Fabrication of Al-Cu-Mg alloy foams using Mg as thickener through melt route and reinforcement of cell walls by heat treatment

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Abstract

Aluminum alloy foams were fabricated through the melt route using Al-Cu-Mg alloy, the compositions of which were equivalent to A2024. Mg exhibited thickening effect in the Al-Cu melt during fabrication of the master alloy. Therefore, the thickening effect enabled us to fabricate Al-Cu-Mg alloy foams through the melt route. Porosity increased as the TiH\textsubscript{2} decomposition proceeded. After the end of TiH\textsubscript{2} decomposition, the pore coarsened. By T6 heat treatment, cell walls of the fabricated Al-Cu-Mg alloy foams were hardened. Minute precipitates of Cu and Mg were observed on cell walls after T6 treatment by EPMA.

1. Introduction

Recently, weight reduction of transport machineries such as airplanes is strongly required for improvement of fuel efficiency, reduction of carbon dioxide emission. Furthermore, comfort and safety of passengers are the most important characteristics for the commercial transport machineries. Therefore, new kinds of light-weight structural materials and functional materials, such as porous metals, are actively developed for these purposes.

Aluminum foams have excellent characteristics, such as inherent low density, energy and sound absorption properties, and so on (Ashby et al. (2000)). They are expected to be applied to automobile vehicles and aircrafts for energy saving and improvement of comfort and safety. However, further improvement of mechanical properties of
aluminum foams is required for these applications. Therefore, fabrication processes are developed for homogeneous pore distribution and strengthening cell walls.

Precursor methods (Banhart (2001)) and melt route (Miyoshi et al. (2000)) are representative conventional fabrication methods for aluminum foams. Pores are generated in aluminum melt by hydrogen decomposed from foaming agent, such as TiH₂, by the heat from the melt or atmosphere. And then, the melt including pores solidifies and becomes aluminum foam.

To obtain homogeneous pore distribution, it is necessary to avoid drainage of aluminum melt, coarsening and rupture of cell walls during solidification, which lead to the generation of coarsened pores. Thickening agents, such as Ca, are usually added to the melt in order to increase the viscosity of the melt to suppress the drainage of aluminum melt during solidification. Recently, it was reported that Mg works as thickening agent for aluminum melt, also (Suzuki et al. (2012)).

Here, we focused on the high-strength aluminum alloy A2024 contains Mg, which oxidizes easily. Mg is expected to be thickening agent. In this study, we investigated the possibility of fabrication of aluminum foams with compositions similar to A2024 by adding Mg as thickening agents and alloying element. Then we investigated the Vickers hardness of the cell walls of the fabricated aluminum foam to compare with commercially used A2024.

2. Experimental

2.1. Preparation of Master Alloys

Pure aluminum ingots (99.99%) of 700g were set in a steel crucible (SPC1), an inner wall of which was coated by Al₂O₃. The ingots were melted and kept at 700°C in an electric furnace. Cu (99.9%) of 4.5 mass% was added into the melt and stirred by two impellers made of stainless steel (SUS304) at 500 rpm. The two impellers were coated by Al₂O₃. The stirring torque was measured to evaluate the viscosity of the melt. After the torque reached the stable state, Mg (99.9%) of 1.5 mass% was added into the melt. After the torque became stable, the stirring was stopped. The quantity of various alloy elements added was decided based on composition of A2024 alloy (Figure 1(a)). Then the melt was poured into cylindrical molds. The solidified ingots were used as the master alloys of A2024. (Figure 1(b)).

Figure 1: Schematic drawing of fabrication of Al-Cu-Mg alloy foams.
Figure 2: Change of torque during stirring the melt for preparation of the master alloy.

Figure 3: Relationship between holding time in furnace and porosity of Al-Cu-Mg alloy foams fabricated with 1mass% and 2mass% TiH2 through melt route. Cross-sections of the fabricated foams.

Figure 4: Vickers hardness of cell wall of Al-Cu-Mg alloy foams fabricated with 1mass% TiH2 and holding time of 250 s, 2mass% TiH2 and holding time of 0 s and 2mass% TiH2 and holding time of 300 s. The dashed line is the hardness of A2024 of T6. The solid line is the hardness of the as-cast master alloy.
2.2. Fabrication of Al-Cu-Mg Alloy Foams

The total amount of 50g ingots of the master alloy were set in a stainless steel (SUS304) crucible, the inner wall of which was coated by BN. The ingots were melted and kept at 700°C in the electric furnace. Then, the foaming agent TiH₂ of 1-2 mass% was added to the melt and stirred by an impeller at 900 rpm for 100 s (Figure 1(c)). The impeller was made of stainless steel (SUS304) and coated by BN. Next, the impeller was removed from the melt. The foaming process took place during holding the melt in the furnace. The holding times were changed every 50 s from 0 to 350 s (Figure 1(d)). After the holding time passed, the crucible was brought out from the furnace and the crucible which contains the foaming melt was cooled by water to fabricate Al-Cu-Mg alloy foams. (Figure 1(e)).

