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Application News

No.i254

Material Testing System

Compression After Impact Testing of Composite Material

Introduction

Carbon fiber reinforced plastic (CFRP) has a higher specific strength and rigidity than metals, and is used in aeronautics and astronautics to improve fuel consumption by reducing weight. However, CFRP only exhibits these superior properties in the direction of its fibers, and is not as strong perpendicular to its fibers or between its laminate layers. When force is applied to a CFRP laminate board, there is a possibility that delamination and matrix cracking will occur parallel to its fibers. Furthermore, CFRP is not particularly ductile, and is known to be susceptible to impacts. When a CFRP laminate board receives an impact load, it can result in internal matrix cracking and delamination that is not apparent on the material surface. There are many situations in which CFRP materials may sustain an impact load, such as if a tool being dropped onto a CFRP aircraft wing, or small stones hitting the a CFRP wing during landing. Consequently, tests are required for these scenarios. One of these tests is compression after impact (CAI) testing. CAI testing involves subjecting a specimen to a prescribed impact load, checking the state of damage to the specimen by a nondestructive method, and then performing compression testing of that specimen. This article describes CAI testing performed according to the ASTM D7137 (JIS K 7089) standard test method.

Measurements Taken Before Compression After Impact Testing

(1) Impact Test

The impact test involved dropping a 5 kg steel ball striker formed with a 16 mm diameter hemispherical point in the middle of the specimen. The specimen is fixed in place with four toggle clamps. The standard test method states that avoiding a second impact is preferred, so impact testing was performed with a mechanism that prevented second impacts. The impact energy recommended in the standard test method is 6.67 J per 1 mm of specimen thickness. For the purpose of comparison, the test was performed at four impact energies of 6.7, 5.0, 3.3, and 1.7 J per 1 mm thickness. Information on the specimen used is shown in Table 1. The test setup is shown in Fig. 1, and test conditions are shown in Table 2.

Table 1 Specimen Information

Dimensions [mm]	: 100 × 150 × 4.56
Lamination Method	: [45/0/−45/90] ns
Material	: T800, 2252S-21

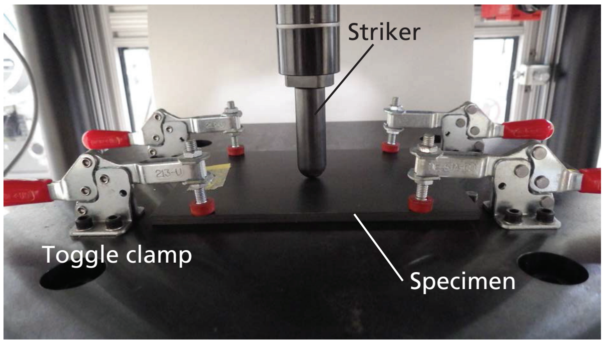


Fig. 1 Impact Test Setup

Table 2 Impact Test Conditions

Impact Energy	: 30.5, 22.9, 15.2, 7.6 [J]
No. of Tests	: n = 4

(2) Non-Destructive Inspection

After the impact test, the delamination area and maximum delamination length that resulted inside the laminate board were measured by nondestructive analysis. An ultrasonic flaw detection device is normally used for the non-destructive inspection step of CAI testing. The standard test method states that if ultrasonic flaw detection shows damage is present across more than half the width of the specimen, edge effects cannot be ignored and lowering the impact energy should be considered. Fig. 2 shows the setup for ultrasonic flaw detection.

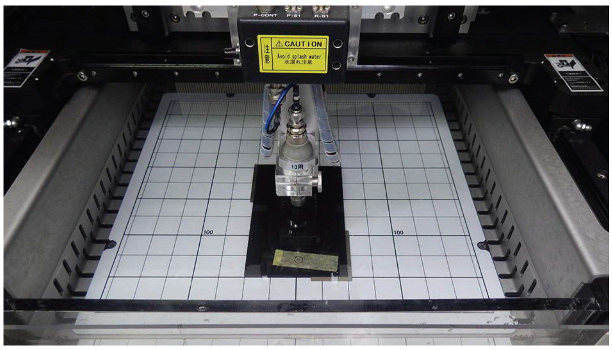


Fig. 2 Ultrasonic Flaw Detection

Fig. 3 shows the specimen after an impact test with an impact energy of 30.5 J. Fig. 3 shows an indentation in the middle of the specimen, but does not show the area of damage caused by delamination. Fig. 4 shows the results of ultrasonic flaw detection at each impact energy. The white areas in Fig. 4 are regions of delamination. Brighter areas show greater delamination. Comparison with Fig. 3 shows that delamination also occurs in areas other than the indentation in the center of the specimen, and the extent of internal damage cannot be determined based on external damage. The results also show that the damage area increases as the impact energy increases.

