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A Study on Fracture Characteristics in Opening Mode of a DCB Specimen Using a Lightweight Material

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경량 재료를 이용한 DCB 시험편의 열림 모드에서의 파손 특성에 관한 연구

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ABSTRACT

Recently, many structures using lightweight materials have been developed. This study was conducted by using Al6061-T6 and carbon fiber reinforced plastic (CFRP), two common lightweight materials. In addition, the failure characteristics of an interface bonded between a single material and a heterogeneous bonding material were analyzed. The specimens bonded with CFRP and Al6061-T6 were utilized by the combination of the heterogeneous bonding material. The specimens had a double cantilevered shape and the bonding between the materials was achieved by applying a structural adhesive. The experiments were conducted in opening mode: the lower part of the samples was fixed, while their upper part was subjected to a forced displacement of 3 mm/min by using a tensile tester. Under the tested amount of strength, energy release rate, and considering the specimens' fracture characteristics in opening mode, the specimen "CFRP-Al" presented the maximum stress, followed by "Al" and "CFRP". We can hence conclude that the inhomogeneous material "CFRP-Al" is useful for the construction of lightweight structures bonded with structural adhesive.

Keywords : Double Cantilever Beam(이중외팔보), Al6061-T6(Al6061-T6), Carbon Fiber Reinforced Plastic(탄소섬유강화플라스틱), Structural Adhesive(구조용 접착제)

1. Introduction

Recently, due to environmental pollution problems, the regulations concerning means of transportation are increasing. Most automotive industries have been kept in the Euro regulation at Europe. This regulation concerns exhaust gases from automobiles, which are closely related with fuel economy. The most popular way to increase the fuel economy is to decrease engine displacement or reduce the weight of vehicle bodies. This study was conducted by using an aluminum alloy and a reinforced plastic (i.e., carbon fiber reinforced plastic

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(CFRP)), which is most commonly used for reducing the weight of vehicle bodies. The experiments presented here were conducted by using not only each of the above materials, but also a bonded CFRP material and an aluminum alloy[1-5]. The failure characteristics of each material were investigated by applying adhesive peeling to a double cantilevered specimen in opening mode and using Al6061-T6 and CFRP as lightweight materials.

2. Specimen and Experimental Setup

2.1 Specimens

Figure 1 shows the shape (designed based on BS7991:2001) and other characteristics of the specimens under Mode I, which were defined as double cantilever beam (DCB) specimens. The bonded interface had a length of 170 mm and a structural adhesive was applied on it (Fig. 2). The actual shapes of the specimens under Mode I are shown in Fig. 3[6-8].

