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Strengthening of Aluminum Foams through Vacuum Impregnation with Epoxy Resin

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Lightweight aluminum foams are attractive structural materials for automotive, aerospace, naval and other industrial applications. However, the compressive strength is much lower than that of dense aluminum. In order to use aluminum foams as a structural material, it is necessary to increase the strength. Resin coating of the open pores was demonstrated for strengthening of aluminum foams. Epoxy resin with low viscosity was effective to fill the open pores. In addition, the coating in vacuum was effective to increase the resin volume ratio. Uniaxial compressive tests revealed that the compressive strength of the epoxy coated aluminum foam in vacuum possesses about six times higher strength than that of original aluminum foam. This is because the buckling was suppressed by the resin coating.

Keywords: *Aluminum foam, Compressive test, Resin coating, Buckling*

1. Introduction

Aluminum foams have lightweight, shock absorption, heat insulating and sound absorption properties. However, the strength is significantly low compared to dense aluminum [1, 2]. In order to use the aluminum foams as a structural material, it is necessary to increase the strength. Although some methods for strengthening of aluminum foams have been proposed [3, 4], they still contain many problems. One method is the addition of alloying elements such as magnesium and zinc [3]. However, this method often causes instability of the foaming process. Anther method is to use aluminum foam sandwich components or aluminum foam filled tubes [4]. However, this method causes the increase of weight and is difficult to apply on the complicated shape.

Recently, we proposed a new method for strengthening of aluminum foams by resin coating [5]. Figure 1 is a schematic illustration of the resin coating. Here, the open surface pores are filled with resin. The resin coating was effective to increase the strength of aluminum foams. However, the resin coating process strongly depends on the viscosity of resin and on the atmospheric condition. In the

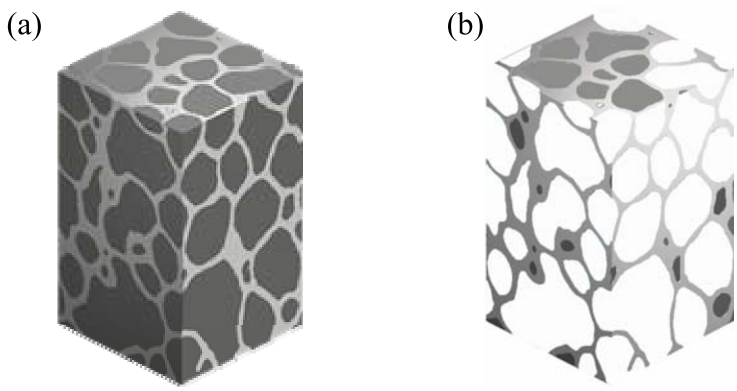

Fig. 1 Schematic illustration of resin coating of aluminum foam. (a) Original aluminum foam. (b) Resin coated aluminum foam. Gray area is the cell walls. Dark area is the open pores. Light area is the resin coated open pores.

present study, the effects of the viscosity of resin on the strengthening of aluminum foams are investigated by comparison between polyester resin with high viscosity and epoxy resin with low viscosity. In addition, the effects of the atmospheric condition are also investigated under the conditions in vacuum and in air.

2. Experimental Procedure

Closed-cell aluminum foam (ALPORAS) was provided by Shinko Wire Company. The open surface pores of the aluminum foam were filled with conventional epoxy or polyester resin. Four types of specimens were prepared in this study. Specimen A is an original aluminum foam without resin coating. Specimen APA is an aluminum foam coated by polyester resin in air. Specimen AEA is an aluminum foam coated by epoxy resin in air. Specimen AEV is an aluminum foam coated by epoxy resin in vacuum. All specimens have a rectangular shape ($L\times L\times 1.5L$) for compressive test. It is noted that resin was only coated on the open surface pores paralel to the compression axis.

The density of the specimen, ρ, is expressed as

$$\rho = \frac{m}{V_A}, \tag{1}$$

where m is the total mass of the specimen and V_A is the volume of the specimen. Resin volume ratio, V is expressed as

$$V = \frac{V_R}{V_A} \times 100 \ (\%), \tag{2}$$

where V_R is the volume of resin.

Uniaxial compressive tests are carried out at room temperature using a SHIMADZU AUTOGRAPH AG-50kNISD testing machine. The crosshead speed is fixed at an initial strain rate of 5.5×10^{-4} s $^{-1}$.

3. Results and Discussion

3.1 Resin Coating

Figure 2 is photographs of specimen AEV and specimen AEA. As shown in Fig. 2(a), the vacuum coating enabled to fill most of the open surface pores. On the other hand, small pores without resin exist at the surface of specimen AEA (Fig. 2(b)). This result indicates that vacuum coating is effective to fill the open surface pores.

