

Impact Response and Damage Prediction of Composite plates

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Introduction

Fiber reinforced composite materials are widely used for various structures especially for aerospace structures because of their high specific stiffness and strength. Metal materials are being replaced to composite materials for reducing weights of structures. However, composite materials have low toughness and they are susceptible to damage from impact loading. Especially for low velocity impact, impact damage appears in the structure and it is hard to be detected.

These barely visible impact damages (BVID) reduce the strength of the structures. And analysis technique is required to figure out the safety of impacted composite structures.

Composite material have several damage modes; such as fiber breakage, matrix crack and delamination. Each damage mode degrades strength of the structures in different way and affects the impact behavior of composite structures. The damage should be considered in the impact analysis of the composite structures.

Recently, progressive damage analysis is generally used for reasonable impact analysis [1,2]. For the progressive impact analysis, damage criteria and progressive damage model are required. Damage criteria are used to decide the initiation of damage and progressive damage model is used to determine the degradation of the strength.

In this research, impact test of composite plate was performed and damage region and damage modes were investigated. And progressive damage model for composite material was developed for impact analysis of composite structures. Impact analysis of composite plate was performed and the result was verified with experiment data.

Experiment

Materials and test procedures

Composite plates were fabricated with carbon/epoxy prepreg CU125NS (HANKUK CARBON Co.). Material properties are represented in Table 1. Lay-up sequence of the plate was $[0^{\circ}_2/90^{\circ}_2/0^{\circ}_2/90^{\circ}_2/0^{\circ}_2]_s$ and dimension of specimens was 100mm x 100mm x 2mm. Impact test was performed with drop weight type impact testing machine INSTRON DYNATUP 9250HV. Steel

impactor with 1/2 inch diameter and 6.5kg of mass was used.

Table 1. Material properties of CU125NS

Modulus[3]		Strength[3,4]	
E_{11}	: 135.4GPa	XT	: 2.93 GPa
E_{22}, E_{33}	: 9.6GPa	XC	: 1.65 GPa
G_{12}, G_{13}	: 4.8GPa	YT	: 54.0 MPa
G_{23}	: 3.2GPa	YC	: 240.0 MPa
ν_{12}, ν_{13}	: 0.31	S12, S13	: 74.0MPa
ν_{23}	: 0.52	S23	: 65.0MPa

Impact tests were performed at several impact energies to investigate both visible and non-visible impact damages. Overall damage area was inspected with C-scan. And cross-section of a specimen with BVID was inspected with light-microscope.

Test results

Maximum contact force and central deflection are represented in Fig.1 in terms of impact energy.

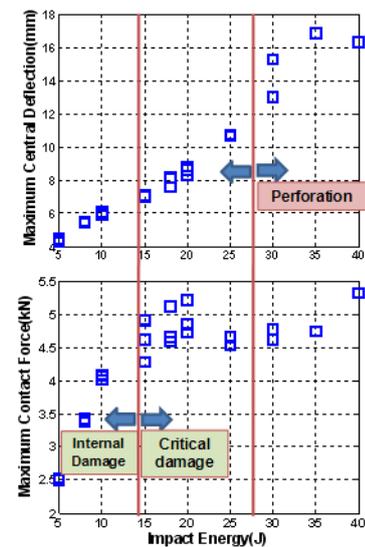


Fig 1. Maximum contact force and Central deflection

Impact energies can be categorized into three levels according to impact damages.

The first energy level was lower than 15J in this model. Only BVID appeared and most damages were

matrix crack and delamination. Fiber damage did not appear. Second energy level was between 15J and 30J, the plates were critically damaged with fiber breakage. Contact force was suddenly decreased with critical damage and the damages clearly appeared in the impact surface. Third energy level was larger than 30J. Composite plates were perforated by the impactor and central deflections abruptly increased and were not recovered. The largest damage mode was delamination for all case.

Analysis

Impact analysis was performed with finite element program ABAQUS/explicit. Progressive damage analysis was used for reasonable impact analysis. Damage analysis algorithm was developed based on maximum failure strain criteria and continuum damage mechanics[5]. It was assumed that the progression of matrix and fiber damage is following the cumulative Weibull distribution as shown in Eq. (1).

$$d = 1 - \exp \left\{ -\frac{1}{me} \left(\frac{E^0 \varepsilon}{X} \right)^m \right\} \quad (1)$$

where, m is a shape parameter and X , E^0 , ε are strength, initial stiffness, and strain, respectively.

The algorithm was implemented in ABAQUS/explicit user defined material subroutine, VUMAT. Cohesive elements were used to simulate delamination failure.

Quad model was used to reduce the computation times.

Results and Discussion

Contact forces of 5J and 15J are compared with experiment data in Fig. 2. At 5J of impact energy only BVID appears. At 15J of impact energy composite plate critically damaged and contact forces abruptly decreased. Analyses well estimate the critical damage.

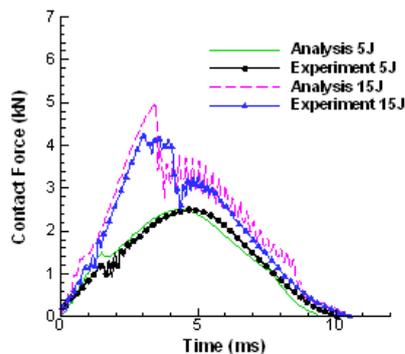


Fig 2. Contact force history

Damage area at 5J was compared with C-scan image in Fig. 3. Overall impact damages are shown in C-scan image around the impact location. Damage area obtained from numerical analysis was overlapped on the C-scan image. The largest damage area was delamination and the damage area is comparable to C-scan image.

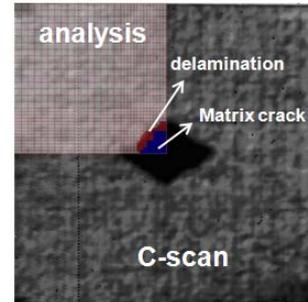


Fig 3. Comparison of damage area at 5J

The developed damage model algorithm well estimates the impact damages both of BVID and critical impact damage.

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References

1. Donadon, M.V., Iannucci, L., Falzon, B.G., Hodgkinson, J.M., Almeida, S.F.M., A progressive failure model for composite laminates subjected to low velocity impact damage, *Compu. And Struct.*, **86**(2008), 1232-1252.
2. Chang, K.-Y, Liu, S., Chang, F.-K., Damage tolerance of laminated composites containing an open hole and subjected to tensile loadings, *J. compo. Mater.*, **25**(1991), 274-301.
3. Choi, I.H., Hong, C.S., New approach for simple prediction of impact force history on composite laminates, *AIAA journal*, **32**(1994), 2067-2072.
4. Kang, S.-G., "Characteristics of composite materials and application to the cryogenic propellant tank", Doctoral dissertation KAIST(2006).
5. Matzenmiller, A., Lubliner, J., Taylor, R.L., A constitutive model for anisotropic damage in fiber-composites, *Mech. Mater.*, **20**(1995), 125-152.