International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.5 (2016), pp.275-284
http://dx.doi.org/10.14257/ijmue.2016.11.5.25

Simulation Analysis for Static Fracture Properties of DCB Aluminum Foams Bonded with Mode III Type

Jung Ho Lee[1] and Jae Ung Cho[2*]

[1]*Department of Mechanical Engineering, Graduate School, Kongju National University, 1223-24, Cheonan Daero, Seobuk-gu, Cheonan-si, Chungnam of Korea 31080*
jungholee8@kongju.ac.kr
[2]*Division of Mechanical & Automotive Engineering, Kongju National University, 1223-24, Cheonan Daero, Seobuk-gu, Cheonan-si, Chungnam of Korea 31080*
**Corresponding Author, jucho@kongju.ac.kr*

Abstract

This study aims to investigate static fracture properties on adhesive layers by conducting simulation static analysis by thickness. Simulation analysis result showed that all specimens at t=35mm, 45mm, and 55mm showed maximum reaction force at approximately 5mm of forced displacement. Simulation analysis showed that maximum reaction forces of specimen models were approximately 0.25kN at t=35mm, approximately 0.28kN at t=45mm, and approximately 0.5kN at 55m, respectively. As such, the maximum reaction forces of specimen models that occur had increasing tendency along with increasing thickness. The study results showed fracture properties of aluminum foam adhesive specimen models at their adhesive layers. Based on accumulated data, it is thought that the data on variables other than variables in this study may be acquired easily, and that the data would contribute to analyzing mechanical properties of DCB adhesive structures with mode III-type.

Keywords*: Aluminum foam, DCB, Mode III-type, Simulation analysis, Static fracture*

1. Introduction

As the weights of transportation vehicles are increasingly being lightened, the issue of lightening materials has newly risen these days. Moreover, properties of various materials that consists of mechanical devices are developing day by day along with developments of many industries such as automobile, transportation, shipbuilding, *etc.* Unlike the past when only steel was used in designing machines, special alloy steel and composite materials are currently being used at improving the performance of machines [1-4]. Regarding this, clamping method that only uses adhesive, not bolts and nuts as previous, is being used. Aluminum foam is a light-weight metal material that is very appropriate for such clamping method. It is a useful material that can be used in various fields, such as lightweight structural materials for buildings, shock absorbent for automobile bumpers, engine sound enclosure using outstanding sound enclosure and soundproof effects as well as other sound enclosure and soundproof materials, and special filters for heat exchangers [5-8]. Aluminum foam has open type and closed type, each of which is used for heat exchange and shock absorbent, respectively [9]. This study aims to study properties of aluminum foam bonded structure based on closed aluminum foam. However, for structures clamped only with adhesives, the data on fracture toughness on adhesive joint part are mandatory to ensure safe usage. Study on fracture toughness is especially important for fracture properties of adhesive parts on aluminum foam, a porous material, because these properties may be different from those of nonporous materials [10-12]. Accordingly, based on British standard (BS7991) and ISO international standard (ISO

ISSN: 1975-0080 IJMUE

11343), the closed aluminum foam bonded structure model using single-lap bonding method as DCB Mode III-type specimen model by thickness is redesigned in this study. For each specimen by thickness, simulation static fracture analysis was conducted by using ANSYS finite element analysis program. Based on results derived from such method, this study is to predict and evaluate shear strength of DCB bonded structure constructed with porous aluminum foam [13-16].

2. Research Method

2.1. Research Model

Configuration from British industrial standard 7991: 2001 was redesigned and 3D-modeled in the form of DCB bonded structure with single-lap bonding method, according to characteristics of this research. As shown in Figure 1, the redesigned DCB bonded structure model was designed with thickness value t as the variable. Width of its upper edge for the model is 80mm, width of the lower edge is 130mm, and length of lower edge is 190mm. The value 50mm was determined by being based on form factor. Three models were designed with thickness value t of 35mm, 45mm, and 55mm, each by the unit of 10mm [17-18].