Fig. 3 Specimen After Impact Test (30.5 J Impact Energy)

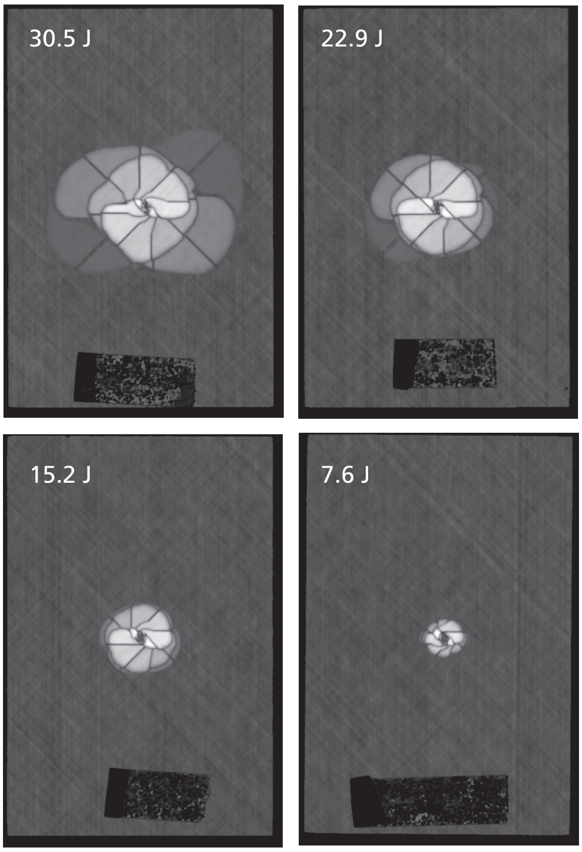
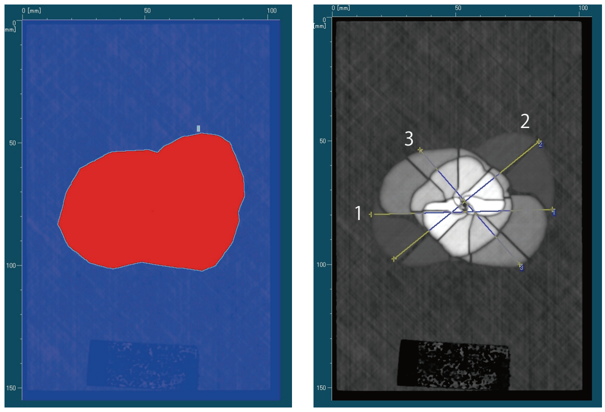


Fig. 4 Results of Ultrasonic Flaw Detection at Each Impact Energy

The damage area and maximum damage length are calculated from the images obtained by ultrasonic flaw detection. As an example, images used to calculate the damage area and maximum damage length after an impact energy of 30.5 J are shown in Fig. 5. Fig. 6 shows the relationship between damage area and impact energy, and Fig. 7 shows the relationship between maximum damage length and impact energy.



