Numerical investigation of low-velocity impact in symmetric and asymmetric GFRP laminate with and without pre-crack

Prashant Rawat[1*], Kalyan K. Singh[2], Nand K. Singh[1]

[1]*Department of Mechanical Engineering, Indian Institute of Technology (ISM), Dhanbad, 826004, India*
[2]*Department of Mechanical Engineering, Indian Institute of Technology (ISM), Dhanbad, 826004, India*

[*]Corresponding author, E-mail: aadiprashant@gmail.com; Tel: (+91) 9472745795

Received: 30 March 2016, Revised: 01 October 2016 and Accepted: 20 December 2016

DOI: 10.5185/amp.2017/304
www.vbripress.com/amp

Abstract

Damage induced in symmetrical and asymmetrical glass fiber reinforced polymer (GFRP) laminate over low-velocity impact (LVI) using a mild steel impactor is investigated. Numerical simulation is done using 3-D finite element analysis software LS-DYNA. Orientations for symmetrical and asymmetrical laminate were [(0,90)/(+45,-45)/(+45,-45)/(0,90)//(90,0)/(+45,-45)/(+45,-45)/(90,0)] and [(0,90)/(+45,-45)/(+45,-45)/(0,90)//(+45, -45)/(90,0)/ (90,0)/(+45,-45)] respectively. Two samples each from symmetric and asymmetric laminate with and without pre-crack were numerically simulated. Induced circular pre-crack was modeled in the midplane of the laminate. A circular specimen of radius 75mm with clamped area of 376mm^2 is modeled. The velocity of 5 m/sec was assigned to the hemispherical headed cylindrical impactor. The result shows that symmetrical laminates absorb high energy and damage area for it is 24.06 % less than asymmetrical laminate for laminate with pre-crack in mid plate. This study concluded symmetrical laminate design is better for structural purpose as compared to asymmetrical design. Results of proposed investigation are directly applicable in aircraft, automobiles and space equipment. Copyright © 2017 VBRI Press.

Keywords: Symmetrical, asymmetrical, GFRP, impact, LS-DYNA.

Introduction

Fiber reinforced polymer (FRP) laminate have gained sufficient attention due to their specific directional properties and tailor-made capacity in several areas like aerospace, marine industries, automobiles. FRP composites also provide excellent damage resistance against low velocity as well as high-velocity impact. Many researchers focused their research on improving the damage resistance by using special stacking order, i.e. symmetrical and asymmetrical design **[1, 2]**, hybrid layup **[3, 4]**, Sandwich Structures **[5]**, Carbon Nanotubes reinforcement **[6, 7]**. Sandeep Agarwal et. al. **[8]** focused on proving impact situation as a real life problem and needs serious consideration. FRP laminates under low velocity cause three major failure modes delamination, debonding and fiber failure **[9].** Thus, failure directly depends on the interaction between fiber and matrix.

Delamination in FRP composites is a grave concern on low-velocity impact loading. Delamination occurs at interfaces of the ply; this delamination directly influences the damaged area as well as the damage pattern in LVI. Delamination failure arises at the interfaces where two, unlike plies, are in contact i.e. at different fiber orientations. The primary cause is a rise of discontinuous stress tensor **[1]**. To avoid this problem study based on layup sequence is done by several researchers also much experimental work has been performed. However, only a few researchers worked on finite element analysis (FEM) to justify their jobs **[10, 11]**. Angrizani et. al. **[4]** used ANOVA for investigating mechanical properties of curaua/glass hybrid interlayer laminates. Ghasemnejad et. al. **[13]** simulated impact behavior of the hybrid composite using LS-DYNA and reported about an excellent agreement between experiment and FEM results. Previous work **[10]** reviewed the importance of numerical investigation in low and/or high-velocity impacts in composites. Impact investigation of FRPs with pre-crack damage has been reported by a few researchers **[1]**. Moreover, experimental analysis has limitations like online monitoring of stress-strains, transverse delamination, tool penetration effects on the specimen. For existing shortcoming, this paper deals with the numerical study (FEM) of damage in symmetrical and asymmetrical laminate with and without pre-crack in GFRP laminate. The objective of the research investigation is to develop a numerical model for analysis of damage in GFRP (with and without pre-crack laminates), stress distribution, penetration pattern in time-steps and damage area comparison.

