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A Study on Mechanical Characteristics of Aluminum Foam Jointed by Adhesive per Thickness under Compression

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This study aims to investigate the mechanical behaviors under compression on the specimens of aluminum foam jointed with various thicknesses by using adhesive after being clipped to the height of 100 mm, the width of 100 mm, and the thickness of 25 mm. For the study, a simulation analysis was conducted by using the commercial finite element analysis program of ANSYS, and the process to verifying the result of simulation analyses in comparison with actual experiments was implemented. According to the results of experiments, reaction forces were risen rapidly to the yield point and this force maintained with a constant value was generally observed up to the rupture although there was the minute vibration due to the irregular arrangement of internal bubble structure as the characteristics of porous material. The simulation results could be seen to be reliable while all specimen models were different in view of the time to reach the yield point. This study identifies the mechanical characteristics of aluminum foams jointed by adhesive per thickness under compression and the result is thought to make a great contribution to the follow-up studies about the real structure jointed with aluminum foam.

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1. Introduction

At the contemporary industry, the using conditions for metallic materials are becoming increasingly particular and harsh. Particularly, the development of new light-weight materials with high rigidity is required throughout the whole industry. There is aluminum foam as a new material frequently used in recent times. The shape of aluminum foam is produced by dissolving the lump of aluminum foam in the outer case, adding the foaming agent and hardening the dissolved aluminum. The thickness or volume of aluminum foam is restricted by the limit of case size. Because of the limit of production at using the interior material of architecture or the exterior plate of machine, the several parts of aluminum foams are combined and used. The aluminum foam is the porous form where bubbles are formed inside like a sponge by addition of a foaming agent upon hardening through cooling after dissolution of aluminum ingot, and has the light weight reduced almost at 1/10 as the specific gravity ratio for general aluminum due to its form. Thus, it has not only many characteristics such as non-flammability, low thermal conductivity, sound absorption, energy absorption, etc., but also recyclability and harmlessness to human body so as to conform to the eco-friendly government policies making it a new material with much likelihood for utilization in the industry.[1-5] Porous materials including aluminum foam are classified into the open and closed cell types. The aluminum foam of open cell type is employed in heat transfer areas, while the closed type is frequently utilized for automobile bumpers, the areas in particular where light weight and shock absorption are important. And it has been utilized as a soundproofing material for not only buildings such as subway stations required to absorb large noises but also apartments due to the high sound-absorbing characteristics.[6-8] The bolt, nut, pin, rivet and adhesive are used as the bonding method of the machine parts.

As the holes are punched on aluminum foam in cases of bolt, nut, pin and rivet, it is difficult to make the holes with the smooth surface precisely on the structural property of aluminum foam. Also, the aluminum foam is crushed during the manufacturing process of foam and the error of dimension is increased. So, the design has been investigated by using the bonding method. By the way, the bonding force at the adhesive joint becomes weak by comparing with other bonding methods. In order to solve this problem, the structural design shall be improved as the bonding force must be increased. Therefore,

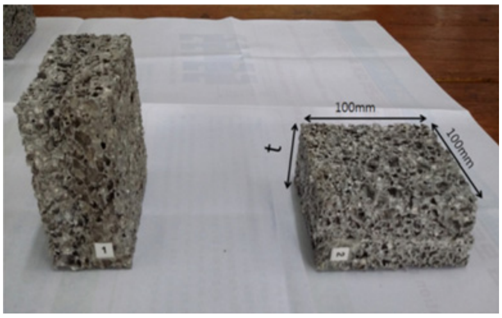


Fig. 1 Aluminum foam with specimen thickness of t=50 mm for experiment

it is necessary to investigate the fracture behavior of the adhesive joint. As the fastening method in the design with aluminum foam, the fastening method by using adhesives is suitable.[9-13] Therefore, the studies capable of providing fundamental material property data for the aluminum foam by using adhesion-type fastening method are necessary. In this study, it is thought that the optimal and safe design of structure with the aluminum foam is possible by investigating the mechanical characteristics of the aluminum foam of adhered closed cell type under compression. In this study, aluminum foams of 100 mm in height, 100 mm in width, 25 mm in thickness for experiments were joined by adhesive and the four types of specimens with the various thicknesses of 25 mm, 50 mm, 75 mm and 100 mm were prepared respectively and the compression experiments were conducted by using a universal tester. The finite elements analysis program of ANSYS is carried out with the same constraint condition of experiment, followed by comparison with the experimental data for verification of reliability of the experiments.

