Delamination study in polymer composites reinforced by glass fiber in ballistic impact

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Keywords: Delamination, Ballistic, polymer composite

Abstract

Study of delamination and damage zone in composite materials under different loading conditions has been always an interesting subject among researchers in composite industry. Effect of material behavior in impact loading is one of the important design parameters in industries. In the current work, damage zone and delamination in polymer composite panels reinforced by glass fiber in ballistic impact are considered. Finite element modeling of composite panel is constructed and its behavior under ballistic impact is studied. Ballistic impact tests have been carried out making of appropriate specimens. Experimental results are compared with FEM results. Experimental results verified FEM with good estimation. Results of this study can be applied in design and optimization of composite panels under different conditions in impact loading.

1 Introduction

Different damage and energy absorbtion mechanisms during ballistic impact have been identified. These are: cone formation on the back face of the target, tension in primary yarns, deformation of secondary yarns, delamination, matrix cracking, shear plugging and friction during penetration [1]. One of the most frequent modes of failure is delamination, which could lead to overall damage of the composite structure. Several kinds of approaches can be found in the literature on this problem. Delamination in composite structures can be a serious threat to the safety of the structure. Delamination leads to loss of stiffness and strength of laminates under some conditions.

Delamination is a phenomenon of degradation of composites laminates that may lead to the failure of the structure or that may reduce its stiffness and strength. This phenomenon generally occurs in free edge zones of the laminated structure due to possible out-of plane stresses in these zones.

During the design process of a fiber composite structural part, its damage tolerance behavior must be considered for mainly three reasons: to assure the integrity of the part and the safety of the aircraft, to anticipate failure and to avoid unnecessary replacement of a part which can still fulfill its structural function. Therefore, studies have focused on the understanding and prediction of the mechanisms of damage initiation and propagation in notched composite [2].

In the previous works, several studies have been reported on the parametric studies of impact process. Cheeseman et al. [3] presented a review of the factors such as projectile geometry and velocity that influenced the ballistic performance. Duan et al. [4] studied the effect of friction on energy absorption of high strength plain wave fabric using a finite element model of fabric impact on yarn level. Cork and Foster [5] investigated the ballistic performance of narrow fabrics and compared with winder one. They showed that the ballistic performance of narrow fabrics was highly sensitive to changes in fabric specifications and also square sized fabrics do not necessarily have higher performance.

Zheng and Sun [6] proposed a double-plate model to predict low velocity impact-induced delamination. This model treats a delaminated composite as two separate Mindlin plates, one above and one below the delamination. Tying constraints and contact conditions were imposed between these two plates to ensure structural integrity. The authors concluded that their model is computationally efficient and accurate in calculating the strain energy release rate along the delamination front. Luo et al. [7] studied the damage initiation and propagation in impacted composite panels. They used the finite element package ABAQUS to perform a three-dimensional analysis. Three failure stress based criteria (fibre breakage, interlaminar delamination and matrix failure) were induced. The damage has been identified as interlaminar delamination coupled with matrix failure. Good agreement was found between FEM simulation and the experiment. It was also noted that further work is needed to evaluate the length of the matrix crack.

Collombet et al. [8] presented some numerical tools to simulate the low velocity impact damage of laminated composite structures. They considered a model of contact impact based on Lagrange multiplier technique. Matrix cracking is represented by an averaging technique developed on the true scale finite element. Delamination is defined as a three-dimensional debonding of the interfacial nodes, coupling with the matrix cracking damage. The results showed good agreement between the experimental and numerical damage observations.

2 Expriments

Fig. 1 shows the specimens used for ballistic experiments. The specimen panels were consisted of twelve plies. Each ply had 0.2 mm thick, and was made of woven fabric E-Glass/Epoxy composite. The material properties of the specimen are measured based on ASTM D3039 [9].

Figure 1. Specimens before the ballistic impact test

Ballistic impact tests were performed using a cylindrical projectile with spherical nose (11 gr mass and 8.68 mm diameter). The 150 mm × 150 mm panels were clamped in edges. Fig. 2 shows the projectile and fixture [10].

