An Analytic Verification on Fracture Behavior of Adhesion Exfoliation with Out-plane Shear Mode due to Tapered Angles of 6°and 8° at TDCB Made of Unidirectional Laminated CFRP

Jae-Woong Park, Jae-Ung Cho

Abstract: Because of environmental issues, the regulations on gas emission from fossil fuels become stricter. Some investigations are being carried out actively to change the fossil fuel power into electrical power. Researches on the reduction of weight in the transportation machine is also executed. Weight reduction is one of the methods of reducing the gas emission and increasing the range of electrically powered machines. The method of weight reduction includes the development of light weight material and light weight structure design method. FRP is the most representative light weight material. Among various FRP materials, (CFRP) has the highest specific strength. Light weight structure design method includes the method of designing the structure by converting the bonding method with bolts and rivets to adhesion method with the use of adhesives. In order to pursue the research on the adhesive structure design method, the research on adhesion exfoliation by using CZM needs to be carried out. There are the researches with various methods in accordance with the style of adhesion exfoliation load and material designs. In this study, the adhesion exfoliation on the tearing fracture of tapered double cantilever beam configuration was applied to the research. Research model was composed by applying the gradient angles of 6° and 8° to TDCB. The model with the gradient angle of 8° has less fracture due to adhesion than that of 8°. The basic data on structural design of adhesion structure were provided by comparatively analyzing the research models. This research was carried out by using finite element analysis method in this study. Finite element analysis method has the advantage of reducing the cost and time taken for experiments in researches. Therefore, the finite element analysis program, ANSYS, was used in this study.

Keywords : Adhesive method, Finite element analysis, FRP(fiber reinforced plastic), TDCB(tapered double cantilever beam), Woven CFRP(carbon fiber reinforced plastic)

I. INTRODUCTION

Many efforts are being made to reduce the use of fossil fuels due to the ensuing environmental issues and depletion of fossil fuels. In case of transportation machine industry, particular efforts are made to reduce the quantity of emitted gas. In addition, the rate of use of electric power source is being increased in order to reduce the quantity of used fossil fuel. In order to reduce gas emission and increase the efficiency of machines operated with electric power source, it is essential to reduce the weight of mechanical structure[1]-[3]. The means of weight reduction of mechanical structures include the use oflight weight material and the development of light weight structure design[4]. Fiber reinforced plastic (FRP), which is a composite material, is a representative light weight material in future[5]. Glass fiber and carbon fiber are used most frequently for FRP materials. Composite FRP material has the advantages combining the tensile strength of fibers, compression strength of matrix and shaping into particular configuration. It is possible to increase the tensile strength of FRP material due to the tensile strength of fiber, and the compression strength of matrix prevents the buckling of fiber and provides convenience in shaping the material[6]-[8]. In addition, carbon fiber reinforced plastic (CFRP) has the highest specific strength among all the new materials currently developed. However, according to the compositional characteristics of the FRP aforementioned, it is greatly affected by the directions of fibers in material[9], [10]. Accordingly, various FRPs with a diverse range of mechanical characteristics that are different from ordinary metals are manufactured by altering the directions of fibers. In case of FRP materials, the adhesion method is most appropriate at binding the materials due to the mechanical characteristics of fibers[11]. However, there is a need for researches on the bonded interface since the mechanical characteristics at the bonded interfaces differ from those of ordinary materials. In this study, TDCB model with mode III type was designed to investigate the characteristics of tearing fracture shown at the bonded interfaces of FRP materials. Double cantilever beam specimens were designed with the gradient angles of 6° and 8°. Fracture characteristics shown at the bonded interface in accordance with the gradient angles of TDCB were examined to analyze the characteristics of CFRP with woven type as FRP materials.

Revised Manuscript Received on July 22, 2019.

Jae-Woong Park, Lamp design center, LS Automotive Technology, 260, Simin-daero, Dongan-gu, Anyang-si, Gyeonggi-do, 14067, Republic of Korea

Jae-Ung Cho*, Division of Mechanical & Automotive Engineering, Kongju National University, 1223-24, Cheonan Daero, Seobuk-gu, **Cheonan-si Chungnam,** 31080, Republic of Korea. Email: jucho@kongju.ac.kr

II. ANALYSIS MODELS AND CONDITIONS

A. Analysis Model

Fig. 1 shows the design drawing of research model for analysis. As the design modelsof double cantilever beam configuration with the gradient angles of 6° and 8°, the length and the thicknesses of bonded interface are 200mm and 5mmrespectively, and the diameter of the hole is 10mm for both of the models. However, according to the difference in gradient angle, the height and inclined surface length of the tapered cantilever beam differ between two models. The height and the inclined surface length of the cantilever beam with gradient angle of 6° are 50.77mm and 150.83mmrespectively, while those of the cantilever beam with gradient angle of 8° are 56.08mm and 151.47mm, respectively.