2. Experimental Results

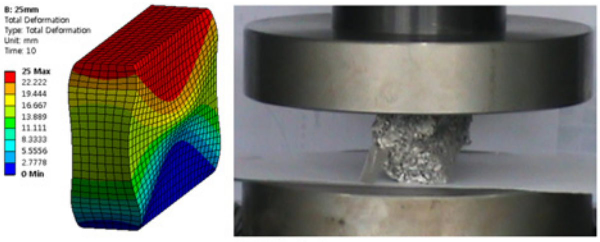
2.1 Specimen and experimental equipment

Fig. 1 shows the configuration of an aluminum foam specimen clipped to the height of 100 mm, the width of 100 mm, and the thickness of 50 mm. The testing specimens were manufactured with aluminum foam manufactured from Foam Tech Co. at Korea. For comparisons with the various specimen thicknesses of t=25, 50, 75 and 100 mm, aluminum foams were prepared by using an adhesive. As the experimental equipment, the universal tester of 'AG-X 250 kN' of SHIMADZU company is shown in Fig. 2.

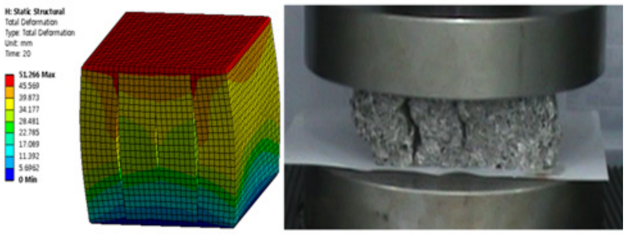
2.2 Experimental process

At the experimental condition, the compressive experiment was implemented at a rate of 5 mm/min downward vertically from top to bottom with the lower face fixed. The compression procedure was carried out up to 70 mm. Fig. 3 shows the pictures during the experimental procedure at the first and last stages. Fig. 3 shows the contours of simulation results for the total deformation at the first and last stages. And the corresponding pictures during the experimental procedure are shown at the points of times. This experiment has been operated at the state that there is attached each other with no gap between the specimen and experimental equipment. So, it has been in progress with no the special lubricant. Therefore, there is the condition attached each other with no gap between the specimen and the lower and upper parts of experimental equipment. As the displacement is applied on the specimen, the load is applied as the static compression.

Fig. 2 Universal tester of AG-X 250 kN



(a) First stage



(b) Last stage

Fig. 3 Simulation contour results for total deformation at first and last stages and the corresponding experimental processes at the specimen thickness of 25 mm

2.3 Experimental results per specimen thickness

Fig. 4 shows the results of reaction force measured by the universal tester per specimen thickness.

At the point where compression progressed by about 5 mm to 7 mm, the upper yield point was reached quickly. Reaction forces are maintained with the constant value in average after passing through the yield point, with the force values of 2300, 5000, 7300 and 10300 N in cases of specimen thickness of t=25, 50, 75 and 100 mm. As shown by the box at Fig. 4, all specimens show the vibrating tendency, which

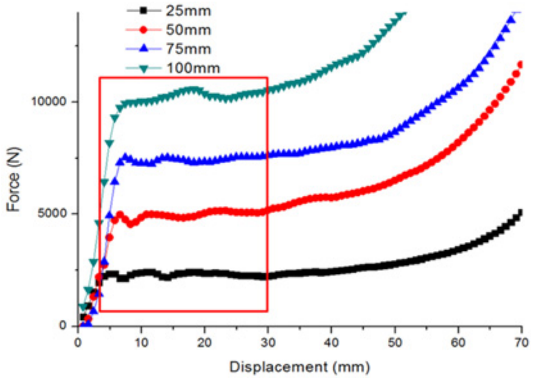
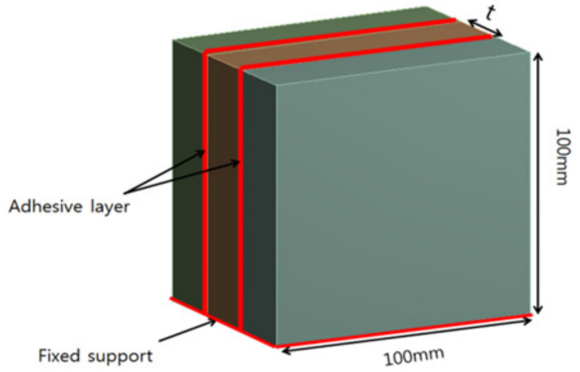