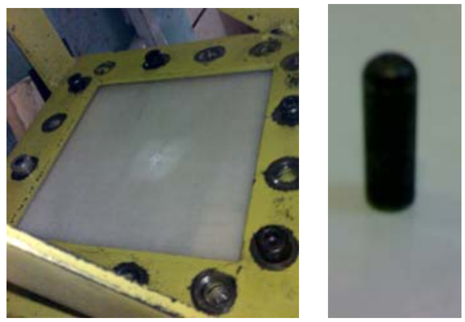

Figure 2. Specimen and projectile after the penetration

3 Finite element modeling

A nonlinear structural finite element code, LS/ DYNA, has been performed for numerical analysis. Due to symmetry in geometry, boundary conditions and loading, a quarter of the specimen has been modeled. The three dimensional solid element (SOLID164) was used for creating the FE model. FE model is illustrated in Fig. 3. Geometrical information for this case is given in Table 1.

Two different material properties have been considered for specimen and projectile. Orthotropic material property was used for composite, as shown in Table 2.

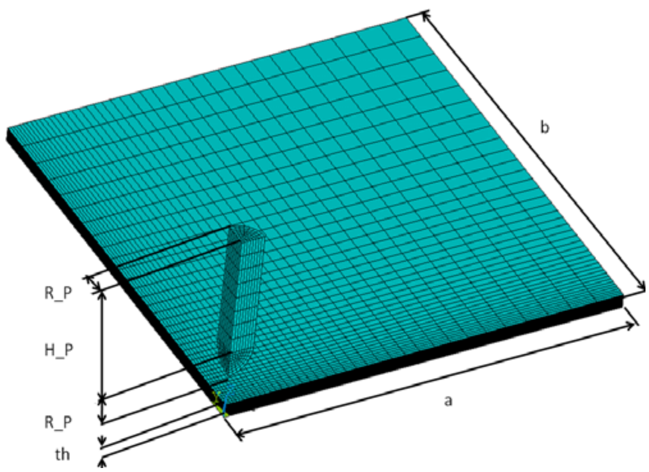

Figure 3. FINITE ELEMENT MODEL OF ONE QUARTER OF SPECIMEN AND PROJECTILE

Parameter	Value (mm)
b	75
a	75
th	2.4
R_P	4.34
H_P	21

Table 1. GEOMETRICAL INFORMATION OF THE COMPOSITE AND PROJECTILE.

It is needed to define a complementary condition for definition of the failure in composite plies. The erosion condition was appended to the material property of the composite. Considering the maximum allowable strain, based on the maximum strain criteria was defined. In other words, if the maximum normal strain results from finite element analysis reach to the critical defined value, failure would be occurred in the element.

Material Specification		Thing Glass/ Epoxy [Gpa]
E_x	Elasticity modulus in fiber direction	15.1
E_y	Elasticity modulus in cross direction	15.1
E_z	Elasticity modulus in thickness direction	5.35
G_{xy}	In-plane Shear modulus	6.0
G_{xz}	Out-plane Shear modulus	4.5
G_{yz}	Out-plane Shear modulus	4.5

Table 2. COMPOSITE LAMINA SPECIFICATION [10,11].

Besides, isotropic material property is used for projectile, as it is shown in Table 3.

Elasticity modulus, [GPa]	200
Poisson's ratio	0.3
Density, [kg/m^3]	7800

Table 3. MECHANICAL PROPERTY OF PROJECTILE

In addition, based on geometrical measurements after the ballistic tests, no changes in dimensions were observed. It is assumed that the projectile is perfectly rigid. Also, it can only move in z- direction. Initial velocity equals to 159 m/s in z- direction is implied on projectile, too.
Two adjacent sides of specimen's panels were fixed in z-direction. Two other opposite sides of the panel and projectile were fixed in x- and y- direction simultaneously due to symmetry.
Although it is optional, an initial distance equals to 10 mm is considered between the projectile and specimen.
For simulation the interlaminar failure between plies of composite, tiebreak surface-to-surface contact is defined in the interface (between two adjacent plies). The normal and shear failure strength of the interface were assumed to be 9 and 21 MPa, respectively.
Moreover, eroding surface-to-surface contact is defined between nodes of composite as a target and nodes of projectile as contact components. Friction coefficient of contact elements were considered to default value. Two types of contact definition are shown in Fig. 4.