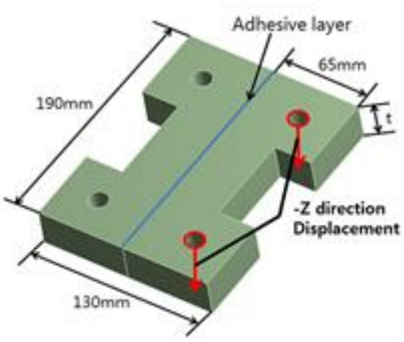

Figure 1. Configuration of DCB Specimen Model

2.2. Boundary Condition for the Simulation Analysis

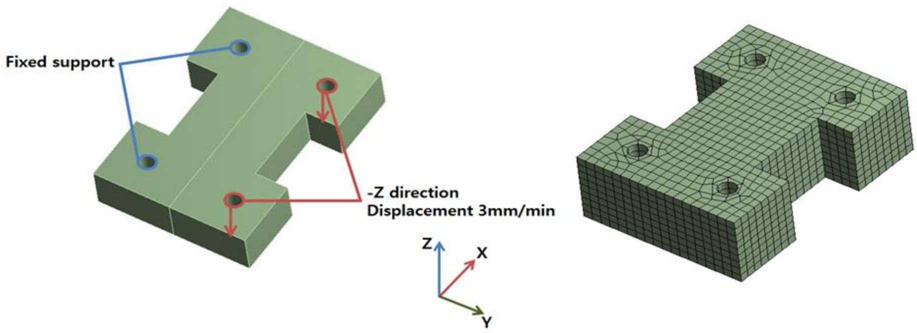

Figure 2. Boundary Conditions (Left) and Mesh of Model (Right)

ANSYS, a finite element analysis program was used in this study, and the analysis based on transient analysis was conducted. Figure 2 shown above shows boundary condition and mesh applied for each DCB specimen model. Holes on one side of the specimen model were fixed by applying the fixed support conditions, with the assumption that each specimen was attached and fixed on tensile tester. Holes on the other side were applied with forced displacement conditions to the direction of – Z axis, with the assumption that forced displacement will be carried out by lower load cell by pulling one side of the specimen to the direction of – Z axis as the forced displacement of 4mm/min. Numbers of nodes and elements for each specimen model are shown in Table 1. Model in this study is the material of Al-SAF40 as aluminum foam. Material properties of specimen model applied in simulation analysis are shown in Table 2. Also, adhesive applied on adhesive layer of the specimen is aerosol-type adhesive, and its adhesive strength is 0.4MPa.

Table 1. Numbers of Nodes and Elements of Analysis Models

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

3. Simulation Analysis Results

3.1. Analysis Result of Specimen with t=35mm

Figure 3 shows analysis result of reaction data for DCB specimen model with thickness t=35mm, when pulling specimen model with – Z axis by applying forced displacement of 4mm/min. Maximum reaction force is shown when forced displacement is approximately 5mm, and its value is approximately 0.25kN. After reaction force occurred, adhesive strength on adhesive layer of specimen model decreased drastically. After forced displacement passed approximately 12mm, the separation of adhesive layers of specimen was accomplished almost perfectly, with reaction force on forced displacement being almost 0. Figure 4 is the analysis result of specimen with thickness=35mm, showing the stress distribution of specimen model along with progress of forced displacement. Stress on specimen model gradually diminished as forced displacement progressed. Figure 5 shows the stress when maximum reaction force is approximately 0.25kN. The stress at adhesive layer was approximately 0.715MPa.

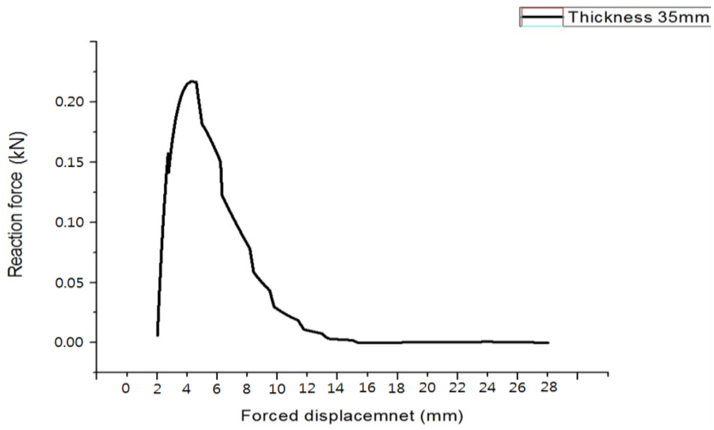

Figure 3. Graph of Reaction Force Due to Forced Displacement at Static Analysis (Thickness of Specimen Is 35mm)