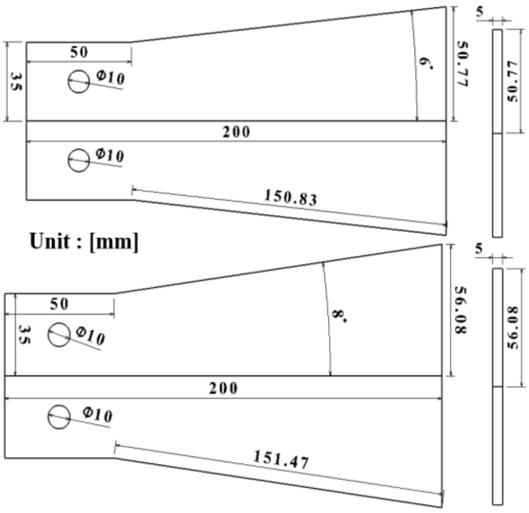


Fig. 1.Design drawing of analysis model

B. Analysis Conditions

Fig. 2 shows the analysis conditions. Analysis conditions are same for all the design models. The displacement is applied to the hole in the cantilever beam on one side while the fixed support is applied to the other cantilever beam for the composition of TDCB in which tearing fracture occurs at the bonded interface.

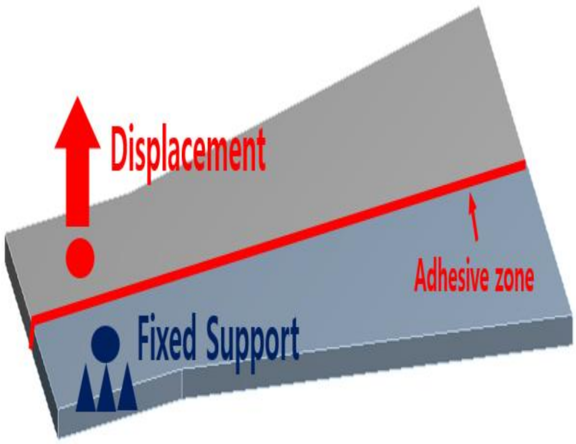


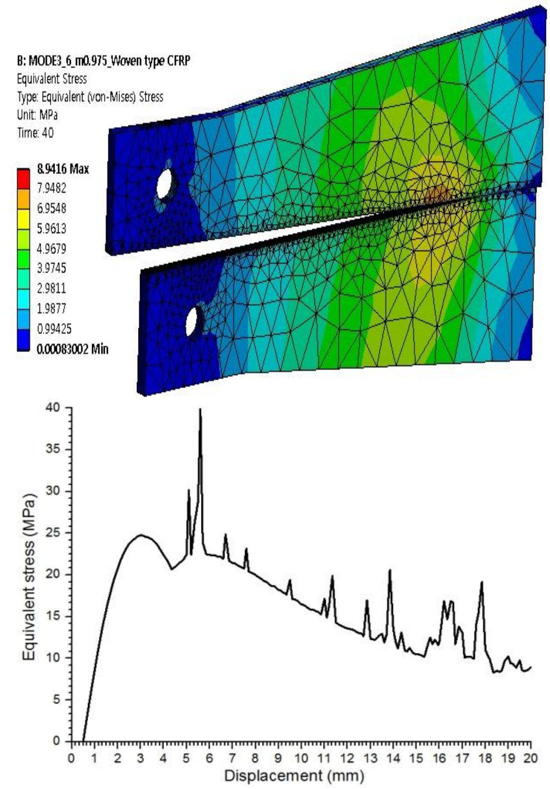
Fig. 2.Analysis conditions

III. RESULT AND DISCUSSION

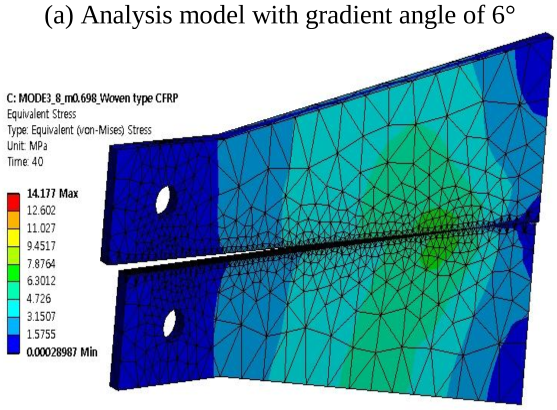
Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

