



Semnan University

# Mechanics of Advanced Composite Structures

journal homepage: <http://MACS.journals.semnan.ac.ir>

## Size Effect on the Damaged Areas of Glass/Epoxy Structures under Low Velocity Impact

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### PAPER INFO

#### Paper history:

Received 9 August 2014  
Received in revised form 16 September 2014  
Accepted 28 September 2014

#### Keywords:

Mode of failure  
Damaged area  
Low impact  
Glass/epoxy composites

### ABSTRACT

Most impact tests are carried out on specimens with specific stacking sequence and dimensions to meet standard and experimental limitations. The damaged areas and the resulted reduction in the strength values of specimens may not agree very well with those of real application. In this paper an attempt is made to study the variation in the size of damaged areas due to varying the dimension of test specimens. Three different types of specimens, namely, A, B and C are examined under the same impact energy. It is found that the area of damage in the smaller size test specimens is larger. It is also concluded that the mode of failure is different for various specimens. The study of impact energy/damage area reveals that the types B and C tend to agree more than the smaller type suggesting a convergence of results as the specimen size approaches the actual size of larger nature. These graphs may be utilized to find impact energy in real structures with a specific stacking sequence and layout, if the size of damaged area is known.

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## 1. Introduction

In recent years Fibre Reinforced Plastic (FRP) composites are increasingly replacing conventional materials in manufacturing of engineering components. This is mainly because of a higher material performance (strength/stiffness to weight ratio, and corrosion resistance) of FRP over conventional materials. These materials in the form of plates, shells and other types of structures are widely being used in aircrafts, submarines, aerospace vehicles, helicopters, missiles, rocket launchers and land transportation at various loading conditions. Impact loading is one of the most common types of loading for these applications.

Analytical methods, currently available, are not capable of revealing true behaviour of composite structures and the extent of damage under impact

loading. The fast growing demand and reliable design data for composite structures have led to wider experimental investigations. Due to the impact, failures of composite structures are initiated by various forms of damage leading to reduction in strength. Considerable research is undertaken to study and determine the dominant mode of failure and methods of preventing and/or reducing the extent of damage. In most of these studies experiments are carried out on standard or specific types of specimens which are somewhat different to the actual structures used in real application [1]. Damage assessment and data for reduction in strength obtained by this method, therefore, may differ from those of real situation where larger and in some cases structures with different lay out may be used. This may result in conservative, heavier and more

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expensive design. In an investigation by, Rilo and Ferreira [2] glass-epoxy laminated plates were subjected to crush experimental tests in a SHIMATSU universal traction machine. The characterization of the damage was done in relation to the type of test, the ply stacking sequence, the plate dimensions and the maximum force achieved in the impact. Rajesh and Jerald [3] experimentally investigated the behavior of glass epoxy composite laminates subjected to low velocity impact at different energy levels.

In the present study the main aims are as follow:

- Most composite structures may encounter low velocity impact during manufacturing, service and maintenance. Investigation of damaged area and more frequent mode of failure under this loading condition is one of the main objectives.
- Investigation of the scaling effect of test specimens, and the extent of damaged area, is the other main objective of the study.

## 2. Dominant Modes of Failure

Generally there are two common types of damages in composite materials.

### 2.1. Intra-Ply Damages

- Debonding: This is one of the important types of damages which may be regarded as the degree of compatibility between fibre and matrix.
- Fibre breakage
- Fibre pull-out
- Matrix cracks: Matrix cracking being the main damage mode in composite laminates does not lead to a catastrophic failure. Microcracks on matrix, however, reduce the stiffness and diminish the structural integrity. This phenomenon has been a subject of numerous scientific studies since 1970's [4]. Experimental investigations [5, 6] on matrix cracking in composite laminates verify that matrix damage is due to the incorporation of either a transverse tension or a combination of transverse tension and in-plane shear. In the lamina failure theory proposed by Hashin [7] matrix cracking is assumed as a function of both transverse tensile and in-plane shear stresses.