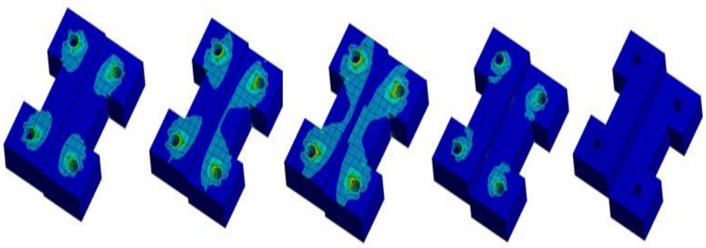

Figure 4. Change of the Equivalent Stress According to the Progress of Forced Displacement (Thickness of Specimen Is 35mm)

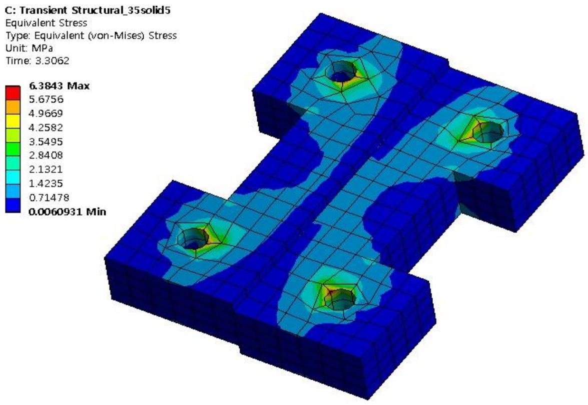

Figure 5. Stress of the Bonded Interface at the Maximum Reaction Force (Thickness of Specimen Is 35mm)

3.2. Analysis Result of Specimen with T=45mm

Simulation analysis result on reaction force data for DCB specimen model with thickness t=45mm is shown in Figure 6. This figure showed similar tendency with specimen model with thickness of 35mm, showing maximum reaction force at approximately 5mm of forced displacement, with maximum reaction force of 0.28kN. After maximum reaction force occurs, adhesive strength on adhesive layer of specimen model gradually diminished. After forced displacement passed approximately 12mm, the separation of adhesive layers of specimen was accomplished, with reaction force on forced displacement being almost 0. Figure 7 below shows the analysis result of specimen with the thickness of 45mm, which is the stress distribution of specimen model as forced displacement progresses. Like previous figure, stress of specimen model gradually diminished as forced displacement progressed. Figure 8 shows the stress when maximum reaction force is approximately 0.28kN. The stress on adhesive layer was approximately 0.653MPa.

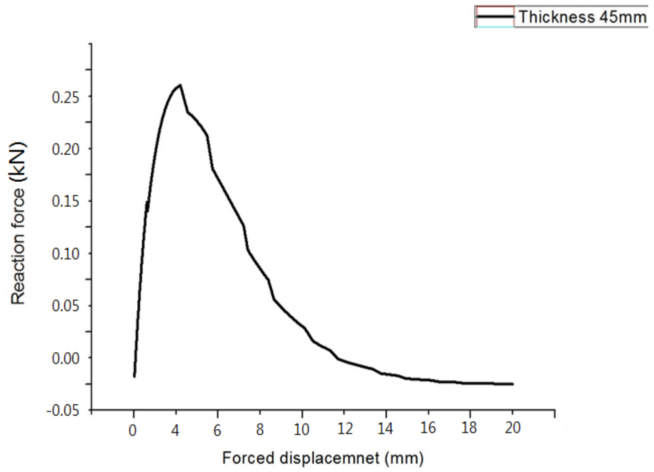

Figure 6. Graph of Reaction Force Due to Forced Displacement at Static Analysis (Thickness of Specimen Is 45mm)

