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Fracture Behavior on the Structures of DCB Jointed with Aluminum Foam in Tearing Mode

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Recently, the tightening method on the machine structure has been used by only adhesive rather than existing bolts and nuts because of light weight problem. As for the porous material such as aluminum foam, the tightening is also possible by using adhesive in the aspect of material's characteristics. In case of the structure tightened by using only adhesive, it is necessary that the fracture toughness data as a part of adhesive joint are requested in order to use safely. Because the adhesive failure characteristic of the aluminum foam which is the porous material is different from the non-porous material, the study on the fracture toughness of the adhesive interface of aluminum is important. In this study, the static experiment was performed on the adhesive specimen with the aluminum foam of DCB on tearing mode. The thicknesses of specimens were 35 mm, 45 mm, and 55 mm, respectively. In case of 35 mm thickness specimen, the maximum reaction of about 0.57 kN occurred when the forced displacement was progressed by about 7 mm. When the forced displacement was progressed by about 8 mm, the maximum reaction of about 0.68 kN occurred in case of 55 mm thickness specimen. And the simulation analysis was carried by using the finite-element analysis program of ANSYS in order to verify the experimental results. This study showed the similar trend at the results between experiment and simulation. Through the results of this study, it can be thought that the simulation analysis data may be applied to the actual jointed part of porous material.

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1. Introduction

According to developments at such numerous industries as vehicles, transportation, shipbuilding, etc., various materials' characteristics, which consist of also machine devices, have been improved daily. Different from past machine design using only steel, currently, the performance of machine has been improved by using special alloy steels and mixed materials, day by day. In addition, according to deepening trend of transportation method, the light weight problem of material has been newly raised. As for such facts, while the existing tightening method on the machine structure has been used by using only adhesive rather than existing bolts and nuts, the aluminum foam is the material of ultra-light metal, which is optimized in such tightening method. Therefore, the aluminum foam has been used for various fields such as light weight structure member for architecture, shock absorber for vehicle bumper, engine acoustical sound enclosure, other sound absorption and sound insulation, and special filter for heat exchanger, etc. The aluminum foam has two types like the open and close types, which are used for heat delivery field and shock absorber field, respectively. The study aims to analyze the static fracture behavior on the structures of DCB jointed with aluminum foam in tearing mode.[1-3] However, in the case of a structure tightened by only using adhesive, fracture toughness data as a part of adhesive joint are requested in order to utilize it safely. Especially, because the aluminum foam, which is the porous material, adhesive failure characteristics become different from the non-porous material, the study on the fracture toughness of the aluminum foam's adhesive surface can be mentioned as important.[4,5] According to such facts, the aluminum foam specimens with the alveolus structure produced at Foam Tech.'s manufacturing company at Korea are redesigned with single- lap joint method as DCB of mode (tearing mode) type according to each thickness, based on British standard ; BS 7991) and ISO 11343. In this study, the simulation analysis of static fracture was carried out as ANSYS finite-element analysis program.[6,7] In addition, the static fracture experiment was performed by using tensile tester in order to verify it. On the basis of the derived results from this study, the shearing strengths of DCB aluminum foam’s jointed structures, which were made as aluminum foam (porous material) can be evaluated.[8-12]