Fig. 4 Reaction force for experiment per specimen thickness

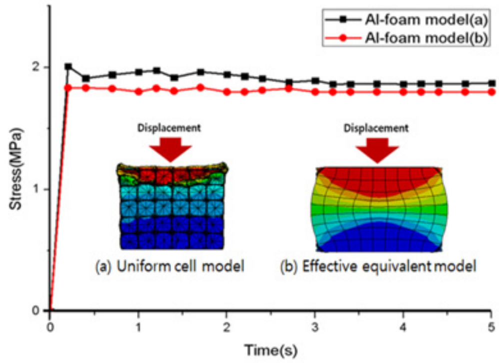
may be considered to be the phenomenon appeared as the result of occurrence of distortion in irregular lattices due to the irregular structures of a porous material. The larger the thickness, the reaction force is shown to be the greater. Rupture occurs at the point where compression passes through the displacement from 40 mm to 60 mm, and the reaction force rose drastically. The points of occurrence of rupture were shown to be 54 mm, 38 mm, 47 mm and 35 mm in the displacements at all specimens.

3. Analysis Results per Specimen Thickness

For analysis, the finite element analysis program of ANSYS was carried out. The model was designed to be identical to the experimental specimen of 100 mm in height, 100 mm in width, 25 mm in thickness, and the other specimens of 50, 75 and 100 mm was superposed with the specimen of 25 mm in thickness. The lower face was set as a fixed support, while displacement condition was applied from the upper face on the downward direction for the downward compression. Since the finite element analysis is carried out before the rupture of the structure occurs, the compression displacement was implemented up to only a 50 mm. The porous material is supposed to be the general solid as analysis model in this study. Fig. 5 shows the verification for the analysis of aluminum foam through solid aluminum. In order to verify solid aluminum whether or not the analysis result can be applied to real aluminum foam, the boundary condition of solid model are schematized in Fig. 5(a). Material property values used for the analysis are shown in Table 1. The displacement of 5 mm is applied with the same constraint condition in cases of uniformly distributed model and effective equivalent model as shown by Fig. 5(b). In case of model (a), each of cell structure in model is collapsed and can be shown concretely by compressed configuration. As number of elements and nodes increase, the analysis time becomes too longer. But the behavior of material can be acknowledged to represent simply in case of model (b). Fig. 5(b) shows the analysis results of both models. Both analysis results are similar each other. For this reason, in case of the analysis of material as complex structure with aluminum foam core, it is more effective to use the effective equivalent model instead of the uniformly distributed model. Therefore, times of modeling and analysis can be reduced by use of the effective equivalent model in this study.



(a) Boundary condition for analysis



(b) Comparison of the analyses between aluminum foam and solid aluminum

Fig. 5 Verification for the analysis of aluminum foam through solid aluminum

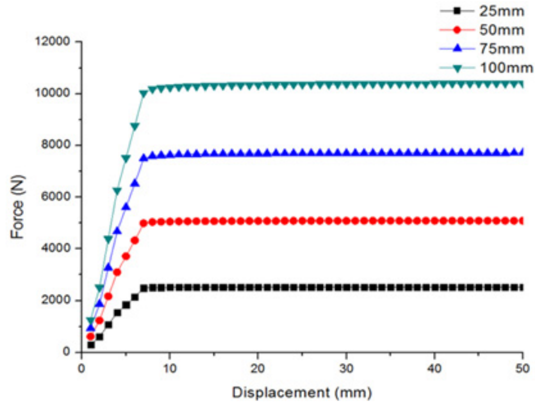
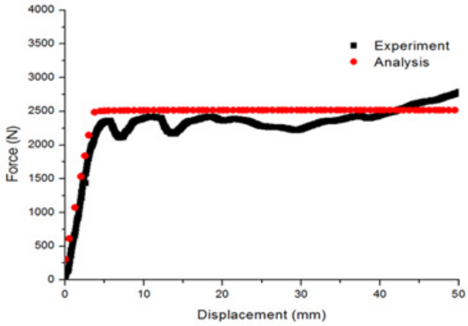


Fig. 6 Analysis results for reaction force

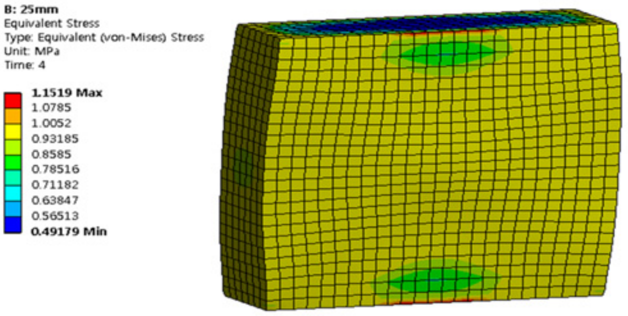
Table 1 Material properties of aluminum

Property	Number
Density (kg/m^3)	400
Young's Modulus (MPa)	23.74
Yield Strength (MPa)	1.0
Poisson's Ratio	0.29