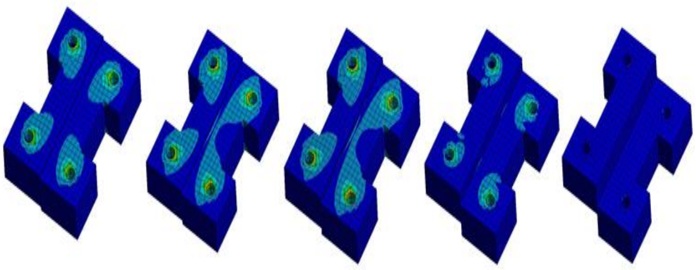

Figure 7. Change of the Equivalent Stress According to the Progress of Forced Displacement (Thickness of Specimen Is 45mm)

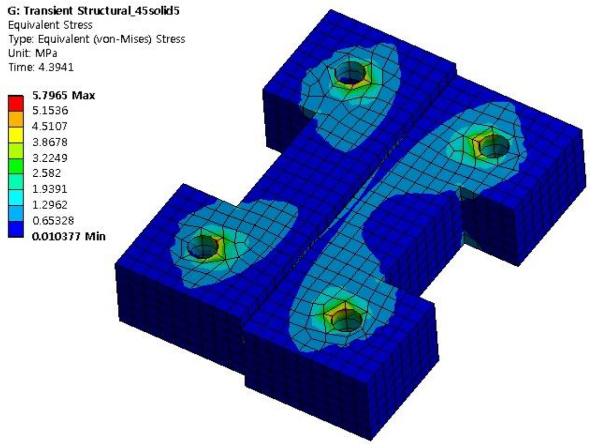

Figure 8. Stress of the Bonded Interface at the Maximum Reaction Force (Thickness of Specimen Is 45mm)

3.3. Analysis Result of Specimen with T=55mm

Simulation analysis result on reaction force data for DCB specimen model with thickness t=55mm is shown in Figure 9. This figure showed similar tendency with specimen models with thickness of 35mm and 45mm, showing maximum reaction force at approximately 5mm of forced displacement, with maximum reaction force of 0.5kN. After maximum reaction force occurs, adhesive strength on adhesive layer of specimen model gradually diminished. After forced displacement passed approximately 12mm, the separation of adhesive layers of specimen was accomplished, with reaction force on forced displacement being almost 0. Figure 10 shows analysis result of specimen with thickness of 55mm, which is the stress distribution of specimen model as forced displacement progresses. The stress of specimen model gradually diminished as forced displacement progressed. Figure 11 shows the stress when maximum reaction force is approximately 0.5kN. The stress on adhesive layer was approximately 0.664MPa.

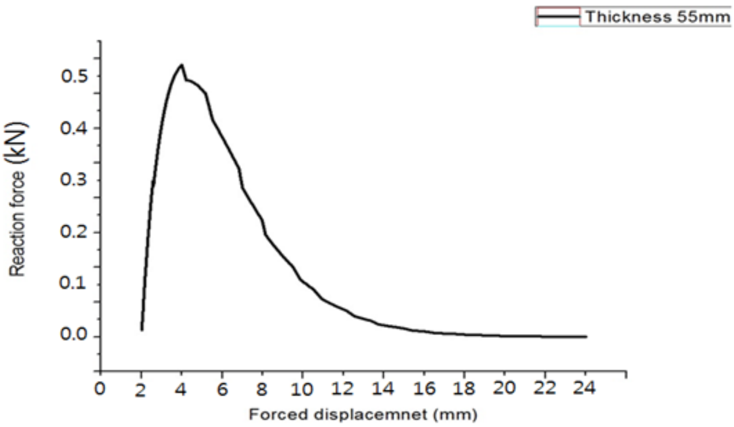

Figure 9. Graph of Reaction Force Due to Forced Displacement at Static Analysis (Thickness of Specimen is 55mm)

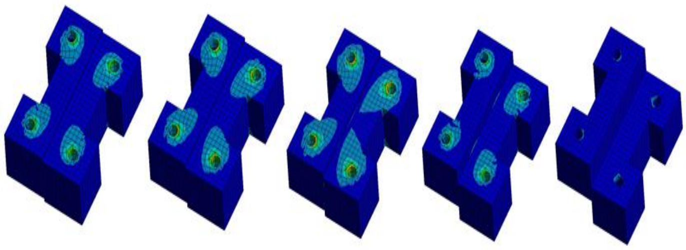

Figure 10. Change of the Equivalent Stress According to the Progress of Forced Displacement (Thickness of Specimen is 55mm)