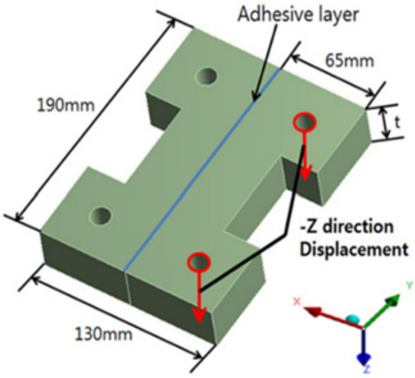

Fig. 1 Configuration of DCB specimen

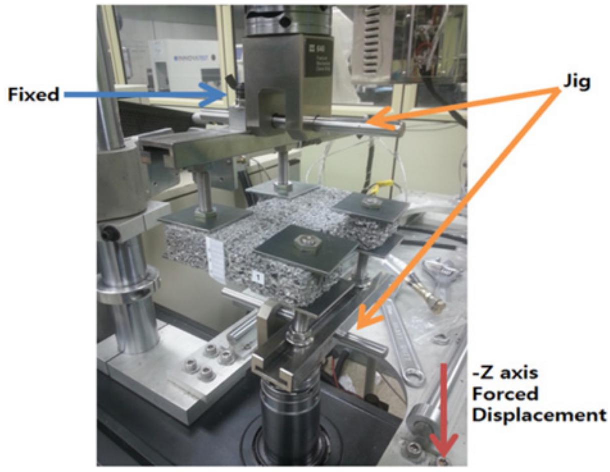

Fig. 2 Experimental setup for static experiment

2. Research Method

2.1 Research model

The study re-designed the drawing, specified in British standard; BS 7991, to DCB type of single-lap joint. Like Fig. 1, the re-designed DCB model has thickness, *t* as variable, which is 80 mm (top lateral length) × 130 mm (bottom lateral length) × 190 mm (width length).[13,14] The thickness value of t as variable, is designed as such three kinds of models as 35 mm, 45 mm, and 55 mm by 10 mm.[15,16]

2.2 Experiment condition

The forced displacement of 5 mm/min is applied for all specimen thicknesses of 35, 45 and 55 mm in this study. Fig. 2 shows how to perform the static experiment on DCB specimen with mode III in order to verify simulation analysis result. The tension tester used in the study is the MTS's tension tester. Because it is difficult for each specimen to be directly connected to top load cell and bottom load cell of tension tester according to the study's experiment method and objectives, there is the manufactured additional jig, from which specimen and tension tester are mutually connected. In the study, the top load cell is fixed and the forced displacement of 5 mm/min toward –Z axis is applied for the bottom load cell.

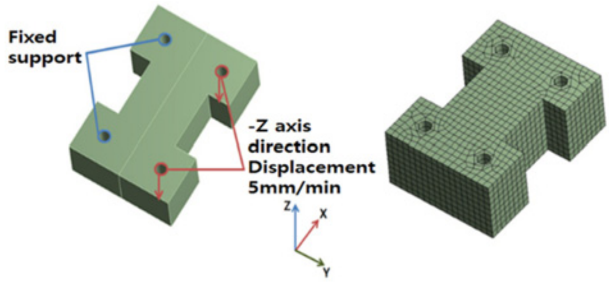

Fig. 3 Boundary condition for the simulation analysis, boundary conditions (left) and mesh of model (right)

Table 1 Numbers of nodes and elements of analysis models

Thickness of specimen model	Nodes	Elements
35 mm	10962	2070
45 mm	13061	2526
55 mm	16841	3352

Table 2 Material properties

Property	Value
Density (kg/m^3)	400
Young's modulus (MPa)	2,374
Poisson's ratio	0.29
Yield strength (MPa)	1.8
Shear strength (MPa)	0.92

2.3 Boundary condition for the simulation analysis

The finite-element analysis program, ANSYS, is performed on the transient analysis. Fig. 3 shows the boundary condition and mesh configuration applied to each DCB specimen model. It is assumed that each specimen is fixed at the tension tester, through which the fixed support condition is applied to the specimen model's holes on one side and the forced displacement is assumed to progress by the bottom load cell on holes on the other side. Under such conditions, the forced displacement is applied toward –Z axis, under which the analysis is performed by pulling one side of the specimen toward –Z axis by the forced displacement of 5 mm/min. It requires the time of 30 minutes minimum to 40 minutes maximum in order to carry out the static experiment in this study. It is not allowed for this experiment to progress too fastest or slowest. So, through the pre-experiment on many times, the condition of forced displacement was set as 5 mm/min evaluated most adequately. The number of nodes and elements of each test specimen model is listed in Table 1. The model, which is used in the study, is Al-SAF40 aluminum foam. The material property of specimen model, which is applied to the simulation analysis is also listed in Table 2. Furthermore, the specimen's adhesive layer's spread adhesive is the adhesive with aerosol type, which strength is 0.4 MPa.