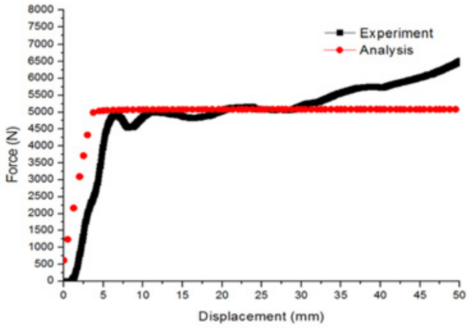
Fig. 6 shows the results for reaction force from the finite element analysis. The results were obtained where the forces remained almost



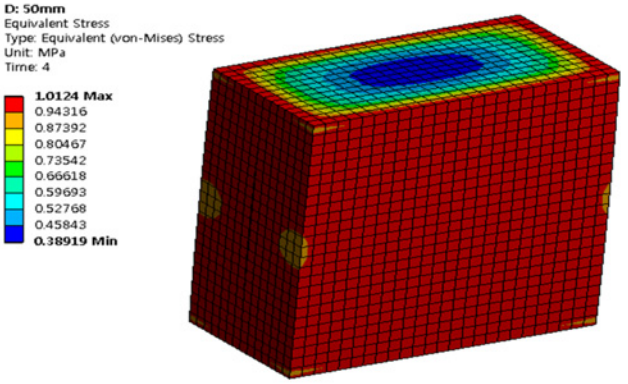
(a) Comparison between experimental and analysis results for the specimen thickness of 25 mm



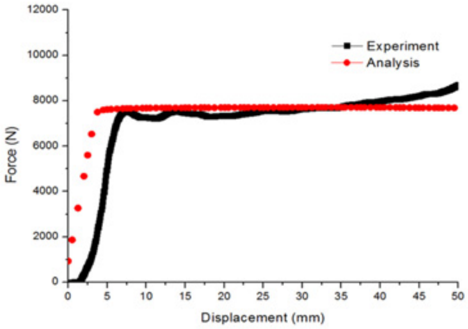
(b) Stress contour at yield point for the specimen thickness of 25 mm



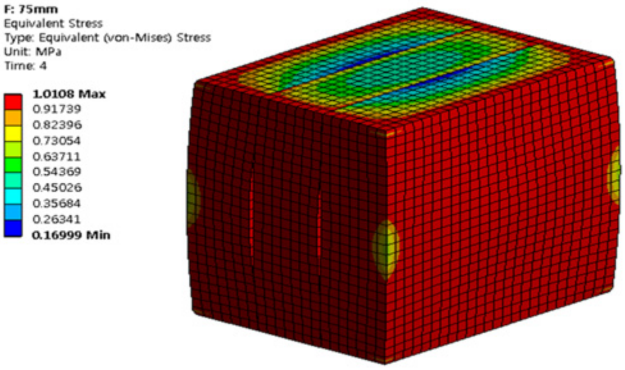
(c) Comparison between experimental and analysis results for the specimen thickness of 50 mm



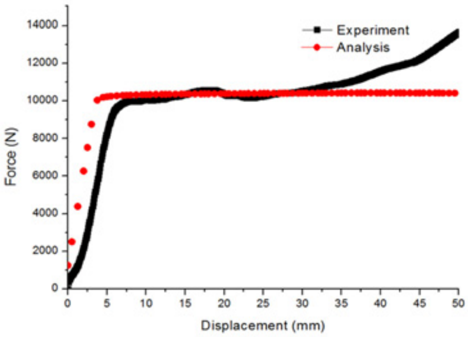
(d) Stress contour at yield point for the specimen thickness of 50 mm



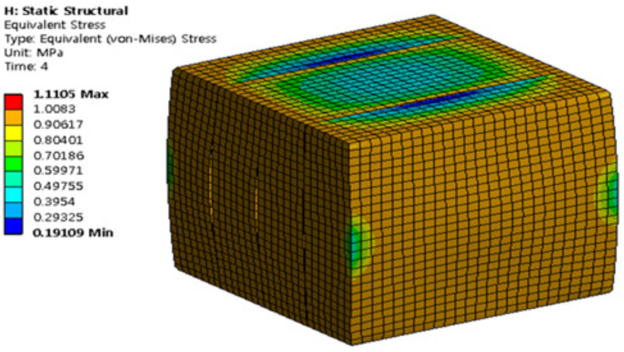
(e) Comparison between experimental and analysis results for the specimen thickness of 75 mm