Region No.	Percentage Area (%)	Absolute Area (mm^2)
1	99.9988	3326.2400

No.	Length (mm)
1	73.03
2	75.50
3	61.37

Fig. 5 Images of Damaged Area and Maximum Damage Length

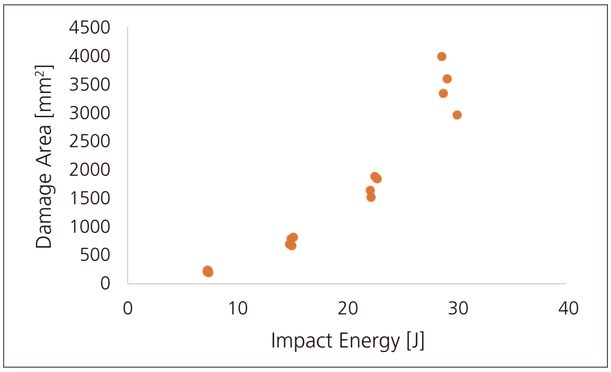


Fig. 6 Relationship between Damage Area and Impact Energy

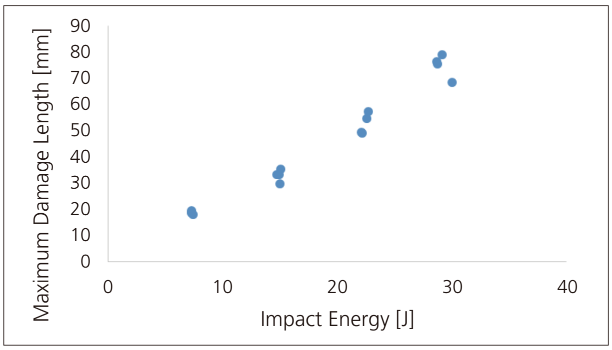


Fig. 7 Relationship between Maximum Damage Length and Impact Energy

Measurement System for Compression After Impact Testing

Two strain gauges must be attached to the front and back of the specimen. A specimen with strain gauges attached is shown in Fig. 8. The specimen shown in Fig. 8 is compressed at up to 10 % its expected compressive strength following impact in a longitudinal direction, and the CAI testing is performed after confirming the difference between front and rear strain gauges is within 10 %. Test conditions are shown in Table 3. The test setup is shown in Fig. 9, and test equipment used is shown in Table 4.

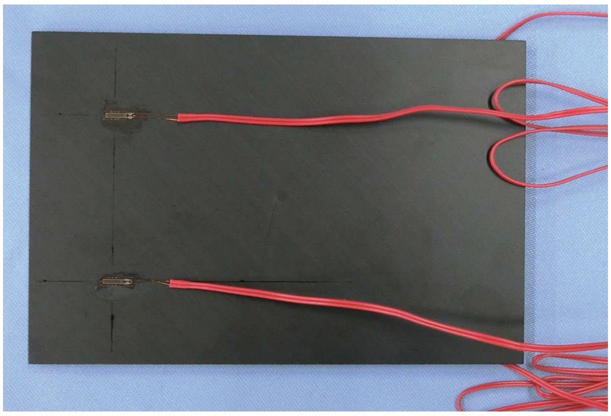


Fig. 8 Specimen

Table 3 Test Conditions

Test Speed	: 1.25 mm/min
No. of Tests	: n = 4

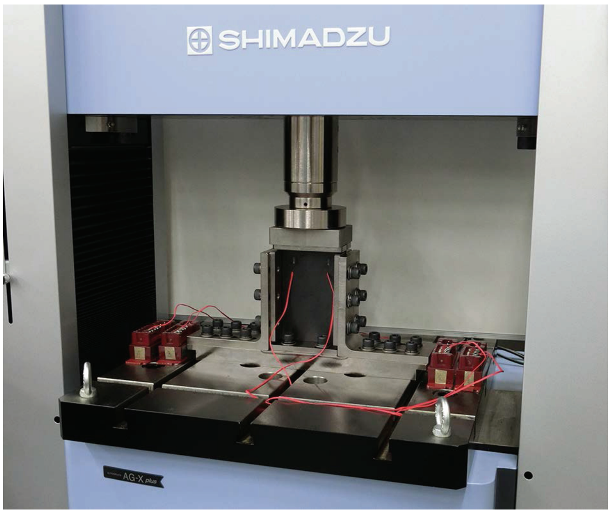


Fig. 9 Test Setup

Table 4 Experimental Equipment

Testing Machine	: AG-Xplus
Load Cell	: 250 kN
Test Jig	: Compression after impact test jig

Test Results

Examples of stress-strain curves at each impact energy are shown in Fig. 10. The compression-after-impact strength and mean compressive elastic modulus after impact are shown for each impact energy in Table 5. The standard test method states the compressive elastic modulus after impact should be calculated in the range of 0.1 % to 0.3 % strain. However, the breaking strain of one or more specimens was ≤ 0.3 % after the 30.5 J impact energy, and so for these specimens the elastic modulus was calculated from a linear region. Fig. 10 and Table 5 show the smaller the impact energy the larger the compression-after-impact strength. They also show the compressive elastic modulus after impact is almost constant regardless of impact energy.

