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EXPERIMENTAL STUDY ON FRACTURE PROPERTY OF DOUBLE CANTILEVER BEAM SPECIMEN WITH ALUMINUM FOAM

DOŚWIADCZALNE BADANIE PĘKANIA MIMOŚRODOWO ROZCIĄGANEJ PRÓBKI Z BOCZNYM KARBEM WYKONANEJ Z PIANY ALUMINIOWEJ

This study aims to investigate double cantilever beam specimen with aluminum foam bonded by spray adhesive to investigate the fracture strength of the adhesive joint experimentally. The fracture energy at opening mode is calculated by the formulae of British Engineering Standard (BS 7991) and International Standard (ISO 11343). For the static experiment, four types of specimens with the heights (h) of 25 mm, 30 mm, 35 mm and 40 mm are manufactured and the experimental results are compared with each other. As the height becomes greater, the fracture energy becomes higher. After the length of crack reaches 150 mm, the fracture energy of the specimen (h=35 mm) is greater than that of the specimen (h=40 mm). Fatigue test is also performed with DCB test specimen. As the height decreases, the fracture energy becomes higher. By the result obtained from this study, aluminum foam with adhesive joint can be applied to actual composite structure and its fracture property can possibly be anticipated.

Keywords: Aluminum foam, Double cantilever beam (DCB), Fracture energy, Adhesively bonded structure

1. Introduction

Adhesive structures based on composite materials are widely used today. Due to development of the excellent adhesive processing method, it is also applicable to metallic materials [1] as fastening ways. For the strength evaluation of the adhesive joint, the approach based on the fracture mechanics is commonly applied. To study the mode I type crack propagation as well as the value of the fracture toughness including a delamination of composite materials along the bonded boundary, the testing method using the double cantilever beam (DCB) specimen was employed. This method has been revised and developed as a standard testing procedure for the fracture behavior of the composite materials [2-3]. In the present study, the DCB specimen made of aluminum foam was prepared for the fatigue testing with reference to ISO standard [4] and British Standard [5]. As static and fatigue behaviors at DCB specimen are investigated experimentally, these mechanical properties of this specimen are understood through this study. The results obtained through the present study would serve as basic data in ensuring safety and durability of the structures [6-11].

2. Specimen

2.1. Configuration and dimension of specimen

Fig. 1 shows the drawing of the specimen and the dimensions are all in mm. Four specimens with the height (h) of 25 mm to 40 mm at 5 mm intervals are fabricated to specimen heights of 25, 30, 35, and 40 mm. The length of the specimen is 200 mm and the width is 25 mm. Load block is designed with 30 mm length and 25 mm height and a 10 mm hole in load-block and 25 mm initial crack are provided. Specimens are fabricated by Foam Tech. company at Korea. The property of aluminum foam is also shown by TABLE 1.

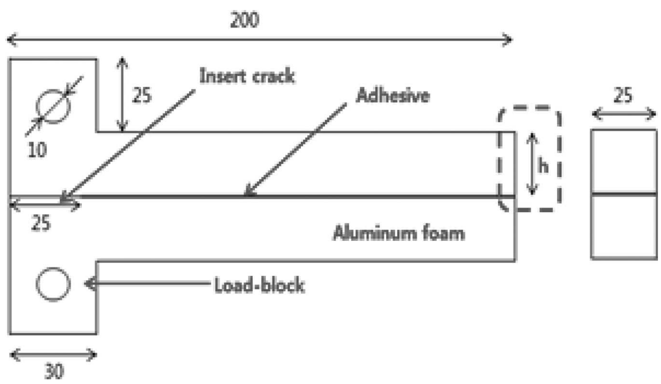

Fig. 1. Dimension of specimen

As seen in Fig. 2, the specimen is tied to the jig connected to the load cell and the test is carried out by using a displacement controlled method. Displacement is vertically imposed on the bottom load cell only and the displacement speed is set at 30 mm/min.