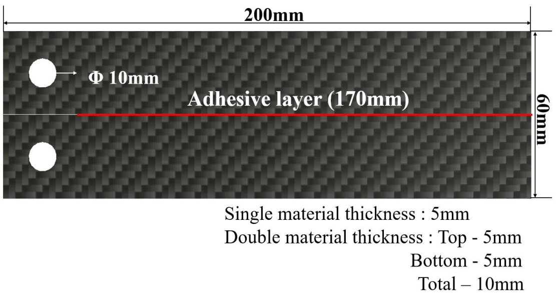

Fig. 1 Shape and specification of the specimen for mode I

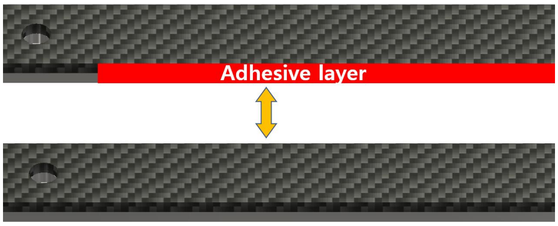

Fig. 2 Adhesion of the specimen for mode I

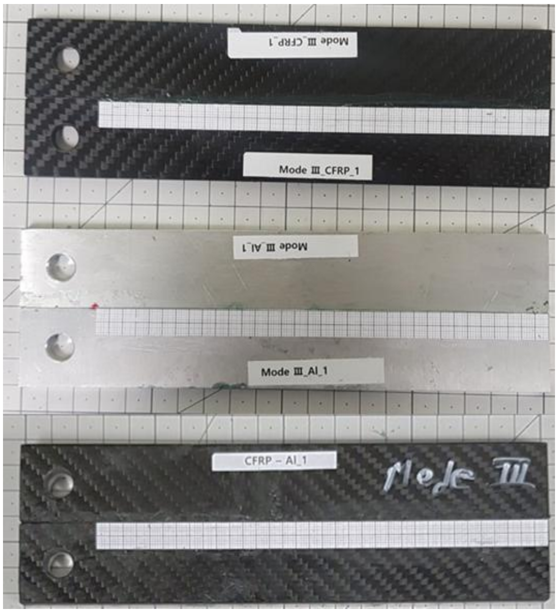

Fig. 3 Actual shapes of the specimens for mode I (Top: CFRP, Middle: Al6061-T6, Bottom: CFRP-Al)

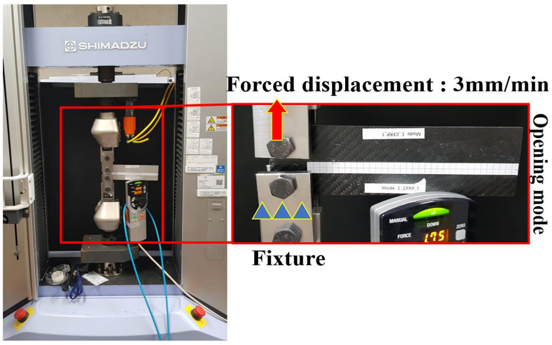

Fig. 4 Specimen-holding method for mode I and the experimental condition

2.2 Experimental Setup

The specimens were held under Mode I in an universal testing machine (UTM): Fig. 4 shows the specimen-holding method and the experimental conditions. While the specimens were held parallel to the plane X-Y, a forced displacement was applied toward the y-axis (at 3 mm/min) to the upper part of cantilever. At the same time, the lower part of the cantilever was fixed, leading to the formation of an opening fracture[9-11].

3. Experimental Results

3.1 Result of the Stress due to Displacement

Figures 5, 6, and 7 show the stress due to displacement for the opening fracture of Mode I by material. The stress, rather than the load, was considered in this study, because the thickness of the bonded specimen was twice as thicker. The specimens were hence compared by the load per unit area as the conversion into stress.

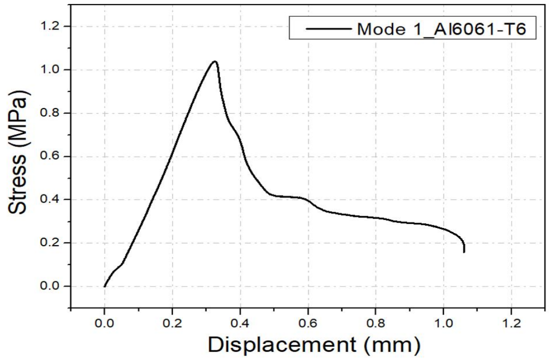

Fig. 5 Stress due to displacement for the opening fracture by Al6061-T6

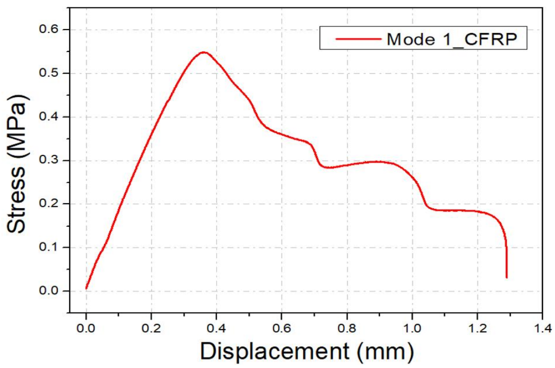

Fig. 6 Stress due to displacement for the opening fracture by CFRP

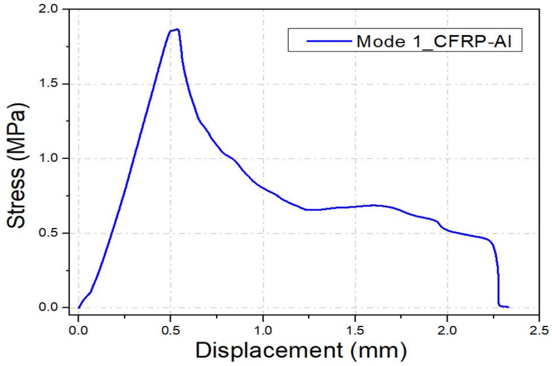

Fig. 7 Stress due to displacement for the opening fracture by CFRP-Al

Notably, "CFRP-Al" experienced the maximum stress (1.8 MPa) , followed by "Al" (1.1 MPa) and "CFRP" (0.55 MPa).