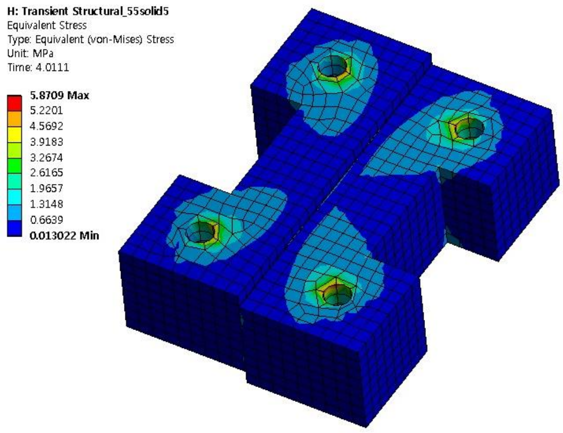

Figure 11. Stress of the Bonded Interface at the Maximum Reaction Force (Thickness of Specimen is 55mm)

3.4. Comparison of Analysis Results for Each Specimen

Table 3 shows the summary of analysis results for each specimen model with thickness of 35mm, 45mm, and 55mm. The analysis results showed that maximum reaction force was approximately 0.25kN for the specimen with thickness t=35mm, approximately 0.28kN for the specimen with t=45mm, and approximately 0.5kN for the specimen with t=55mm, showing increased maximum reaction force with increased thickness. The stress on adhesive layer was approximately 0.715MPa for the specimen with t=35mm, approximately 0.653Mpa for the specimen with t=45mm, and approximately 0.664MPa for the specimen with t=55mm, showing decreased stress with increased thickness.

Table 3. Maximum Reaction Forces and Maximum Equivalent Stresses of Specimens at Static Analysis

Thickness of specimen model	Maximum reaction force(kN)	Stress on adhesive layer(MPa)
35mm	0.25	0.715
45mm	0.28	0.653
55mm	0.5	0.664

4. Conclusions

This study aims to investigate static fracture properties on adhesive layers by conducting simulation static analysis by thickness and derived the following conclusions.

1. Simulation analysis result showed that all specimens at t=35mm, 45mm, and 55mm showed maximum reaction force at approximately 5mm of forced displacement.

2. Simulation analysis showed that maximum reaction forces of specimen models were approximately 0.25kN at t=35mm, approximately 0.28kN at t=45mm, and approximately 0.5kN at 55m, respectively. As such, the maximum reaction forces of specimen models that occur had increasing tendency along with increasing thickness.

3. The study results showed fracture properties of aluminum foam adhesive specimen models at their adhesive layers. Based on accumulated data, it is thought that the data on variables other than variables in this study may be acquired easily, and that the data would contribute to analyzing mechanical properties of DCB adhesive structures with mode III-type.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2011-0006548).

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2015R1D1A1A01057607).

References

[1] J. C. Kim and S. K. Cheong, "Effect of Oxide Film Formation on the Fatigue Behavior of Aluminum Alloy", Journal of the Korean Society of Mechanical Engineers, vol. 36, no. 4, **(2012)**, pp. 421-428.

[2] S. J. Yoon and N. S. Choi, "High Cyclic Fatigue Life and Fracture Behaviors of Shot-Peened Bearing Steel", Journal of the Korean Society of Mechanical Engineers., vol. 35, no. 9, **(2011)**, pp. 1119-1129.

[3] K. W. Jeon, K. B. Shin and J. S. Kim, "An Evaluation of Fatigue Life and Strength of Lightweight Bogie Frame Made of Laminate Composites", Journal of the Korean Society of Mechanical Engineers, vol. 35, no. 8, **(2011)**, pp. 913-920.

[4] N. Y. Chung and S. I. Park, "Detection of Interfacial Crack Length by Using Ultrasonic Attenuation Coefficients on Adhesively Bonded Joints", International Journal of Automotive Technology, vol. 5, no. 4, **(2004)**, pp. 303-309.

[5] S. K. Parida and A. K. Pradhan, "3D finite element analysis of stress distributions and strain energy release rates for adhesive bonded flat composite lap shear joints having preexisting delaminations", Journal of Mechanical Science and Technology., vol. 28, **(2014)**, pp. 481-488.