Density and resin volume ratio of all specimens are listed in Table 1. Density and resin volume ratio of specimen AEA are higher than those of specimen APA. This is because the viscosity of epoxy resin is lower than that of polyester resin. This result indicates that the resin with low viscosity is effective to fill the open surface pores.

(a) (b)

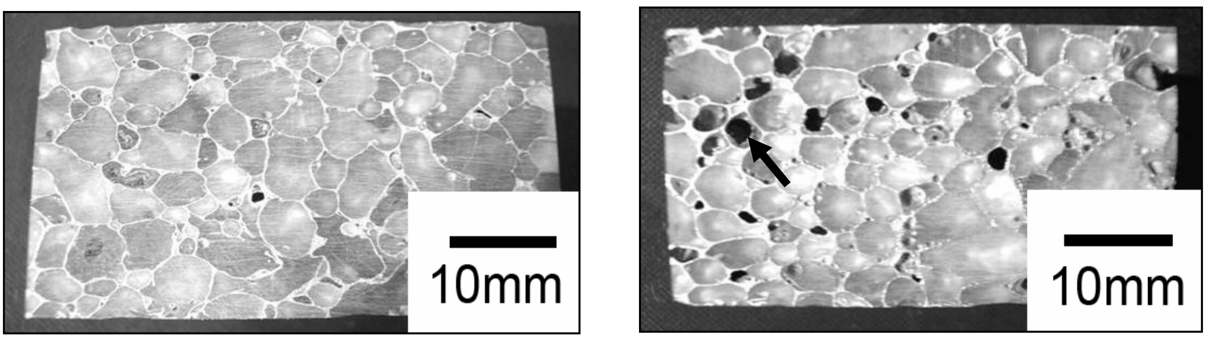

Fig. 2 Photographs of the surface of (a) specimen AEV and (b) specimen AEA.

Table 1 Results of compressive tests. Specimen size is L = 30 mm.

	Density, ρ (Mgm^{-3})	Resin volume ratio, V (%)	Initial peak stress, σ_I (MPa)	Plateau stress, σ_{pl} (MPa)	Specific strength, σ_I/ρ (MPa(Mgm^{-3})$^{-1}$)	Energy absorption, W (MJm^{-3})
Specimen AEV	0.69	36.1	15.8	3.9	23.0	2.2
	0.65	33.1	11.7	4.2	18.0	2.5
	0.64	31.7	12.1	6.6	19.0	2.3
Specimen AEA	0.52	21.8	8.1	2.3	15.4	2.2
	0.52	21.0	8.0	3.6	15.5	2.3
	0.50	19.9	7.7	4.3	15.4	2.3
	0.49	19.1	6.1	3.9	12.3	2.1
Specimen APA	0.43	14.4	5.6	4.3	13.6	2.0
	0.48	14.0	5.7	5.4	11.9	2.5
	0.48	17.8	6.2	5.4	13.0	2.4
Specimen A	0.27	0	2.1	2.0	7.7	1.0
	0.26	0	2.3	2.2	8.8	1.1
	0.26	0	2.2	2.1	8.3	1.1

3.2 Compressive Behavior

Compressive stress-strain curves of specimens A, AEV, AEA and APA are shown in Fig. 3. The resin coated specimens (specimens AEV, AEA and APA) showed high initial peak stress, σ_I, and plateau stress, σ_P, compared to specimen A. this is because the buckling was effectively suppressed by resin coating. Though specimen AEV showed remarkably high initial peak stress, the plateau stress was not so high.

Resin coated specimens (specimen AEV, AEA and APA) have high specific strength, σ_I/ρ, and high energy absorption, W. Here Energy absorption is expressed as

$$W = \int_0^{\varepsilon_0} \sigma \, d\varepsilon , \tag{3}$$

where σ is the compressive stress, ε is the compressive strain and ε_0 is the upper limit of integration defied as 50 %. Improved mechanical properties are due to limited local buckling by the resin coating of the open pores.

