 20 % reduction with a swager. And then intermediate annealing at 793 K for 3.6 ks was done. The cold-swaging and annealing cycle was repeated 6 times up to total reduction of 78 % in section area. SF material [4], [5] was produced by Ospray method and hot-extruded at 673 K by 67.4 % reduction.

Tensile and Fatigue Tests

Tensile test was done in a motor-driven testing machine at 296 K (in air) and 77 K (in liquid nitrogen) under displacement control. Using a servo hydraulic fatigue test machine, load-controlling tests were carried out with stress ratio, R ($\sigma_{min}/\sigma_{max}$) = 0.01, in a sine wave at 77 K (in liquid nitrogen) and 296 K (in air). Hourglass shaped fatigue test specimens were machined with minimum diameter of 3 mm. In both tensile and fatigue tests specimens, longitudinal direction was parallel to the extruded or swaged direction.

3. RESULTS AND DISCUSSION

Microstructures

Microstructures of three kinds of materials are shown in Fig. 1. In SF material (Fig. 1(a)), Si crystals are uniformly dispersed with high density in the aluminum matrix and their size is about 2 μm in diameter. In RTMT material (Fig. 1(b)), most of primary Si crystals are cracked into pieces smaller than 20 μm in diameter. However, a few of coarse primary Si crystals of about 100 μm in diameter still remain. Eutectic Si crystals in acicular form are broken and dispersed as fine particles. In cast material (Fig. 1(c)), there are coarse primary Si crystals of over 100 μm in diameter.

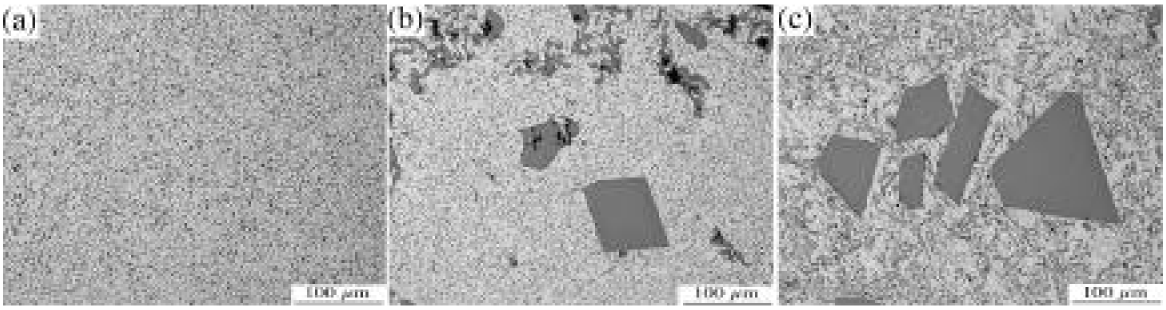

Figure 1. Optical micrograph of test materials in the transverse section:
(a) SF, (b) RTMT, and (c) Cast.

Tensile Properties

Tensile properties are summarized in Table 1. Figure 2 shows true stress – true strain curves at 296 K for each material and their strain hardening rate up to maximum load point. Cast material shows early fracture. In SF material, however, about 9 % uniform elongation is obtained and plastic instability occurs. For the RTMT material, uniform elongation reaches about 10 %, and early fracture is overcome. Microstructural modifications by both spray forming and RTMT are effective to improve tensile properties.

Table 1. Tensile properties of test materials.

	SF		RTMT		Cast	
	77 K	296 K	77 K	296 K	77 K	296 K
Tensile strength (MPa)	296	201	205	124	156	112
0.2 % Proof stress (MPa)	139	102	81	54	108	82
Total elongation (%)	11.5	13.4	10.1	13.2	1.8	2.2
Reduction of area (%)	11.1	21.6	13.8	13.3	0.0	2.8

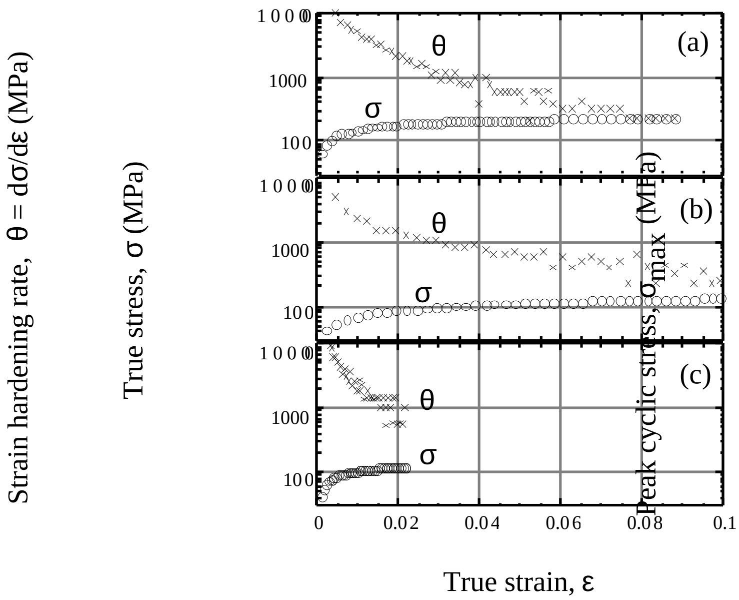

Figure 2. True stress-true strain curves and strain hardening rate of Al-20.6%Si materials at 296 K: (a) SF, (b) RTMT, and (c) Cast.