(f) Stress contour at yield point for the specimen thickness of 75 mm



(g) Comparison between experimental and analysis results for the specimen thickness of 100 mm



(h) Stress contour at yield point for the specimen thickness of 100 mm

Fig. 7 Comparisons between experimental and analysis results for all specimens

constant values after reaching the yield point from the point of 4.5mm similar to the experimental results. A difference in comparison with the experimental result is that almost the constant value without vibration was exhibited in the analysis while the graphs with the minute vibration of reaction force were shown after yielding in the experiment. For the reason that such analysis results were shown to be relatively simple, it may be pointed out that the irregular porous structure cannot be represented in the finite element analysis. For the model employed in the analysis, an ordinary rectangular parallelepiped was used where irregular inside structures of a porous structure were not applied. Therefore, such small fluctuations of the reaction force as in the experiments were not visible in the analysis. As with the experiments, the reaction force was shown to be the greater, the larger the specimen thickness, with the values of 2510, 5080, 7700 and 10400 N.

4. Comparisons between the Results of Experiments and Analyses per Thickness

Fig. 7 shows the graphs of comparisons between experimental and analysis results per thickness and the contours for equivalent stresses at yield points. As the reason for differences occurred in the graphs of comparison for reaction forces, some slight differences occur in displacement points for reaching the yield point due to irregular internal structures of aluminum foam, although the displacement points per thickness for reaching the yield point are almost in agreement since the analysis was made with an ordinary rectangular parallelepiped in the finite element analysis. However, the results of considerable agreement can be affirmed in the slope risen to the yield point and the values of reaction forces are maintained after the yield point. Since there is no need for consideration after rupture, the analysis results may be considered reliable when compared with the experimental results. Also, when considering the stress distribution diagram, stresses at the time of yield point can be seen to be uniformly distributed throughout all specimens. At Figs. 7(f) and (h), the stresses decrease abruptly with the separation of bonding at the bonding face. Because the bonding stress does not endure the pressure at the maximum load, the fracture occurs and the foam deforms. Fig. 7(b) shows the lump of aluminum foam with no bonding. As the stress is concentrated at the middle instead of surface, the smaller stress is applied on the surface. At Figs. 7(d), (f) and (h), the bigger stresses are shown at the surfaces. These stresses result to the separation of bonded face and the deformation of foam.

5. Conclusions

In this study, experiments and analyses were conducted to investigate the differences in mechanical behavior per specimen thickness for aluminum foam jointed by adhesive and the following conclusions have been derived.

1) Based on the experimental results of the reaction forces, the yield point was reached around the point where the compression displacement was nearly 4.5mm as the equivalent stress, followed by a constant value being maintained while minutely vibrating, and then the reaction force was risen drastically after the compression displacement of 40 to 60 mm where the rupture occurred. When the rupture occurred, the drastic rise of reaction force could be seen. As a consequence of this time, the rupture occurred after the values are remained at 2300, 5000, 7300 and 10300 N in cases of specimen thickness of t=25, 50, 75 and 100 mm. The fact that the reaction force figures vibrated minutely after the yield point may be attributed to the irregular arrangement of bubbles which were formed inside due to the characteristics of a porous structure of aluminum foam.

2) Considering the reaction force results from the finite element analysis, the values are remained constant after the yield point and could be seen to become the greater, the larger the specimen thickness although the points of reaching the yield point were the same. The values of reaction forces after yield point were 2510, 5080, 7700 and 10400 N in all specimens. The values after yield point can be remained almost constant without the minute vibration as in the experimental results. The reason for the lack of irregular behavior as shown by the experimental result values is considered attributable to the fact that the analysis was conducted in a uniform lattice condition with no irregular arrangement of the inside bubble structure as the characteristics of a porous material of the aluminum foam since a general rectangular parallelepiped model was employed in the finite element analysis.

3) By comparing between the experimental and the analysis results, they may be considered in general agreement although there is a slight error before reaching the yield point, and hence the experimental and analysis results may be deemed reliable. This study identifies the mechanical characteristics of the aluminum foam and is thought to be capable of making a great contribution to the corresponding follow-up studies about the real structure jointed with aluminum foam.

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