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TABLE 1

Property of aluminum foam

Property	Value
Young's modulus (GPa)	2.374
Poisson's ratio	0.29
Density (kg/m^3)	400
Yield strength (MPa)	1.8
Shear strength (MPa)	0.29

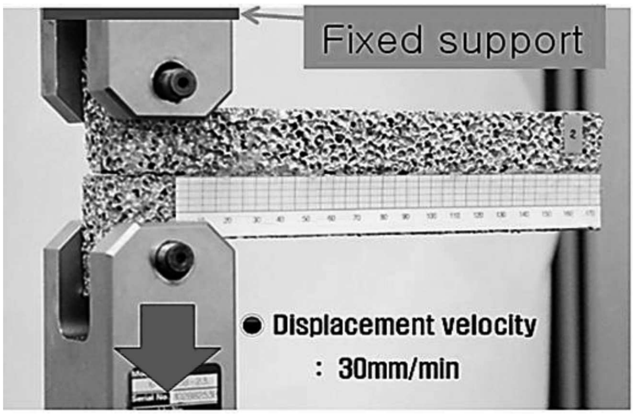

Fig. 2. Testing condition of static experiment

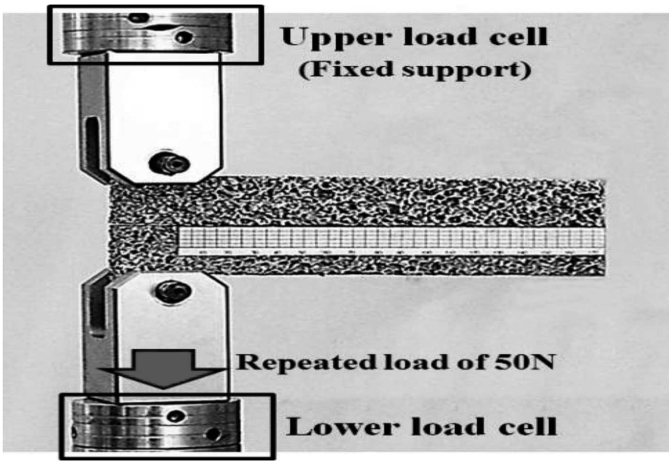

Fig. 3. Testing condition of fatigue experiment

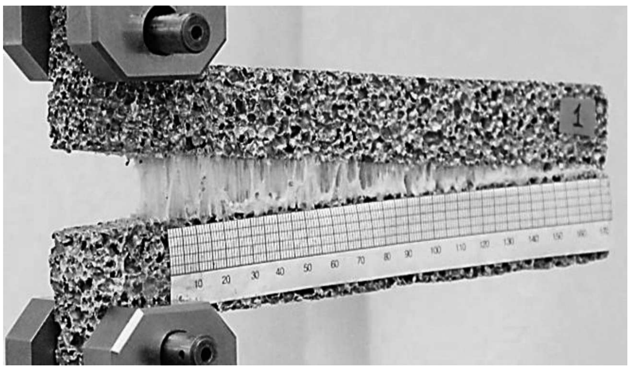

Fig. 4. Segregated form of specimen

Test specimens are loaded on the jig connected with the load cell as shown in Fig. 3. As can be seen from the figure, the upper load cell is fixed and fatigue test was executed by imposing a 50N repeated loading. The loading frequency employed was 5 Hz. According to the test result, the adhered part is segregated to the end of the specimen but due to the characteristics of the adhesive, the adhesive was not completely segregated from the initial crack as indicated in Fig. 4.