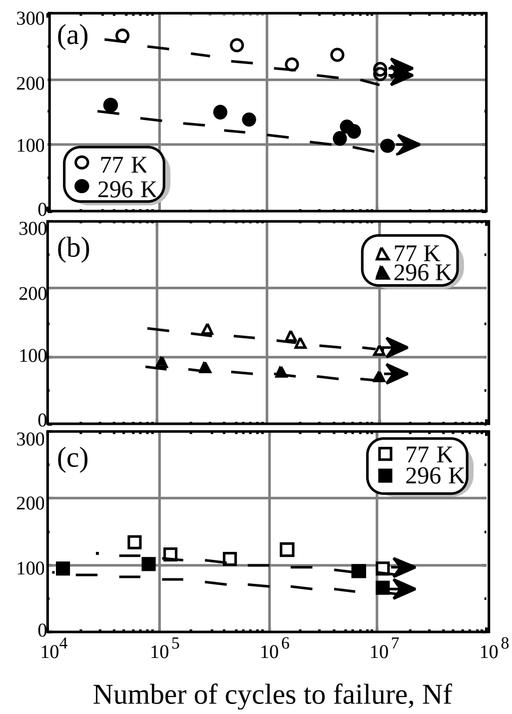

Figure 3. S-N data of Al-20.6%Si materials at 77 K and 296 K: (a) SF, (b) RTMT, and (c) Cast.

Fatigue Strength

SF material shows the highest fatigue strength in high-cycle range among three materials as shown in Fig. 3. In SF material, 10^7 cycles fatigue strength is about 90 MPa at 296 K. At 77 K, fatigue strength in high-cycle range is 100 MPa higher than that at 296 K, which is proportional to an increase in tensile strength. On the other hand, there is no large difference of fatigue strength between RTMT and cast materials at 296 K (Figs. 3(b) and (c)). In RTMT material, 10^7 cycles fatigue strength is about 70 MPa at 296 K. At 77 K, the fatigue strength is 40 MPa higher than that at 296 K, although tensile strength increase is 80 MPa. In cast material, 10^7 cycles fatigue strength is about 60 MPa at 296 K and 85 MPa at 77 K. The fatigue strength becomes 25 MPa higher, although tensile strength is 44 MPa higher. In those materials including coarse primary Si crystal, the difference in fatigue strength between 77 K and 296 K does not correspond to that in tensile strength.

Crack Initiation Site

In SF material, fatigue crack initiated near specimen surface. In some cases pore and inclusion were detected at the origin, but no Si cracking was observed. On the contrary, coarse primary Si crystal was selected as a major origin of fatigue crack initiation site in both cast and RTMT materials (Figs. 4(b) and (c)). Primary Si crystals in RTMT material were almost broken during RTMT process, but a few of larger Si crystals remained. It is considered that cracking of the remained large Si crystals gave an origin of fatigue crack initiation. In order to improve fatigue strength of RTMT material, further refinement of those large Si crystals is required.

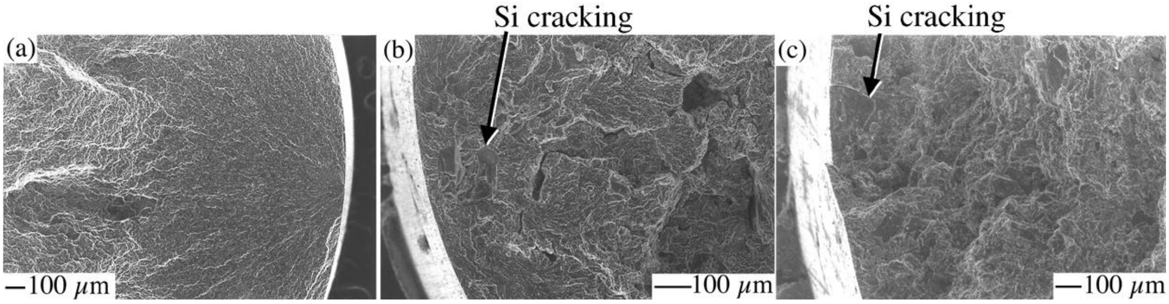

Figure 4. SEM photographs near crack initiation sites.
(a) SF: σ_{max} = 222 MPa, Nf = 163,8800 cycles, 296 K, (b) RTMT: σ_{max} = 133 MPa,
(b) Nf = 1604240 cycles, 77 K, (c) Cast: σ_{max} = 117 MPa, Nf = 128,170 cycles, 77 K

4. SUMMARY

We have studied the influence of Si crystal size and its distribution on both tensile and high-cycle fatigue properties for hyper-eutectic Al-20.6 wt% Si alloy. Coarse primary Si crystal cracking performed negative on tensile and fatigue properties, since it led to early fracture. Fine dispersion of Si crystals with a few micrometer in diameter resulted in higher tensile and fatigue strength than materials including coarse primary Si crystals. A few remained large Si crystals in RTMT material resulted in low fatigue strength, although early fracture in tensile test was overcome. To increase fatigue strength, refinement of large Si crystals is necessary.

REFFERENCE

[1] Y. Murakami *et. al*., J. Soc. Mat. Sci., Japan, 44 (497), 194, (1995), in Japanese
[2] O. Umezawa and K. Nagai, Metall. Mater. Trans. A, 30A, 2221, (1999)
[3] K. Shibue, and N. Tokizane, Materia Japan, 34 (6), 736, (1995), in Japanese
[4] N. Tokizane *et. al*., J. Jpn. Soc. Powder and Powder Metall., 41 (8), 927, (1994), in Japanese