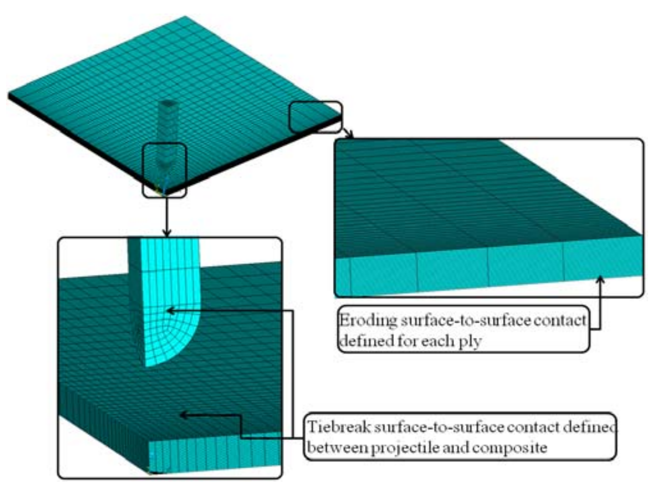

Figure 4. CONTACT DEFINITION IN FE MODEL

4 results and discussion

Finite element analysis has been performed for solution time of 200 μs. Comparison of FE results and experiments are illustrated in Fig. 5. It is obvious that finite element model can smoothly verify the delamination area of experimental results.

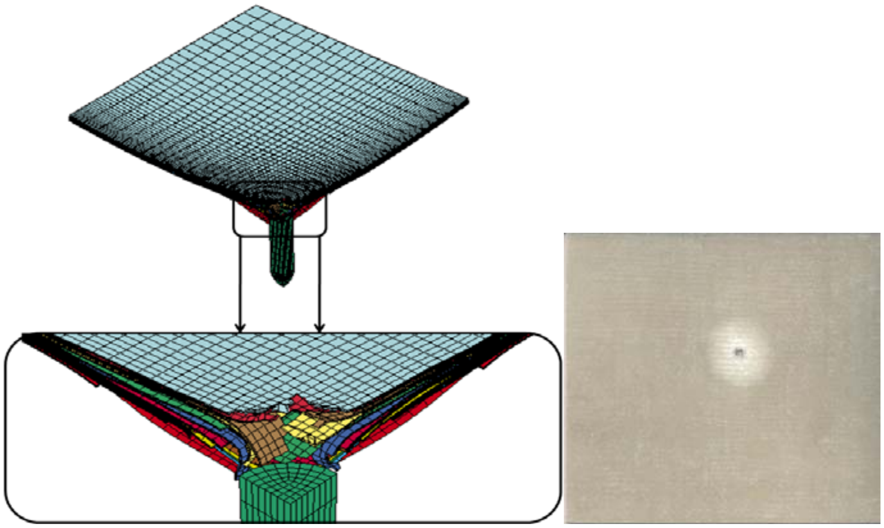

Figure 5. COMPARISION OF FEA AND EXPERIMENT.

Residual velocity of the projectile obtained from experiment and FE are shown in Table 4. It can be inferred that finite element results are near to the experiment in acceptable margin. The difference between results may be of disparate condition of experiment and analysis. For instance, different strain rates produce different maximum failure strain.

	Residual velocity (m/s)
FE	53
Experiment	46

Table 4. RESIDUAL VELOCITY OF THE PROJECTILE.

In polymer matrix composites, damage zone consists of three main aspects: fiber breakage, matrix cracking and delamination. In the delamaniation area, composite laminate lost its mechanical properties. So it is very important to calculate this region. Table 5 shows the comparison of delamination area obtained from finite element analysis and experiments.

	Diameter of delamination (mm)
FEA	40
Experiment	35

Table 5. COMPARISON OF DELAMINATION AREA IN FINITE ELEMENT ANALYSIS AND EXPERIMENTS

5 CONCLUSION

Delamination is one of the important modes of mechanical property reduction. Due to the delamination, the interlaminar damaged nodal points form finite element model was detected by observation and experimental measurement. As the model dimensions and material behavior parameters in this finite element model were very close to those in the measurement, it became possible to compare the experimental and computational results.

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