3. Study Results

3.1 Specimen's test result in case of thickness, t=35 mm

Fig. 4 shows the result of specimen (t=35 mm thickness)'s static experiment, in which reaction force is graphed according to forced

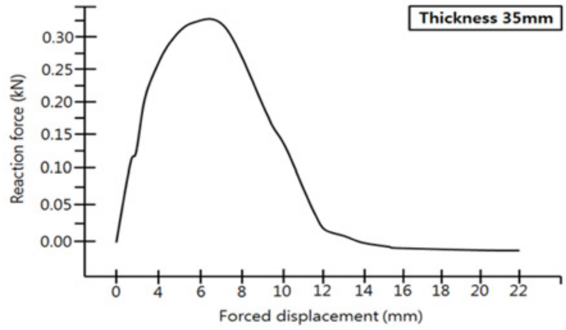

Fig. 4 Graph of reaction force due to forced displacement at static experiment (Thickness of specimen is 35 mm)

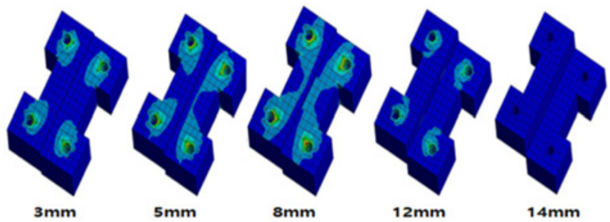

Fig. 5 Change of the equivalent stress according to the progress of forced displacement (Thickness of specimen is 35 mm)

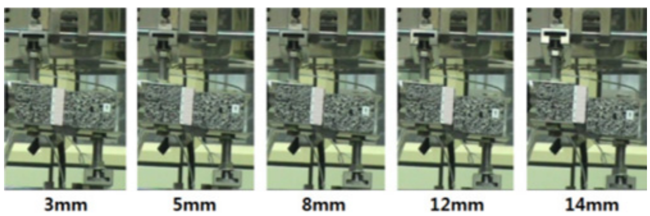

Fig. 6 Change of the static fracture according to the progress of forced displacement (Thickness of specimen is 35 mm)

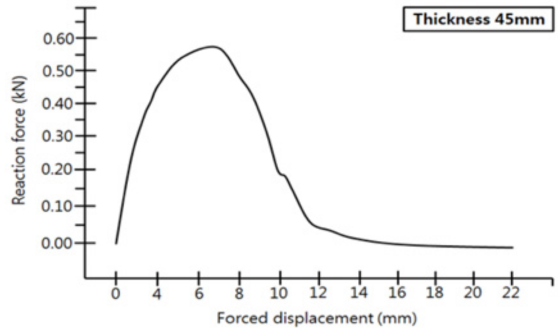

Fig. 7 Graph of reaction force due to forced displacement at static experiment (Thickness of specimen is 45 mm)

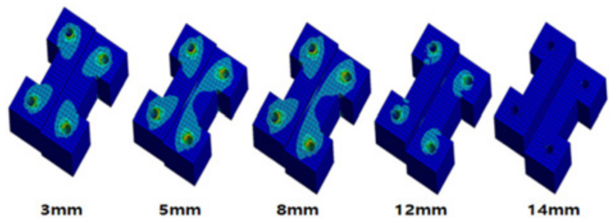

Fig. 8 Change of the equivalent stress according to the progress of forced displacement (Thickness of specimen is 45 mm)