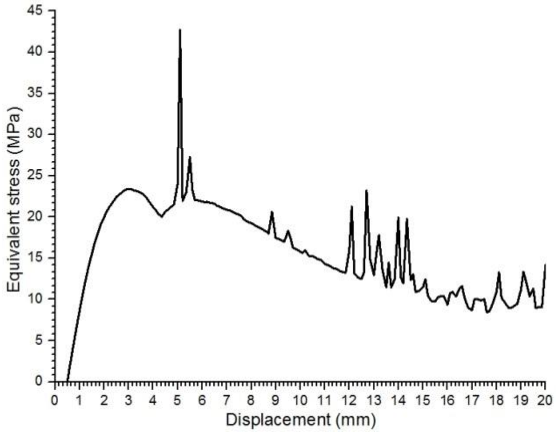
A. Analysis Result of Equivalent Stress

Fig. 3 shows the contour of equivalent stress of CFRP with woven type for each analysis model. The maximum equivalent stress of tapered double cantilever beam with the gradient angle of 6° was 8.94MPa while that of tapered double cantilever beam with gradient angle of 8°was 14.18MPa. Both models show the maximum equivalent stress at the bonded interface. Accordingly, it was confirmed that the equivalent stress was distributed in accordance with the direction of fracture in the bonded interface.



(a) Analysis model with gradient angle of 6°



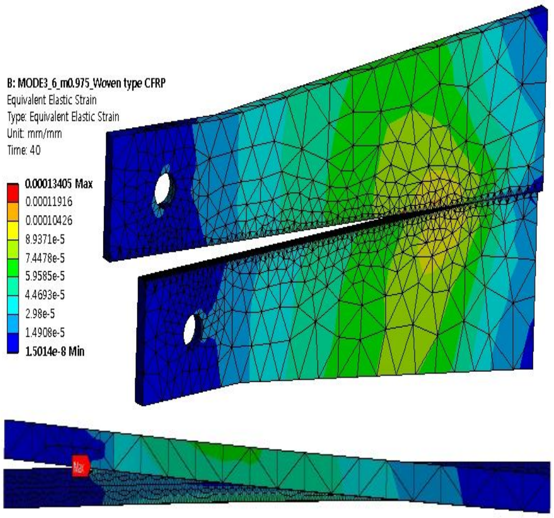


(b) Analysis model with gradient angle of 8°

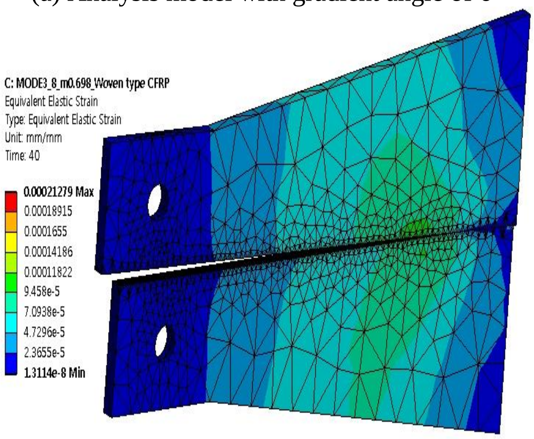
Fig. 3.Analysis result of equivalent stress at the complete fracture of bonded interface

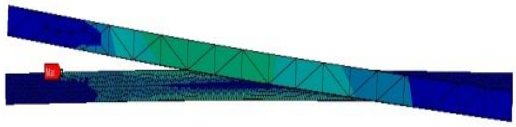
B. Analysis Result of DeformationRate

Fig. 4 shows the contour of the strain of CFRP with woven type for each of the analysis models. The maximum strain of double cantilever beam with the gradient angle of 6° was 0.13×10^{-3}mm/mm while that of double cantilever beam with the gradient angle of 8° was 0.21×10^{-3}mm/mm. The strain was distributed in accordance with the direction of fracture in the bonded interface in both models. It was possible to confirm that the strain was very low in both of the models.