[6] K. Ikegami, "Static strength of epoxy adhesively bonded butt, single-lap and double-lap joint", International Journal of Adhesion & Adhesives., vol. 16, no. 3, **(1996)**, pp. 219-226.

[7] J. P. M. Gonçalves, M. F. S. F de Moura and P. M. S. T de Castro, "A three-dimensional finite element model for stress analysis of adhesive joints", International Journal of Adhesion and Adhesives., vol. 22, no. 5, **(2002)**, pp. 357-365.

[8] A. D. Crocombe and G. Richardson, "Assessing stress stateand mean load effects on the fatigue response of adhesively bonded joints", International Journal of Adhesion and Adhesive she., vol. 19, no. 1, **(1999)**, pp. 19-27.

[9] P. Briskham and G. Smith, "Cyclic stress durability testing of lap shear joints exposed to hot-wet conditions", International Journal of Adhesion and Adhesives, vol. 20, no. 1, **(2000)**, pp. 33-38.

[10] M. S. Han, H. K. Choi, J. U. Cho and C. D. Cho, "Experimental Study on the Fatigue Crack Propagation Behavior of DCB Specimen with Aluminum Foam", International Journal of Precision Engineering and Manufacturing, vol. 14, no. 8, **(2013)**, pp. 1395-1399.

[11] S. S. Kim, M. S. Han, J. U. Cho and C. D. Cho, "Study on the Fatigue Experiment of TDCB Aluminum Foam Specimen Bonded with Adhesive", International Journal of Precision Engineering and Manufacturing, vol. 14, no. 10, **(2013)**, pp. 1791-1795.

[12] H. S. Cho, J. U. Cho and C. D. Cho, "Experimental and analytical verification of the characteristics of shear fatigue failure in the adhesive interface of porous foam materials", Journal of Mechanical Science and Technology., vol. 29, no. 6, **(2015)**, pp. 2333-2339.

[13] H. J. Bang, S. K. Lee, C. D. Cho and J. U. Cho, "Study on crack propagation of adhesively bonded DCB for aluminum foam using energy release rate", Journal of Mechanical Science and Technology., vol. 29, no. 1, **(2015)** ,pp. 45-50.

[14] T. Gao, A. J. Kinloch, B. R. K. Blackman, F. S. R. Sanchez, S. K. Lee, C. D. Cho, H. J. Bang, S. S. Cheon and J. U. Cho, "A study of the impact properties of adhesively-bonded aluminum alloy based on impact velocity", Journal of Mechanical Science and Technology., vol. 29, no. 2, **(2015)**, pp. 493-499.

[15] S. K. Parida and A. K. Pradhan, "3D finite element analysis of stress distributions and strain energy release rates for adhesive bonded flat composite lap shear joints having preexisting

delaminations", Journal of Mechanical Science and Technology., vol. 28, no. 2, **(2014)**, pp. 481-488.
[16] J. U. Cho, S. K. Lee, C. Cho, F. S. Rodriguez Sanchez, B. R. K. Blackman and A. J. Kinloch, "A study on the impact behavior of adhesively-bonded composite materials", Journal of Mechanical Science and Technology., vol. 2, no. 10, **(2007)**, pp. 1671-1676.
[17] J. U. Cho, A. Kinloch, B. Blackman, S. Rodriguez, C. D. Cho and S. K. Lee, "Fracture behavior of adhesively-bonded composite materials under impact loading", International Journal of Precision Engineering and Manufacturing., vol. 11, no. 1, **(2010)**, pp. 89-95.
[18] M. S. Han, H. K. Choi, J. U. Cho and C. D. Cho, "Fracture property of double cantilever beam of aluminum foam bonded with spray adhesive", Journal of Mechanical Science and Technology., vol. 29, no. 1, **(2015)**, pp. 5-10.

Authors

Jung-Ho Lee, is a graduate school student in the Division of Mechanical Engineering of Kongju National University, Cheonan. His field of specialization are Fracture Mechanics (Dynamic Impact), Impact Fracture of Composite Material), Fatigue & Strength Evaluation, and Durability & Optimum Design.

Jae-Ung Cho, received his M.S. and Doctor Degree in Mechanical Engineering from Inha University, Incheon, Korea, in 1982 and 1986, respectively. 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.