Experimental

Problem description

Previous work **[1]** experimentally justified that symmetrical layup with pre-crack provides better impact response as compared to asymmetrical design. The limitation of past work was the unavailability of damage pattern, stress distribution, and penetration pattern. These limitations are eliminated in the present work as well as justification for better impact resistance for symmetrical laminate i.e. the simulation work is also done using LS-DYNA (FEM) simulation.

Materials and fabrication methods

Materials used for numerical modeling are 12K and 600 GSM glass woven (supplied by M. S. Industries, Kolkata, India), Bisphenol-A based epoxy resin [L-12] and hardener [K-6] (provided by Atul Ltd., Gujrat) and a steel impactor. Thus, to investigate material properties, FRP composite is fabricated by hand layup method assisted by vacuum bagging method **[2]** as discussed below:

Step 1. Cutting of woven in $(0^0/90^0)$ and $(+45^0/-45^0)$ orientations.

Step 2. Mixing of epoxy and hardener in 10:1 ratio.

Step 3. Placing the first layer of glass woven on a flat surface and applying resins using a soft brush.

Step 4. Placement of second woven layer over first and applying roller to extract extra resins.

Step 5. Eight layers were placed according to symmetrical and asymmetrical design.

Step 6. The wet laminate was placed inside vacuum bag for 30 minutes at 1 atm i.e. squeezing extra resins.

Step 7. This laminate was cured for 24 hours in atmospheric conditions.

Properties of the materials are given in **Table 1**.

Table. 1. Material properties

GFRP Material (0^0-90^0)		**Value**
Young’s Modulus (GPa)	E_{11}	26
	E_{22}	26
	E_{33}	8
Poisson’s *Ratio*	υ_{21}	0.1
	υ_{31}	0.25
	υ_{32}	0.25
Tensile Strength (GPa)	T_X	.850
	T_Y	.850
	T_Z	.120
Compressive Strength (GPa)	C_X	.720
	C_Y	.720
	C_Z	.50
Shear Strength (GPa)	S_{12}	.105
	S_{13}	.065
	S_{23}	.065

Numerical simulation

Finite element method is the most popular technique for composite structure analysis; it also eliminates the limitations of experimental methods like stress distribution pattern, ply by ply stress analysis, plastic deformation of material at different time steps, plotting energy displacement, force-displacement graph. This paper numerically investigates limitation of experimental work **[1]**. The meshing of defined problem is done by using Hypermesh v9.0 and LS-DYNA 4.2 (beta) for numerical simulation.

Material model

MAT-59 (SOLID-COMPOSITE-FAILURE-SOLID-MODEL) material card used for material modeling which provides orthotropic material properties. The only limitation of this material card that it cannot predict delamination in failed material, but the sectional view of the impact can clearly represent ply failure status. Material model is shown in (**Fig. 1**).

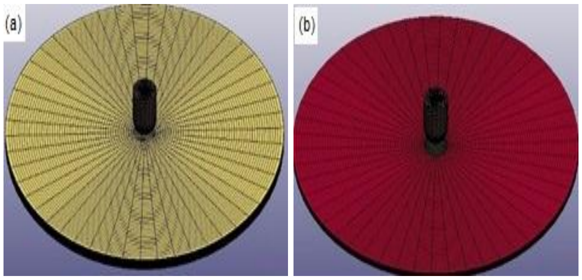

Fig. 1. FEM model (a) without pre-crack, (b) pre-crack in mid plies.

Contact

Impact simulation requires proper contact between the impactor and laminate as well as adhesion between all plies of the laminate. Three contact cards were used in this simulation for defining proper contact with the proposed model. AUTOMATIC_SURFACE_TO_SURFACE card used to provide contact between the impactor and layers of the laminate; AUTOMATIC_ONE_WAY_ SURFACE_TO_SURFACE used to provide contact between the lamina and INTERIOR was used to avoid the negative volume condition

Boundary conditions

BOUNDARY_SPC used to constrain laminate boundaries in translational and rotational directions. Boundary conditions were applied in the range of 60-75 mm radius as shown in (**Fig. 2**).