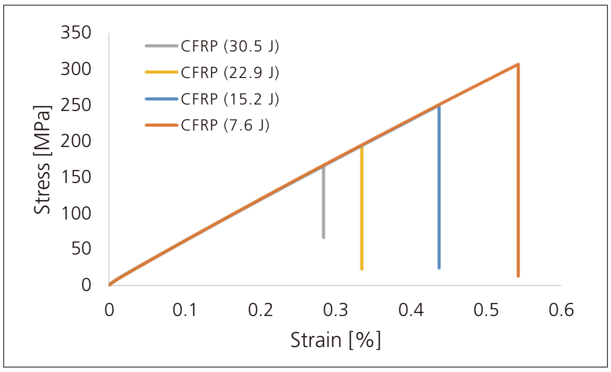


Fig. 10 Stress-Strain Curve

Table 5 Test Results (Mean)

Impact Energy [J]	Compression-After-Impact Strength [MPa]	Compressive Elastic Modulus After Impact [GPa]
30.5	162.9	57.2
22.9	203.3	56.4
15.2	246.4	56.0
7.6	308.6	56.3

The relationship between damage area and compression-after-impact strength is shown in Fig. 11, and the relationship between maximum damage length and compressive elastic modulus after impact is shown in Fig. 12. Fig. 11 and Fig. 12 show the smaller the damage area or maximum damage length, the larger the compression-after-impact strength. As a reference, the compressive strength of a specimen tested without applying any impact energy was 388 MPa.

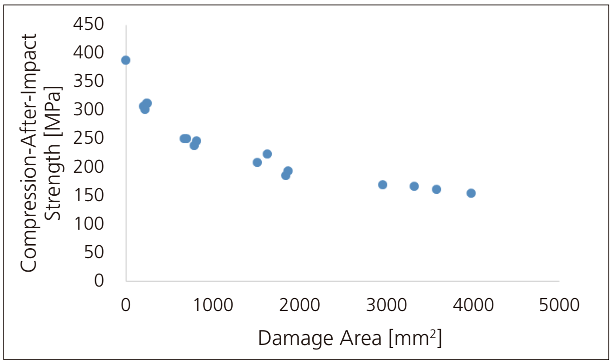


Fig. 11 Relationship between Damage Area and Compression-After-Impact Strength

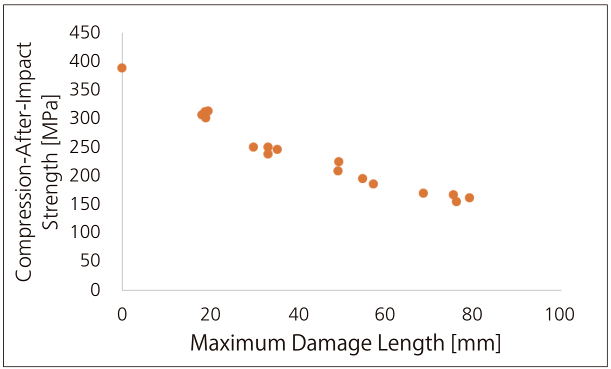


Fig. 12 Relationship between Maximum Damage Length and Compression-After-Impact Strength

Conclusion

CAI testing was performed on specimens at four different impact energies. As shown by the results, the larger the impact energy the smaller the compression-after-impact strength. Also, even a small amount of impact energy (in this experiment, an impact energy of 7.6 J amounted to 5 kg dropped from 0.15 m) reduced the compression-after-impact strength compared to the undamaged compressive strength, showing the importance of testing scenarios for impact loading. Shimadzu's testing system was used successfully to perform CAI testing according to ASTM D7137 (JIS K 7089), and can be used for evaluation of CFRP materials.

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