SEMI-SOLID FORMING OF A390 HYPER-EUTECTIC ALUMINUM ALLOY

Rudi Suhradi Rachmat*, Nahunnop Bunname*
Shigeharu Kamado, Yo Kojima****
*Graduate Student of Nagaoka University of Technology
1603-1 Kamitomioka, Nagaoka, Niigata, 940-2188 JAPAN
**Department of Mechanical Engineering, Nagaoka University of Technology
1603-1 Kamitomioka, Nagaoka, Niigata, 940-2188 JAPAN

ABSTRACT Strain-introduced A390 hyper-eutectic aluminum alloy specimens were press-formed at their semi-solid temperatures and their microstructural changes, heat treatment characteristics and tensile properties were investigated. Fine and spherical solid particles of α phase can be obtained on heating to the semi-solid temperature, and the particles distribute uniformly by semi-solid forming at 565 ℃ using 15% strain-introduced bulk. A specimen having such microstructure indicates a similar age hardening to as-cast specimen and relatively high tensile strength as compared with that formed at other semi-solid temperatures.

Keywords : *hyper-eutectic Al-Si alloy, semi-solid forming, microstructure, aging characteristics, tensile property*

1. INTRODUCTION

Hyper-eutectic aluminum silicon alloys are very attractive for automotive and aircraft industries due to their lightness, low thermal expansion coefficient, high Young's modules, acceptable mechanical properties and excellent wear resistance[1]. However, high temperatures are required for melting alloys with high silicon contents when conventional casting techniques are used. Furthermore, low cooling rate such as in sand casting makes silicon to float at upper side of casting because silicon has smaller density than aluminum melt. This phenomenon results in degradation of mechanical properties of the alloy.

To avoid these problems, semi-solid forming is one of the solutions because materials handling temperature is low and spherical solid particles could control floating of both primary and eutectic silicon. Therefore, the purpose of this research is to determine optimum semi-solid forming conditions for A390 aluminum alloy and to evaluate the tensile properties of the semi-solid formed sample of the alloy.

2. EXPERIMENTAL PROCEDURE

In the present study, A390 with nominal composition: Al-17%Si-4.5%Cu-0.55%Mg was used for the experiments. The alloy was prepared using aluminum of 99.7% purity, magnesium of 99.9% purity, Al-25% Si master alloy and Al-40% Cu master alloy with a total weight of 3.3 kg. The materials were melted in an electrical furnace. At 820℃ a refining agent, 0.05% mass P, in the form of Cu-15% P master alloy was added[2]. After that the melt was stirred and then held for 1 h before pouring into a permanent mold held at a temperature of 100℃ with a cavity of 50 mm thickness, 150 mm length and 100 mm height.

Fig. 1 shows the procedure for the semi-solid forming process. Cylindrical specimens of 40 mm diameter and 28.3 mm length were machined from the rectangular ingots and then subjected to compressive strain of 15% by using a hydraulic press at 220℃, which made it possible for the alloy to deform without internal cracks. After that, the specimens were machined to dimensions of 40 mm diameter and 24 mm length[3].

Semi-solid forming of specimens employed in the evaluation of heat treatment characteristics and tensile properties was conducted by the following procedure: first, the deformed specimens were heated to the desired semi-solid temperature at an average heating rate of 30℃/min in preheated container in an electric furnace; then the specimens were immediately press-formed in a mold by using a high pressure die casting machine. The press forming was conducted at a pressure of 49 MPa, press velocity of 0.05 m/s, die temperature of 300℃, plunger tip temperature of 200℃, and a holding time of 30 s. Specimens for aging characteristics, microstructural observation and tensile test were machined from the central part of the formed specimens which had a diameter of 55 mm and a thickness of 12.8 mm. Two tensile test specimens were taken from one formed specimen and machined to a diameter of 6 mm and a gauge length of 20 mm[3].