### 2.2. Inter-Ply Damages

When one layer in a laminate is damaged and a reduction in strength is occurred, the other layers will experience extra load. Initially matrix cracks form leads to debonding of layers. Malvern and Sierakovski [8] carried out experimental study on

failure mechanism of UD composite structures. They reported the shape of delamination to be elliptical damaged area between layers. In some of their experiments they notice that the principal direction of delaminated surface between two plies seems to be in the same direction of the fibres of the lower ply. The main source of damage is known to be due to shear type matrix cracks. In the same area of research Chang et al [9], performed a series of tests on [0/90/0] structure. They model a 3D finite element model of composite materials and observe that as cracks are formed in a layer, distribution of stress is no longer balanced. The stress on one side of the element, namely,  $\sigma_{11}$  may exist whereas on other side where matrix cracks are formed this normal stress does not seem to be dominant. To balance the overall stress distribution some out of plane stress,  $\tau_{xz}$ , has to be imposed on the elements. This phenomenon will damage the resin between layers causing delamination. Experimental studies as well as numerical studies [10] show that delamination in woven laminates is less than that of UD laminates.

## 3. Experimental Procedure

### 3.1. Specimens

Symmetrical Glass/epoxy composite plate with ply sequence of [0/90/ $\pm$ 45/0/90/ $\pm$ 45]<sub>s</sub> and thickness of 1.85 mm thickness is manufactured using wet layup technique and vacuum bag at 60 °C. Three different types of specimens are machined, namely, 100x100 mm<sup>2</sup> (A type), 150x150 mm<sup>2</sup> (B type) and 200x200 mm<sup>2</sup> (C type). Each series of specimens are loaded by drop hammer from four different heights of 25 mm to 100 mm in steps of 25 mm. Each test is coded such as A50-1, where A is the type of specimen, 50 indicates the height of the weight dropped and 1 is the number of tested sample (1-3). To complete the experiment there are 3 specimens in each three different types tested under four different energy levels, producing 36 sets of results.

### 3.2. Drop Hammer

A weight of 1.812 kg with a 9.5 mm spherical radius of tip can be dropped from a maximum height of 100 mm. The specimens are fixed to a fixture depending on the size of the specimen and boundary condition under consideration. The whole assembly is placed on a table 400 x 400 mm in dimension with holes at various positions for mounting test fixtures as shown in Figur 1.

### 3.3. Boundary Conditions of the Test Plates

The boundary condition for test plate is clamped to all sides. A 290x290 mm with the same hole pat-

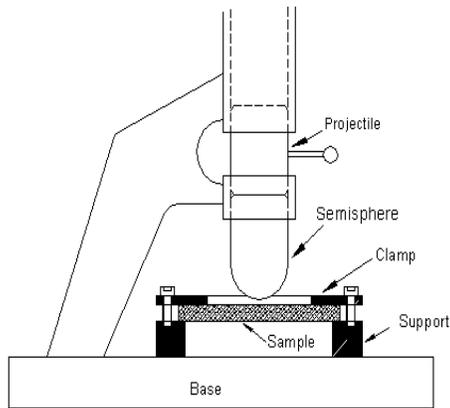


Figure 1. Schematic view of test set-up

tern as the work bench is utilized. Test specimen is secured between clamp and the plate with eight bolts, as shown in Figure 1.

#### 4. Test Results and Analysis

Determination of exact extent of damage in every layer and calculation of the corresponding area is a difficult task. For Glass/epoxy composites, it is relatively simple to see the affected area by inspection, so the maximum damage detectable is chosen to show the damage of the laminate. Results of these measurements are shown in Table 1.

##### 4.1. Modes of Failure

Damage seems to be started by matrix cracks followed by delamination and some minor fibre breakage. This trend for all three different types of specimens is the same. The dominant mode of failure in all specimens, particularly in series A, is delamination of layers. Delamination in series A specimens is remarkably more than series B and C specimens. Under lower impact load specimens experience some shear type matrix cracking in  $45^\circ$  direction, as depicted in Figure 2. In some cases where the height of drop weight is more than 50 cm, matrix cracks along the fibre direction can be observed at the lower layers of the impact point. As the top and bottom layers of the specimens are [0/90], cross ply layers and so the damaged areas have the same crossed shape patches in both sides and it is the main source of delamination, (see Figure 3). These cracks seem to be of bending matrix crack type as reported by other researchers [11, 12].