2.3. Evaluation and Heat Treatment of Al-Cu-Mg Alloy Foams

The porosities of the fabricated Al-Cu-Mg alloy foams were calculated by their volume and mass. The fabricated Al-Cu-Mg alloy foams were cut so that the center axis should be on the cross-section. The cross-section was polished and observed. Several cubic specimens of 10mm in length were cut out from selected Al-Cu-Mg alloy foams. The Al-Cu-Mg foams with different fabrication conditions (TiH₂ of 1 mass%, holding time of 250 s), (TiH₂ of 2 mass%, holding time of 0 s) and (TiH₂ of 2 mass%, holding time of 300 s) were evaluated to investigate the influence of quantity of TiH₂, holding times and porosities. The specimens were held at 495°C for 4 h for solution heat treatment followed by water-quenching. Then, the specimens were held at 190°C for 9 h for T6 treatment. The heat-treated specimens were embedded in resin so as to fill the pores with the resin. Vickers hardness tests were performed at each 10 points on the cell walls of the specimens with and without heat treatment at 0.49 N for 15 s. Indenting points were decided so that diagonal length of indentation was shorter than 1/3 of cell wall thickness. For the reference, Vickers hardness tests were performed on non-porous A2024 without heat treatment. Then, distributions of alloy elements of specimens were analyzed by EPMA (JEOL Ltd., JXA-8230).

3. Results and Discussion

3.1. Viscosity of Master Alloys

Figure 2 shows the change of the stirring torque during preparation of master alloy. The stirring torque did not change after Cu was added to the Al melt. The sudden decrease of the torque just before addition of Mg was due the
stop of stirring. After Mg was added to the Al-Cu melt, the stirring torque increased. These results suggest that Mg worked as a thickening agent for the Al-Cu melt.

3.2. Influence of Holding Time on Porosity

Figure 3 shows the relationship between holding time and porosity of Al-Cu-Mg alloy foams as well as cross section of fabricated Al-Cu-Mg alloy foams. For the first 250 s, porosity increased with increasing holding time. The porosities of fabricated foams (TiH₂ of 1 mass%, holding time of 250 s), (TiH₂ of 2 mass%, holding time of 0 s) and (TiH₂ of 2 mass%, holding time of 300 s) were 59%, 59% and 82% respectively. As the added TiH₂ decomposition proceeded, the amount of hydrogen for formation of pores increased. However, the porosity decreased after the holding time of 250 s. The decrease of the porosity was caused by the end of the TiH₂ decomposition, settling out of the melt in the cell wall and collapse of cell walls. Therefore, the porosity can be controlled by changing the holding time.

3.3. Effects of Heat Treatment on Hardness of Cell Walls

Figure 4 shows the Vickers hardness of Al-Cu-Mg alloy foams at holding time of 0 s and 300 s (TiH₂ of 2 mass %) and holding time of 250 s (TiH₂ of 1 mass %). The dashed line in Figure 4 shows the literature result of T6 heat treated A2024 (Araki (1984)). The solid line in Figure 4 shows the experiment result of as-cast samples of master alloys. This shows that all combinations of fabricated Al-Cu-Mg alloy foams were hardened by the T6 heat treatment. However, Vickers hardness of fabricated Al-Cu-Mg alloy foams after T6 treatment was lower than the literature result of T6 heat treated A2024. The EPMA analysis result (Figure 5) shows that Cu and Mg segregated at grain boundaries of the cell walls of as-cast sample. These elements spread widely and are minute precipitates after T6 treatment. It is considered that the increase in hardness was caused by formation of minute precipitates of Cu and Mg in grains, which are considered to be nonequilibrium phases.

4. Conclusions

- Added Mg increases the viscosity of Al-Cu alloy melt and works as a thickener. Therefore, Al-Cu-Mg alloy foam with equivalent composition of A2024 can be fabricated with Mg thickener.
- The porosity of fabricated foams increases with increasing holding time. Pores are expanding and coarse with increasing holding time.
- The Vickers hardness of the cell walls increased by T6 treatment. The hardening is considered to be caused by minute precipitates of Cu and Mg formed in grains of cell walls.

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