(a) Analysis model with gradient angle of 6°



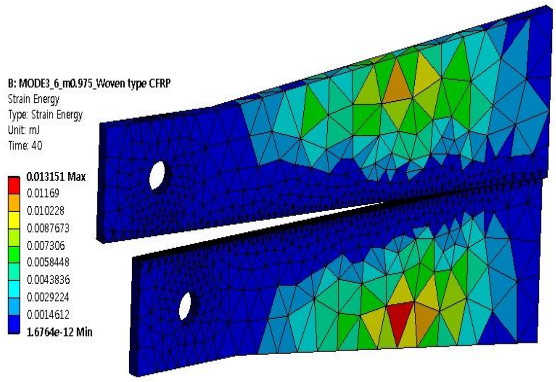


(b) Analysis model with gradient angle of 8°

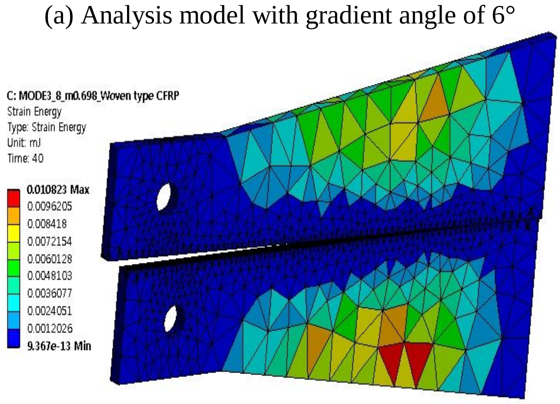
Fig. 4.Analysis resultof deformation rate at the complete fracture of bonded interface

C. Analysis Result of Strain Energy

Figure 5 shows the contour of strain energy of CFRP with woven type for each of the analysis models. The maximum strain energy of tapered double cantilever beam with the gradient angle of 6° was 0.013mJ while that of tapered double cantilever beam with gradient angle of 8° was 0.011mJ. The maximum strain energy occurred inside the tapered double cantilever beam material in both models. That is, the fracture energy, rather than deformation energy, happens at the adhesive interface.



(a) Analysis model with gradient angle of 6°



(b) Analysis model with gradient angle of 8°

Fig. 5.Analysis result of strain at the complete fracture of bonded interface

IV. CONCLUSION

In this study, the analytic research was conducted to investigate the mechanical characteristics of tearing fracture shown at the bonded interface of CFRP with woven type. The tapered double cantilever beam was designed and used in the research with the gradient angles of 6° and 8° for analysis. The conclusions derived from this study are as follows;

1) When the equivalent stresses of the models with gradient angle of 6° and 8° are compared with each other, the model with gradient angle of 8° shows higher maximum equivalent stress. In addition, the comparative analyses on the equivalent stresses of two models illustrate that the model with gradient angle of 8° shows greater concentration of stress at the bonded interface than the model with the gradient angle of 6°. That is, in case of CFRP with woven type, the concentration of stress shown at the bonded interface increases with the increase of gradient angle.
2) When the strains of two models are compared with each other, the model with gradient angle of 8° showed greater strain than the model with gradient angle of 6°. In the analysis, the strainmeans the deformation of material against the load that manifests under the adhesion exfoliation situation rather than the deformation of the adhesives. Therefore, when the maximum strain and contour of strains are analyzed, it is deemed that the deformation around bonded interface is greater in the model with gradient angle of 8° due to the greater concentration of stress.
3) As the analysis results of strain energies of two models, the model with gradient angle of 6° showed greater strain energy than the model with gradient angle of 8°. Both models showed the strain energy in the material itself rather than in areas around the bonded interface. This result means that the strain energy that occurs at the bonded interface is not distributed since it is in the state of occurrence of the release of strain energy. Therefore, although the strain is greater in the model with the gradient angle of 8°, the strain energy is greater in the model with the gradient angle of 6°. It is deemed that the reason for this occurrence is the greater delivery of the force against the deformation at the fracture time of bonded interface in the case of the model with the gradient angle of 6°.
4) Based on the overallanalysis results of the model with the gradient angle of 8°, it can be confirmed that the strain energy is small due to manifestation of greater concentration of stress. Although the maximum adhesive strength becomes high when the fracture happens at the bonded interface, the cohesive bonding force of adhesive is quickly cut off. That is, it is possible to confirm that the fracture occurs with the quick release of strain energy with low durable property at the bonded interface. However, there is the manifestation of high maximum strength due to the high maximum stress.
5) When the results of comprehensive analyses are examined, the magnitude of resisting force at the bonded interface is found to be greater in the model with the gradient angle of 8°. In addition, when viewed from fracture dynamics, the fracture characteristics through the strain energy and strain are dealt with more importantly than the strength. When the strain energy and strain are examined, it is deemed that the model with the gradient angle of 8° has less fracture of material due to adhesion fracture, thereby resulting in greater design stability.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(NRF-2018R1D1A1B07041627).