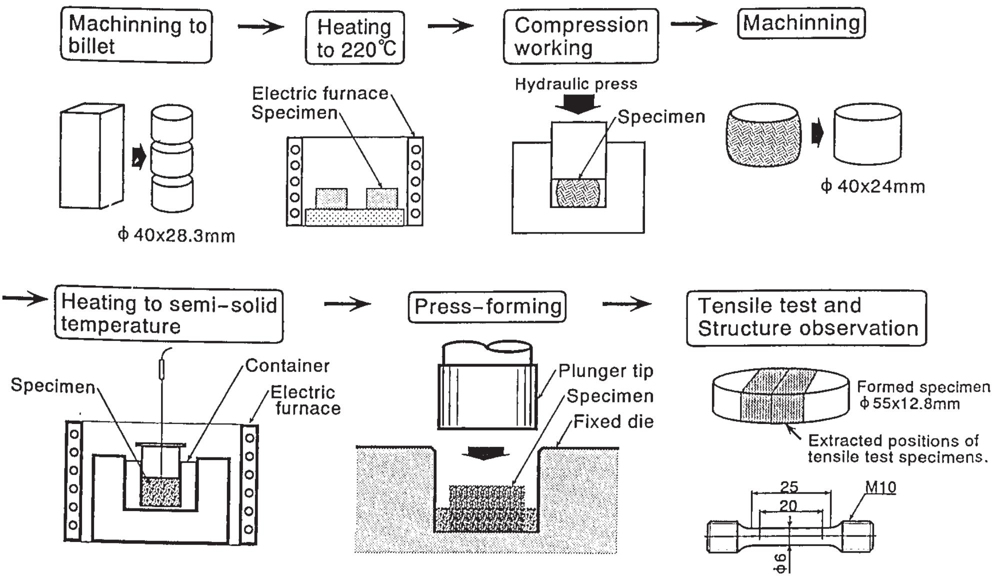

Fig.1 Experimental process for semi-solid forming using strain-introduced bulk.

3. RESULTS AND DISCUSSION

3.1 Microstructure of As-Cast Ingot

Fig. 2 shows the microstructure of as-cast A390 hyper-eutectic aluminum alloy. The melt was poured into permanent mold held at 100℃. The micrograph shows the presence of primary silicon, eutectic silicon, Al-Cu compound and dendritic phase of aluminum solid solution (α phase). P reacts with aluminum melt and forms AlP, which plays a role of nuclei for primary silicon. Therefore, P addition leads to the refining of primary silicon, but results in the crystallization of the coarse and needle like eutectic silicon.

Fig.2 Microstructure of as-cast A390 hyper-eutectic aluminum alloy.

3.2 Microstructural Evolution in Strain-Introduced Specimens During Heating

Fig. 3 shows the microstructural evolution of 15% strain-introduced A390 hyper-eutectic aluminum alloy specimens during heating. Each specimen was subjected to a strain of 15% by using hydraulic press at 220℃, and then the specimens were heated to the given temperature and quenched in water. At 550℃ melting occurs at interfaces between the α phase and the eutectic compounds, and at recrystallized grain boundaries[4]. Also, α phase starts breaking up. With rising temperature the breaking up and coarsening of the α phase advances and the amount of liquid phase increases. At 565℃ α phase perfectly divides into spherical particles, while primary silicon unchanges. At temperatures more than 570℃, α phase with spherical shape disappears, and primary silicon coarsens at 575℃.

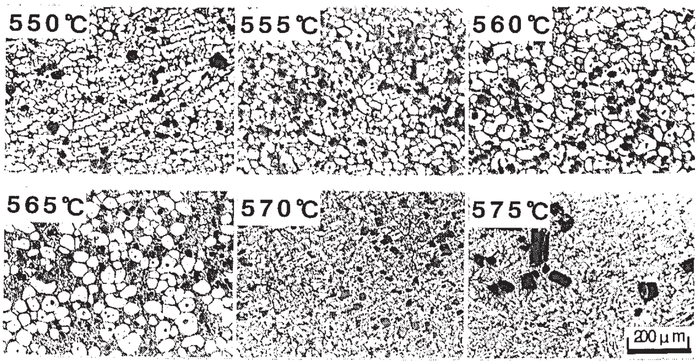

Fig.3. Microstructural changes in the strain introduced A390 hyper-eutectic aluminum alloy bulk during heating.