2.2. Theory of fracture energy

In mode I condition, G_{IC} or critical fracture energy is calculated by using Eq. 1 [5,6]:

$$G_{IC} = \frac{P^2}{2B}\frac{dC}{da} \tag{1}$$

where C is the compliance by δ/P, B is the width of the specimen, P is the load measured by load cell of the tester and a is the length of the crack. C is calculated from bending and shear deformation and obtained from relational expression such as Eq. 2.

$$\frac{dC}{da} = \frac{\mathbf{8}}{E_S B}\left(\frac{\mathbf{3}a^{\mathbf{2}}}{h^{\mathbf{3}}} + \frac{\mathbf{1}}{h}\right) \tag{2}$$

where E_S is elastic modulus of the beam and h is the height of the beam. By differentiating Eq. 2 and substituting to Eq. 1, the critical fracture energy on simple beam theory is as following Eq. 3.

$$G_{IC} = \frac{4P^2}{E_s B^2}\left(\frac{3a^2}{h^3} + \frac{1}{h}\right) = \frac{4P^2}{E_S B^2}\cdot m \tag{3}$$

However, according to simple beam theory, compliance value is calculated less than actual value because of the assumption that the beam is fastened incompletely. Thus, compliance value C which is closer to the actual value is calculated based on assumption that the beam is fastened completely by using corrected beam theory. A cube root equation of $C^{1/3}$ or $(C/N)^{1/3}$ is drawn and $|\Delta|$ or an intercept value on X-axis is obtained. This value is then included with crack length and expressed as $(a+|\Delta|)$. Calculation of critical fracture energy, G_{IC}at mode I load condition is dependent on load condition. In this study, $G_{IC}$is calculated using Eq. 4 and load block.

$$G_{IC} = \frac{3P\delta}{2B(a+|\Delta|)}\frac{F}{N} \tag{4}$$

where δ is the displacement on load line and Δ is the correction to crack length at the beam which is incompletely fastened. N is corrected value of stiffness by the rotation of the load block and F is the correction factor corresponding to the reduction of bending moment by large deformation. F and N are calculated by Eqs. 5 and 6.

$$F = 1 - \frac{3}{10}\left(\frac{\delta}{a}\right)^2 - \frac{3}{2}\left(\frac{l_1\delta}{a^2}\right) \tag{5}$$

$$N = 1 - \left(\frac{l_2}{a}\right)^3 - \frac{9}{8}\left[1 - \left(\frac{l_2}{a}\right)^2\right]\frac{l_1\delta}{a^2} - \frac{9}{35}\left(\frac{\delta}{a}\right)^2 \tag{6}$$

Here, l_1 is the vertical distance between the center of load pin and the beam center where the load block is combined. $l_2$is the distance between the load pin center and block edge.

3. Experimental results

Fig. 5 is the graph showing the variation of G_{IC} value in case of static experiment, the critical fracture energy depending on length of the crack. As shown in the experimental static result, two curves on fracture energy due to crack length coincide nearly from the beginning to 90 mm in cases of h = 25 and 30 mm. In these cases, two specimens have the curves of slow slopes by comparing with others, these energies have the lowest values.

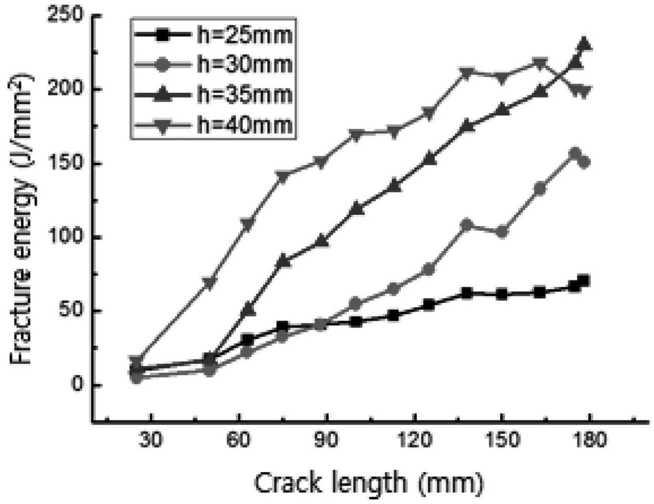

Fig. 5. Graph of fracture energy due to crack length(static experiment)

The bending moment happens during de-bonding. During fracture, fracture energy depends on the configuration of specimen. As the height of beam as h becomes higher, the bending moment becomes higher and the fracture energy becomes higher. According to the result, the higher the h as the height of the beam, the greater G_{IC} value. Beyond the crack length of 170 mm, fracture energy in case of h = 35 mm becomes larger than h =40 mm. After the length of crack reaches 170 mm, G_{IC} value for the specimen with the height of 40 mm is significantly reduced to the level below the data for the specimen with the height of 35 mm. This means that it is not useful to increase the height of more than 35 mm at designing the model because the fracture energy rather decreases than increases beyond the crack length of 170 mm.