REFERENCES

1. B. R. K. Blackman, H. Hadavinia, A. J. Kinloch, M. Paraschi,J. G. Williams.(2003) "The Calculation of Adhesive Fracture Energies in Mode I: Revisiting the Tapered Double Cantilever Beam (TDCB) Test," Eng. Frac. Mech., 70(2), pp. 233-248.Available: https://www.sciencedirect.com/science/article/pii/S0013794402000310
2. M. De Giorgi, A. Carofalo, V. Dattoma, R. Nobile, F. Palano.(2010) "Aluminum Foams Structural Modelling," Comp.Struc., 88(1-2), pp. 25-35.Available: https://www.sciencedirect.com/science/article/pii/S0045794909001746
3. Q. Shi, J. Liu, W. Liu, F. Wang, Y. Wang. (2019)"Barker-coded modulation laser thermography for CFRP laminates delamination detection,"Infra. Phys.& Tech., 98, pp. 55-61.Available: https://www.sciencedirect.com/science/article/pii/S1350449518308867
4. C. V. Opelt, G. M. Candido, M. C. Rezende.(2018) "Fractographic study of damage mechanisms in fiber reinforced polymer composites submitted to uniaxial compression,"Eng. Fail. Anal., 92, pp. 520-527. Available: https://www.sciencedirect.com/science/article/pii/S1350630717313596
5. J. S. Binoj, J. S. Bibin. (2019)"Failure analysis of discarded Agave tequilana fiber polymer composites,"Eng. Fail. Anal., 95, pp. 379-391.Available: https://www.sciencedirect.com/science/article/pii/S1350630718300335
6. M. Mohamed, S. Anandan, Z. Huo, V. Birman, J. Volz, K. Chandrashekhara. (2015) "Manufacturing and characterization of polyurethane based sandwich composite structures," Comp. Struc., 123, pp. 169-179. Available: https://www.sciencedirect.com/science/article/pii/S0263822314007089
7. C. Li, L. Ke, J. He, Z. Chen, Y. Jiao. (2019)"Effects of mechanical properties of adhesive and CFRP on the bond behavior in CFRP-strengthened steel structures,"Composite Structures, 211, pp. 163-174. Available: https://www.sciencedirect.com/science/article/pii/S026382231833023X
8. K. B. Katnam, A. J. Comer, W. F. Stanley, M. Buggy, T. M. Young. (2012) "Investigating tensile behaviour of toughened epoxy paste adhesives using circumferentially notched cylindrical bulk specimens," Int. J. of Adhesion & Adhesives, 37, pp.3-10. Available: https://www.sciencedirect.com/science/article/pii/S0143749612000085
9. C. Schmandt, S. Marzi.(2018) "Effect of crack opening velocity and adhesive layer thickness on the fracture behaviour of hyperelastic adhesive joints subjected to mode I loading."Int. J. of Adhesion and Adhesives, 83, pp. 9-14. Available: https://www.sciencedirect.com/science/article/pii/S0143749618300678
10. M. Imanaka, K. Ishii, K. Hara, T. Ikeda, Y. Kouno. (2018)"Fatigue crack propagation rate of CFRP/aluminum adhesively bonded DCB joints with acrylic and epoxy adhesives,"Int. J. of Adhesion and Adhesives, 85, pp. 149-156. Available: https://www.sciencedirect.com/science/article/pii/S0143749618301544
11. S. Marzi, A. Biel, U. Stigh. (2011)"On experimental methods to investigate the effect of layer thickness on the fracture behavior of adhesively bonded joints,"Int. J.of Adhesion and Adhesives, 31(8), pp. 840-850. Available: https://www.sciencedirect.com/science/article/pii/S0143749611001229

AUTHORS PROFILE

Jae-Woong Park received his M.S. Degree in Department of Mechanical Engineering from Kongju National University, Cheonan, Korea in 2019. Now he is a researcher in Lamp design center of LS Automotive Technology.

Jae-Ung Cho received his M.S. and Doctor Degree in Mechanical Engineering from Inha University, Incheon, Korea, in 1982 and 1986, respectively. And he got Post Doctor Fellowship in Department of Mechanical Engineering from Imperial College of London, United Kingdom. Now he is a professor in Mechanical & Automotive Engineering of Kongju National University, Korea. He is interested in the areas of fracture mechanics (Dynamic impact), composite material, fatigue and strength evaluation, and so on.