3.3 Microstructures of the formed specimens

Fig. 4 shows the microstructures at central parts and at edge positions in the formed specimen. Both non-strained and 15% strain-introduced specimens formed at semi-solid temperature of 560℃ show microstructures composed of primary silicon particles, α phase and eutectic constituents. Fine and nearly spherical solid particles distribute uniformly throughout the formed specimen as shown in the micrographs for strain-introduced specimen. Furthermore, eutectic constituents become finer due to rapid cooling as compared with those of the as-cast specimen shown in Fig.2

In contrast, the non-strained specimen after forming under the same conditions possesses markedly non-uniform microstructure. That is to say, dendritic α phase is rich at the central part and liquid phase is mostly pressed out towards the edges. Such a flow of only liquid phase is caused by the fact that coarse α phase is not enough to become spherical and remains as a dendritic shape.

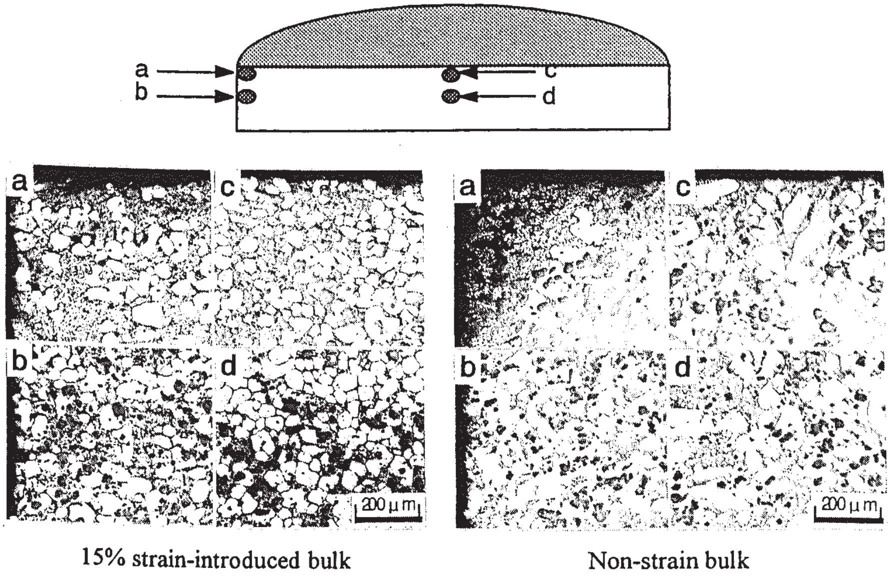

Fig.4 Microstructure of A390 hyper-eutectic aluminum alloy press-formed at 560℃

3.4 Heat Treatment Characteristics

Fig. 5 shows aging curves for specimens formed at different semi-solid temperatures. Solution heat treatment was conducted at 495℃ for 6 h. Aging was carried out at 175℃. Age hardening behavior for semi-solid formed specimens is similar to that obtained from as-cast specimen. This means that same volume fraction of precipitates contributes to the age hardening of the semi-solid formed specimen as that in as-cast specimen.

Peak hardness of strain-introduced specimens occurs after aging time of 8 h and reach about 180 Vickers hardness number (VHN) in the whole specimens. Therefore, aging conditions for full heat treatment (T6) were determined as a temperature of 175℃ and aging time of 8 h.