Fig. 6 shows variation of the fracture energy as a function of crack length for the specimens with various specimen heights in case of fatigue experiment. As the experimental fatigue result, three curves on fracture energy due to crack length coincide nearly from the beginning to 60 mm in cases of h = 30, 35 and 40 mm. Three specimens in these cases have the energies of the lowest values. As the height of the beam as h becomes smaller, the bending moment becomes higher and the fracture energy becomes higher. Fracture energy due to crack length in case of h =25 mm with the smallest height becomes highest among the cases of h =25, 30, 35 and 40 mm. As can be seen from the figure, the fracture energy increases with an increase in the crack length, and further with a decrease in the specimen height. In the specimens having heights of 30 mm, 35 mm, and 40 mm, the increase rates of the energy release become slower as compared with that of 25 mm height, showing that the load and displacement applied to the specimen greatly affect the fracture energy. The maximum fracture energy around 60J/mm^2 can be seen for the specimen with a height of 25 mm.

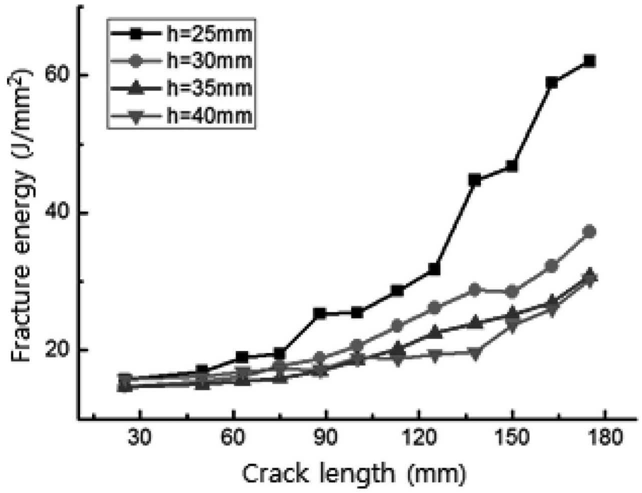

Fig. 6. Graph of fracture energy due to crack length (fatigue experiment)

4. Conclusions

As the result of static and fatigue behavior tests of the DCB specimen of aluminum foam bonded with spray adhesive, the following conclusions are as follows.

The bending moment happens during de-bonding. During fracture, fracture energy depends on the configuration of specimen. As the height of beam as h becomes higher at the experimental static result, the bending moment becomes higher and the fracture energy becomes higher. Beyond the crack length of 170 mm, the fracture energy in case of h = 35 mm becomes larger than h =40 mm. It is not useful to increase the height of more than 35 mm at designing the model at the static experiment because the fracture energy rather decreases than increases beyond the crack length of 170 mm. As the height of the beam as h becomes smaller at the experimental fatigue result, the bending moment becomes higher and the fracture energy becomes higher. Fracture energy due to crack length in case of h =25 mm with the smallest height becomes highest among the cases of h =25, 30, 35 and 40 mm. The lower the value of h, the higher the fracture energy, which is due to a greater effect of the load and the displacement of fracture energy. The fracture energy increases with an increase in the crack length at fatigue experiment, and further with a decrease in the specimen height. With the correlations obtained from the study, fracture behavior of the adhesion material was analyzed and bonded aluminum foam using adhesive was applied to the actual composite structure so as to analyze the mechanical properties and fracture roughness of the material. The result obtained through this study, therefore, would provide basic information in drafting a safety design for structures with composite materials.

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