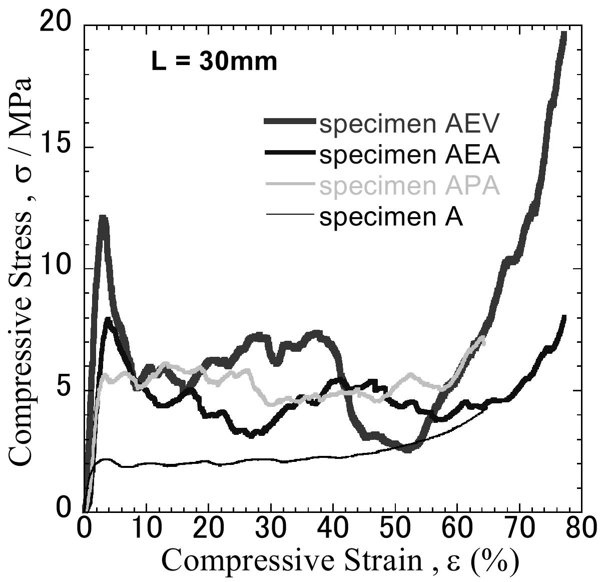

Fig. 3 Compressive stress-strain curves of specimen AEV, specimen AEA, specimen APA and specimen A.

3.3 Effect of Specimen Size

In Fig. 4, the specific strength of all specimens are plotted as a function of specimen size. The specific strength of specimen A gradually increased with increasing the specimen size. This result can be explained by the size effect [6]. On the other hand, specimens AEV, AEA and APA showed quite different size effect from specimen A. The specific strength of specimens AEA and APA do not change by changing the specimen size, according to a line of best fit drawn through the experimental data. The specific strength of specimen AEV decreased with increasing the specimen size. In the case of small specimens, the strengthening effect becomes large because of the large resin volum ratio. Even though large specimens have lowe specific strength, all resin coated specimens (specimen AEV, AEA and APA) have higher specific strength than that of specimen A.

3.4 Effect of Resin Volume Ratio

Figure 5 shows the relation between the initial peak stress and the resin volume ratio. The initial peak stress increased with increasing the resin volume ratio. In addition, all experimental data can be fitted by a line. This result indicates that the strength of resin itself gives null effect on the initial peak stress of the aluminum foam. It is noted that the resin volume ratio is important to increase the compressive strength of aluminum foams.

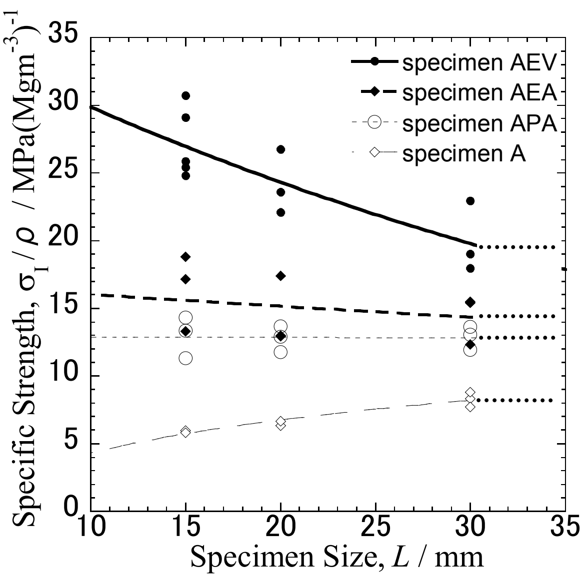

Fig. 4 Specific strength is plotted as a function of specimen size.

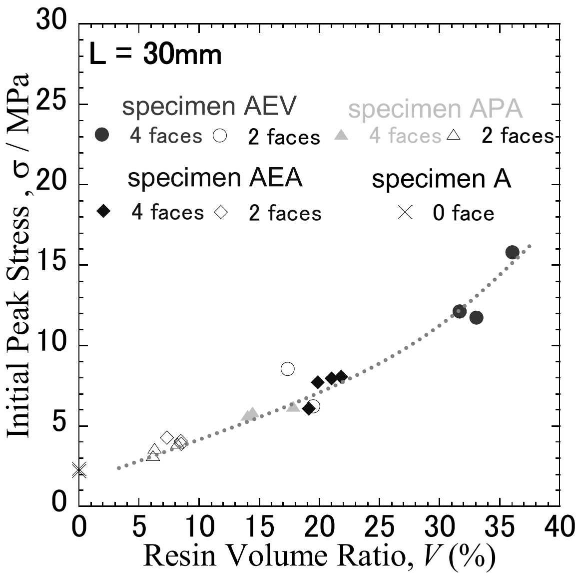

Fig. 5 Relation between the initial peak stress and the resin volume ratio.

4. Summary

Epoxy resin with low viscosity was effective to fill the open surface pores of aluminum foam. Resin coating in vacuum was desirable to increase the resin volume ratio. The compressive strength of the resin coated specimens decreased with increasing the specimen size. On the other hand, the initial peak stress increased with increasing the resin volume ratio independently of a kind of resin. Therefore, the resin volume ratio plays an important role in this strengthening mechanism.

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