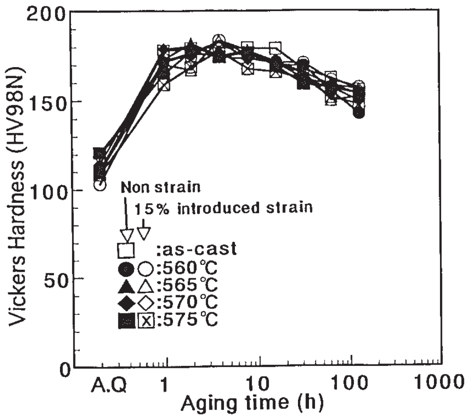

Fig. 5 Aging curves of A390 hyper-eutectic aluminum alloy fabricated by semi-solid forming

3.5 Tensile properties

Fig. 6 shows tensile properties of as-formed and fully heat treated (T6) specimens as a function of test temperature. Those of as-cast specimens are also presented in the same figures for reference. The tensile strength of as-formed specimens with 15% strain is higher than that of as-formed specimens without strain because of the fine and homogeneous microstructure of the former. Relatively high tensile strength could be obtained by semi-solid forming of strain-introduced specimens at 565℃. This may have arisen from the uniformly distributed fine and spherical α phase as observed in Fig.3 and Fig.4. However the tensile strength of the semi-solid formed specimens is lower than that of as-cast specimen. In hyper-eutectic Al-Si alloys, cracks initiate and propagate at primary silicon particles[4]. As-cast specimen was extracted near the bottom of permanent mold, where cooling rate is high, therefore has fine primary silicon particles. Consequently, as-cast specimen having finer primary silicon than observed in semi-solid formed specimen exhibits high tensile strength. T6 treatment considerably improve tensile strength. But at temperatures more than 200℃ tensile strength decreases remarkably.

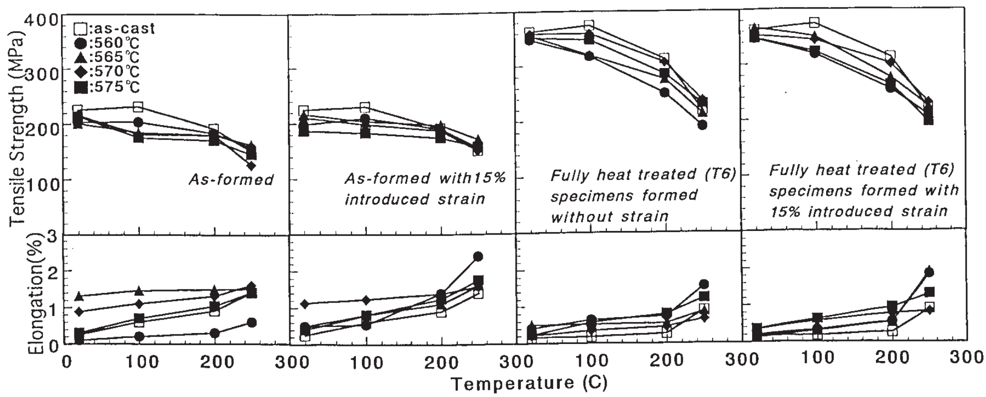

Fig.6 Tensile properties of as-formed and fully heat-treated (T6) specimens as a function of test temperature.

All of the investigated specimens indicate low elongation of less than 1.3% at room temperature and less than 2.5% even at a high temperature of 250℃. This may indicate that elongation is independent on microstructural changes such as the refinement of eutectic constituents and spheroidization of α phase by semi-solid forming, but depends only on size and amount of primary silicon particles.

4. CONCLUSIONS

In the present study, strain introduced A390 hyper-eutectic aluminum alloy specimens were press-formed in their semi-solid state and their microstructural changes, heat treatment characteristics and tensile properties were investigated.

The results are summarized as follows:

1. Optimum temperature for semi-solid forming of 15% strain-introduced specimens is 565℃ and this makes it possible to obtain fine and spherical α phase that are uniformly distributed.
2. Semi-solid formed specimens indicate a similar age hardening behavior as the as-cast specimen.
3. A specimen formed at the optimum temperature of 565℃ has relatively high tensile strength and same level of elongation as compared with that formed at lower and higher temperatures than the optimum temperature.

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