Figure 2. Shear Matrix Cracks

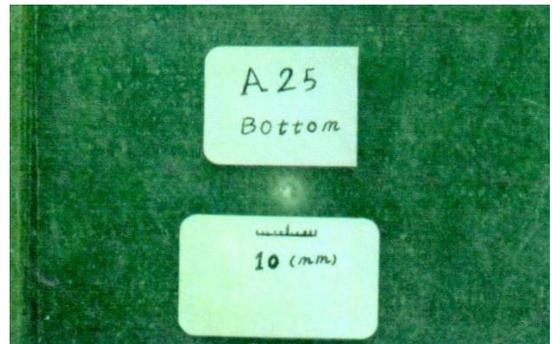


Figure 3. Bending Matrix Cracks

##### 4.2. Modes Effect of Dimensions on the Extent of Damage

The impact tests are carried out on three different types of specimens. It is observed that the damaged areas on the specimens with the same thickness but different dimensions tested under the same impact load, are different.

The smaller specimens are more rigid, therefore, having less flexibility and experiencing more impact force. It is thus expected to have more deflection and deformation in larger plates. Both of these factors, i.e. higher deflection and higher impact force, are the key factors for damage. In A series specimens, due to higher impact force, the damaged area is larger compared to B and C series. In all test specimens the most damaged layer is the lower plies, especially the bottom layer.

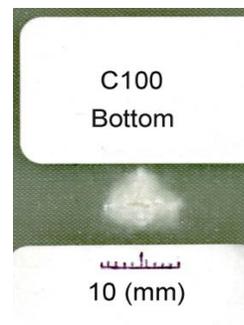
Figure 4-6 show the areas of damage on three series of specimens from each three different types of the specimens tested in this study. The reason for this may be due to the high deflections which occur on these layers at the point of impact.

**Table 1.** Damaged areas in test specimens (series A, B, C)

Drop Weight Height (cm)	Impact Energy (J)	Damaged Area in A series (mm <sup>2</sup> )				Damaged Area in B series (mm <sup>2</sup> )				Damaged Area in C series (mm <sup>2</sup> )			
		A1	A2	A3	mean	B1	B2	B3	mean	C1	C2	C3	mean
25	4.44	16.7	10	12.5	13	3.9	3.9	---	3.9	13.9	7.7	8.6	10
50	8.88	63	57	45	55	19.6	23.7	19.6	21	17	16.3	14	15.8
75	13.3	135	110	115	120	72	67.5	60	66.5	48	42	56	48.6
100	17.7	160	187	164	170	94.5	92.5	87.5	91.5	70.1	61.8	87.5	71.5



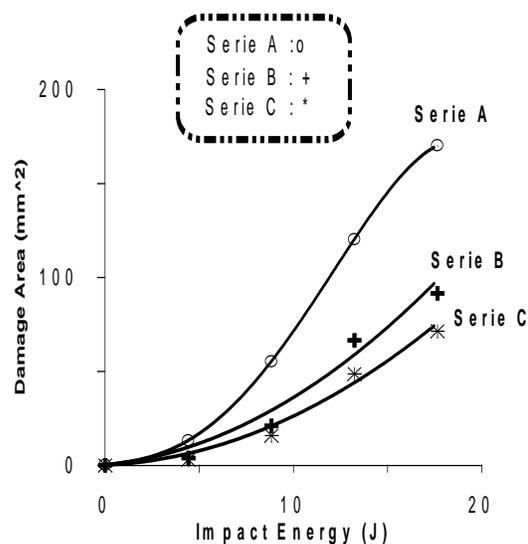
**Figure 4.** Damage in the impacted bottom layer of A100



**Figure 6.** Damage in the impacted bottom layer of C100



**Figure 5.** Damage in the impacted bottom layer of B100



**Figure 7.** Plot of damage area and impact energy for type A, B and C

Figure 7 shows the relation between damaged area and impact energy for three different series of A, B and C. From this graph it is seen that the damage curves for B and C series are closer together than those for series A and B.

Results of types B and C seem to be closer to each other and may be a good representative of real applications. Increasing the dimensions there will be a point where the energy-damage plot may not experience change and simulate a real case.

## 5. Conclusion

From the results of the tests carried out on different types of specimens it was concluded that:

- In the impact energy range of up to 18 J, no fibre breakage was observed as mode of damage.
- In larger size specimens the extent of damage was found to be less than that of specimens with smaller dimensions. In real structures with even larger dimensions, the damage is expected to be less. This point may be considered valid until fibre breakage occurs, since fibre breakage severely affects the structural strength of the material. Fibre breakage requires more energy compared to the delamination mode of failure. Therefore, in repair and maintenance applications low impact energy may exist and most of the damage may be formed in delamination mode.
- Results of types B and C seem to be closer to each other and may be a good representative of real applications. Increasing the dimensions, there will be a point where the energy-damage plot may not experience change and simulate a real case.

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