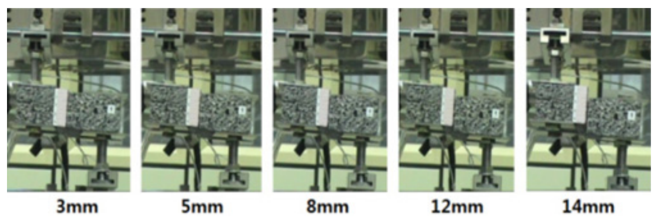

Fig. 9 Change of the static fracture according to the progress of forced displacement (Thickness of specimen is 45 mm)

displacement. When the forced displacement is progressed for about 7 mm, the maximum reaction force occurs at the test specimen. At this state, the maximum reaction force is about 0.35 kN. After the maximum reaction force occurs, while the specimen's bonding force of adhesive interface is rapidly decreased, when the forced displacement is progressed for about 13 mm, the specimen's bonding interface is totally separated, which shows the value of 0. Fig. 5 shows the specimen (t=35 mm thickness)'s simulation analysis result, while the forced displacement is progressed, it shows the stress contour occurring at the specimen. While the forced displacement is progressed, the stress on the specimen is gradually disappeared. For the comparison between analysis and experiment, Figs. 5 and 6 show the actual shearing procedure according to the forced displacement. Through these results, the stress change can be checked according to the specimen's shearing procedure.

3.2 Specimen's test result in case of thickness, t=45 mm

Fig. 7 shows the result of specimen (t=35 mm thickness)'s static experiment, in which reaction force is graphed according to forced displacement As a result of experiment, it shows the similar trend with thickness t=35 mm, specimen, in which maximum reaction force occurs on the specimen when the forced displacement is progressed for about 7 mm. At this state, the maximum reaction force is about 0.57 kN. After the maximum reaction force occurs, while the specimen's bonding force of adhesive interface is rapidly decreased, when the forced displacement is progressed for about 13 mm, the specimen's bonding interface is totally separated, which shows the value of 0. Fig. 8 shows the specimen (t=45 mm thickness)'s simulation analysis result, while the forced displacement is progressed, it shows the stress contour on occurring at the specimen. While the forced displacement is progressed, the stress on the specimen is gradually disappeared. Also, following Fig. 9 shows the actual shearing procedure according to the forced displacement, which is compared with the simulation analysis result of Fig. 8. Through these results, the stress change can be checked according to the specimen's shearing procedure.

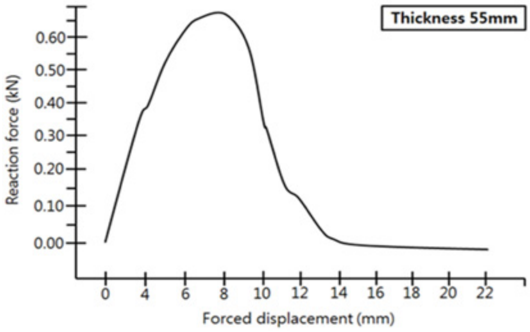

Fig. 10 Graph of reaction force due to forced displacement at static experiment (Thickness of specimen is 55 mm)

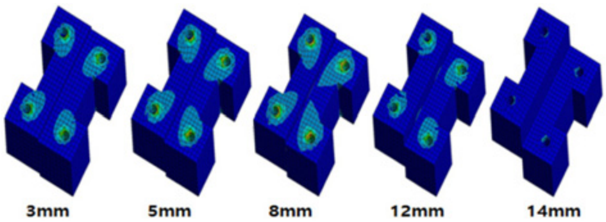

Fig. 11 Change of the equivalent stress according to the progress of forced displacement (Thickness of specimen is 55 mm)

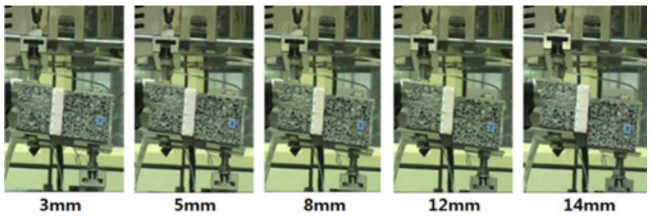

Fig. 12 Change of the static fracture according to the progress of forced displacement (Thickness of specimen is 55 mm)