3.2 Specific Strength Derived from the Displacement

Figures 8, 9, and 10 show the specific strength experienced by the materials due to displacement in opening fracture Mode I. In this regard, it is important to note that the specific strengths of Al6061 and CFRP are typically higher than those of ferrous metals. Therefore, this study focused on determining the maximum possible reduction of weight structures by examining the experimental results of stress in relation to density. The stresses depicted in Figs. 5, 6, and 7 were calculated by dividing the density of each material ("Al" = 2.7 kg/m^3, "CFRP" = 1.7 kg/m^3, "CFRP-Al" = 2.2 kg/m^3). The inhomogeneous material "CFRP-Al" was not very heavy. Considering that the adhesive was applied between CFRP and Al, the density of the above sample was considered to be equal to the mean value of CFRP and Al. Notably, the sample "CFRP-Al" (850 Pa * m^3/kg) presented the highest specific strength, followed by "Al" (390 Pa * m^3/kg) and "CFRP" (370 Pa * m^3/kg). On the basis of these results, the bonded material of "CFRP-Al"

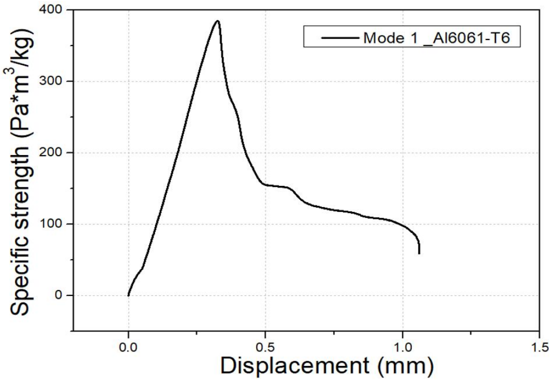

Fig. 8 Specific strength due to displacement for the opening fracture by Al6061-T6

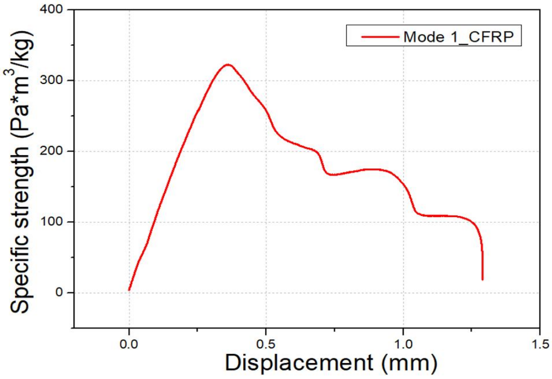

Fig. 9 Specific strength due to displacement for the opening fracture by CFRP

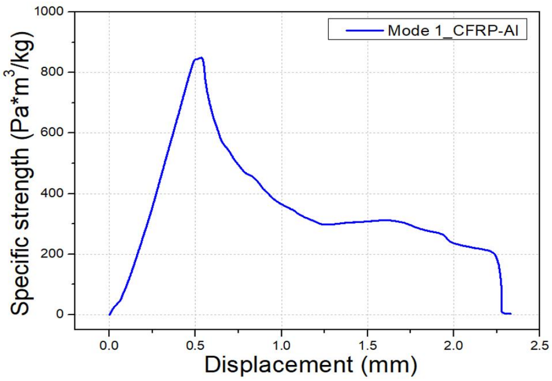

Fig. 10 Specific strength due to displacement for the opening fracture by CFRP-Al

can be considered helpful for the construction of lightweight structures.

3.3 Energy Release Rate Related to the Crack Length

Figures 11, 12, and 13 show the energy release rate related to the crack length experienced by the material in opening fracture Mode I (i.e., the "resistance curve").

In the three tested materials, the energy release rates were the highest at the very beginning of crack propagation. The maximum energy release rate was measured for "CFRP-Al" (20 MPa/mm),

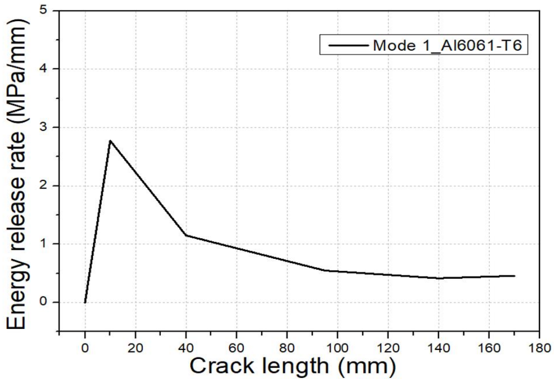

Fig. 11 Energy release rate due to crack length for the opening fracture by Al6061-T6

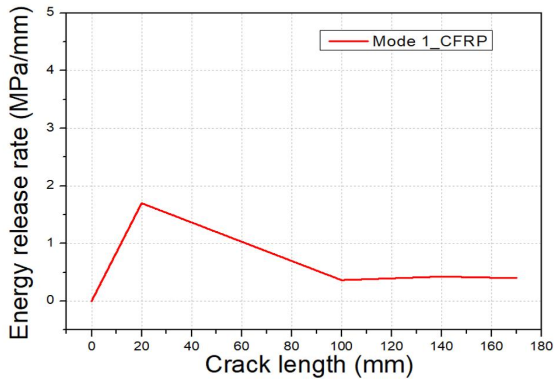

Fig. 12 Energy release rate due to crack length for the opening fracture by CFRP

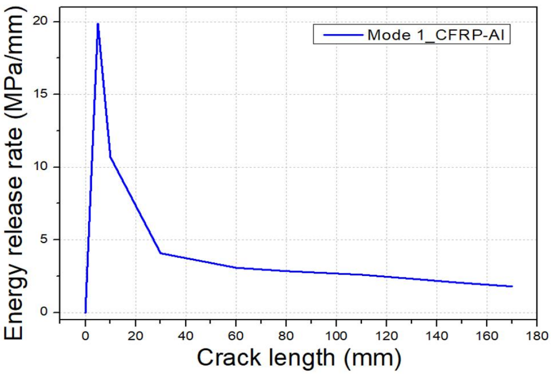

Fig. 13 Energy release rate due to crack length for the opening fracture by CFRP-Al

followed by "Al" (3 MPa/mm) and "CFRP" (2 MPa/mm).

4. Conclusion

This study investigated the failure characteristics of a double cantilevered specimen (containing the lightweight materials Al6061-T6 and CFRP) through adhesive peeling in opening mode. Our conclusions summarized listed below.

1. The failure characteristics of each tested material were examined by conducting experiments in opening mode. Since the thicknesses of the simple and bonded materials differed from each other, we investigated the stress (rather than the load) related to the displacement. The sample "CFRP-Al" experienced the maximum stress (1.8 MPa), followed by "Al" (1.1 MPa) and "CFRP" (0.55 MPa).
2. Since Al6061-T6 and CFRP represent materials with high specific strengths, the fracture characteristics of the adhesive could not be accurately determined solely based on stress: rather, they were investigated based on a graph showing the specific strength in relation to the displacement. Notably, sample "CFRP-Al" had the highest specific strength (850 Pa * m^3/kg), followed by "Al" (390 Pa * m^3/kg) and "CFRP" (370 Pa * m^3/kg). On the basis of these results, the bonded material "CFRP-Al" can be considered useful for the construction of lightweight structures.
3. In order to examine the strain energy in relation to the crack propagation, we prepared a graph of the energy release rate (i.e., resistance curve), obtaining the energy release rate for each material. For all three materials, the energy release rates were the highest at the very beginning of crack propagation. Interestingly, "CFRP-Al" showed the maximum energy release rate (20 MPa/mm), followed by "Al" (3 MPa/mm) and "CFRP" (2 MPa/mm).
4. Overall, this study defined opening fracture characteristics in the opening mode in terms of maximum stress, specific strength, and energy release rate. The maximum values of all these parameters were obtained in the case of sample "CFRP-Al", followed by "Al" and "CFRP". These results confirmed that the inhomogeneous material "CFRP-Al" is can be effectively used for the construction of lightweight structures bonded with structural adhesive.

Acknowledgements

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