3.3 Specimen's test result in case of thickness, t=55 mm

Fig. 10 shows the result of specimen (t=55 mm thickness)'s static experiment, in which reaction force is graphed according to forced displacement As a result of experiment, it shows thesimilar trend with thickness t=35 mm, specimen, in which the maximum reaction force occurs on the specimen when the forced displacement is progressed for about 8 mm. At this state, the maximum reaction force is about 0.68 kN. After the maximum reaction force occurs, just like other specimen, while thespecimen's bonding interface adhesive is rapidly decreased, afterthe forced displacement is progressed for about 14 mm, the specimen's bonding interface is totally separated, which shows the value of 0. Fig. 11 shows the specimen (t=55 mm thickness)'s simulation analysis result, while the forced displacement is progressed, it shows the stress contour occurring at the specimen.While the forced displacement is progressed, the stress on the specimen is gradually disappeared. And Fig. 12 shows the actual shearing procedure according to the forced displacement, which is compared with Fig. 11's simulation analysis

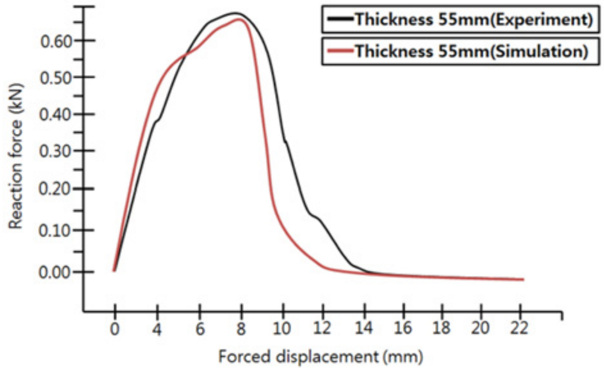

Fig. 13 Comparison between experimental and simulation analysis data (Thickness of specimen is 55 mm)

result. Through these results, the stress change can be checked according to the specimen's shearing procedure.

3.4 Comparison of experimental and simulation analysis at specimen's test result in case of thickness, t=55 mm

In order to verify the static analysis result, the static experiment is carried out. The forced displacement of 5mm/min is applied for the comparison with the simulation analysis result. Fig. 13 shows the reaction force data of experimental and simulation analysis on the specimen (t=55 mm). It is shown that the experimental results approach the simulation analysis. When the forced displacement is progressed for about 8 mm, the maximum reaction force can be checked. At this state, the maximum reaction force on analysis is about 0.65 kN, which is little different with about 0.68 kN of the experiment result. After the maximum reaction force on the experiment occurs, the specimen's bonding of adhesive interface is rapidly decreased like the simulation analysis. When the forced displacement is progressed for about 12 mm, the specimen's bonding interface is totally separated, which shows the value of 0. Also, at the state that bonding interface is totally separated, the forced displacement on experiment becomes about 14 mm, which is little different with about 12 mm of the simulation analysis. In addition, the reaction force according to the forced displacement is checked to be continuously increased until the maximum forced displacement at both of mutual comparison result experiment and its analysis. When the forced displacement is progressed for about 8 mm, the maximum reaction force occurs. However, when the graph is checked, a little difference occurs between analysis and experiment data after the maximum reaction force is disappeared. This may be considered because of the adhesion inertia for the adhesive (spread on the specimen's bonding interface) to interrupt the forced displacement progress while it is not disappeared. Fig. 14 shows the stress contour of specimen (t=55 mm) at the state happened with the maximum stress at bonding interface on simulation analysis, the contour of stress change at analysis and the specimen at experimental procedure for comparison according to forced displacement. When the maximum reaction force occurs for the specimen, the stress on bonding interface is about 0.0212 MPa. Also, while forced displacement is progress, the contour of stress and the state of specimen's bonding interface can be checked. As shown by Figs. 6, 9 12 and 14, it was shown that the

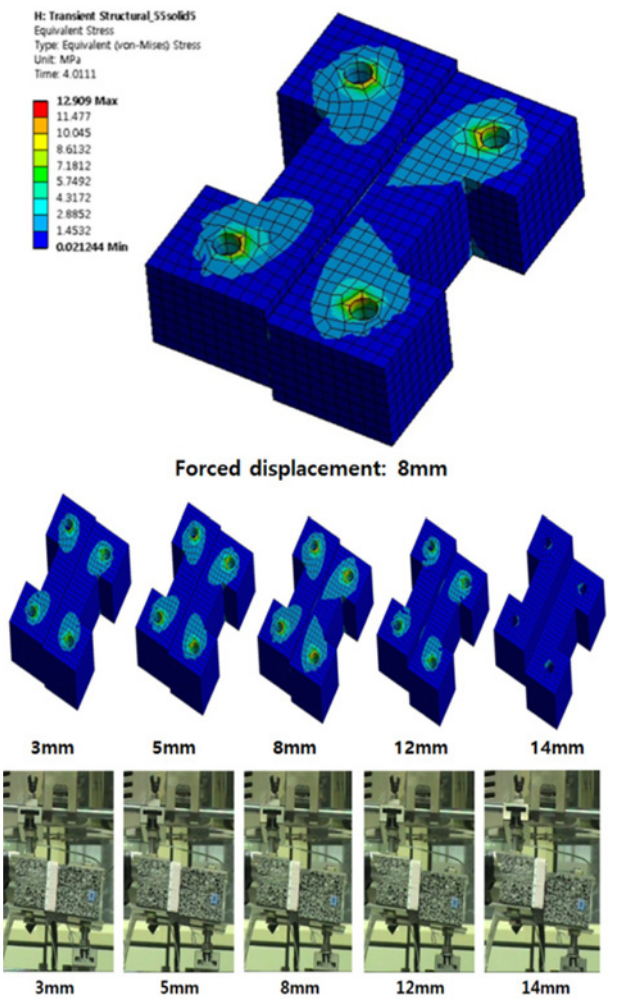

Fig. 14 Stress contour of specimen (t=55 mm) at the state happened with the maximum stress at bonding interface on simulation analysis, the contour of stress change at analysis and the specimen at experimental procedure for comparison according to forced displacement

forced displacements of 3 mm, 5 mm, 8 mm, 12 mm, 14 mm progressed at each specimen model. All specimens had the similar trends. The forced displacement was applied identically in order to compare the shearing process of each specimen. At the forced displacements of 3 mm and 5mm, the reaction forces had been increased. At the forced displacement of 8 mm, the maximum reaction force was shown. As the shears was perfectly accomplished at the forced displacements of 12 mm and 14 mm, it was shown that the values of reaction forces become nearly 0 constantly.

4. Conclusion

As the experimental and simulation results of fracture behavior on the structures of DCB Jointed with aluminum foam in tearing mode, the following conclusions are made in this study:

1. According to thickness of the static experiment, namely, specimens of t=35 mm, 45 mm, 55 mm show the maximum reaction force when the forced displacement is progressed for about 7~8 mm. As for analysis, the maximum forced displacement is shown when the forced displacement is progressed for about 8mm.
2. Each specimen's maximum reaction force is shown t=35 mm, 0.35 kN, 45 mm, 0.57 kN, 55 mm, 0.68 kN. According to the specimen's thickness is increased, the specimen's maximum reaction force is increased, as well.
3. This study showed the similar trend at the results between experiment and simulation. Through the results of this study, it can be thought that the simulation analysis data without the experiment procedures may be applied to the actual jointed part of porous material. The shearing strengths of DCB aluminum foam's jointed structures with tearing mode III, which were made as aluminum foam (porous material) can be evaluated.

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