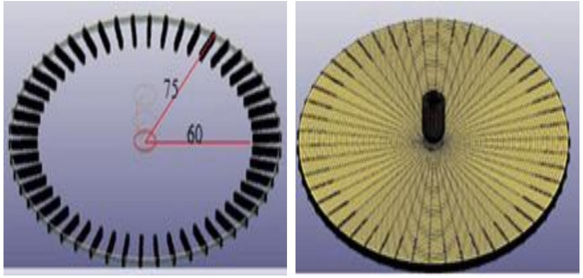

Fig. 2. Boundary condition for defined problem.

Impact energy

Hemispherical headed cylindrical indenter with a hemispherical radius of 10 mm made of steel impacted with 12 J energy on eight layered GFRP laminate.

Simulation time

Impact simulation time was defined 3.0 msec for this problem.

Results and discussion

In this research work four parameters have been compared to justify the efficient performance of the symmetrical design. Maximum stresses distribution pattern as shown in (**Fig. 3(a)** and **3(b)**). for laminate without pre-crack.

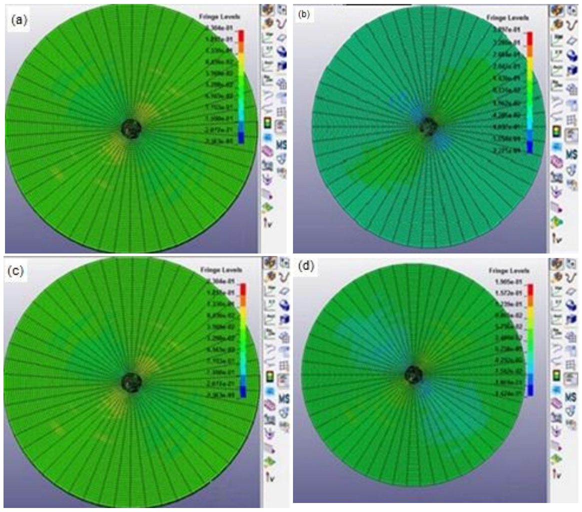

Fig. 3. Stress pattern for laminate (a) symmetrical without pre-crack (b) asymmetrical design without pre-crack (c) symmetrical with pre-crack (d) asymmetrical design with pre-crack.

Fig. 3(c) and **3(d)** represent stress pattern for laminate with pre-crack at midplane. Thus, stress patterns clearly indicated that symmetrical laminate had less stress generation.

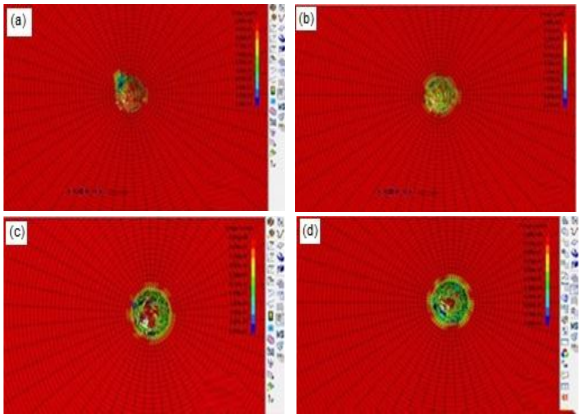

Fig. 4. Maximum damage for laminate without pre-crack (a) asymmetrical without pre-crack (b) symmetrical design without pre-crack (c) asymmetrical with pre-crack (d) symmetrical design with pre-crack.

Stress pattern results justified that impact performance of symmetrical laminate is best in both cases with and/or without pre-crack. Damage pattern also clearly validated less damage for symmetrical laminate in both cases with and/or without pre-crack (**Fig. 4(b)** and **4(d)**).

In the laminate with pre-crack, it is found that impactor generated punching effect on the sample as pre-crack was induced in the midplane. So, in the case of pre-crack fiber fracture occurred on both sides, i.e. on the top layer as well as bottom ply **(Fig. 5).**

Penetration of hemispherical indenter inside laminate signified that maximum penetration was found in the case of asymmetric laminate with pre-crack. Also, maximum fiber damage observed in the same case (**Fig. 5. d**), i.e. asymmetrical laminate with pre-crack. Rectangular damage area of laminate with the pre-crack case was also calculated using ‘measure tool’ in LS-DYNA, and it was observed that maximum rectangular damage area of asymmetric laminate with pre-crack was 206.76 mm^2 (**Fig. 6**).

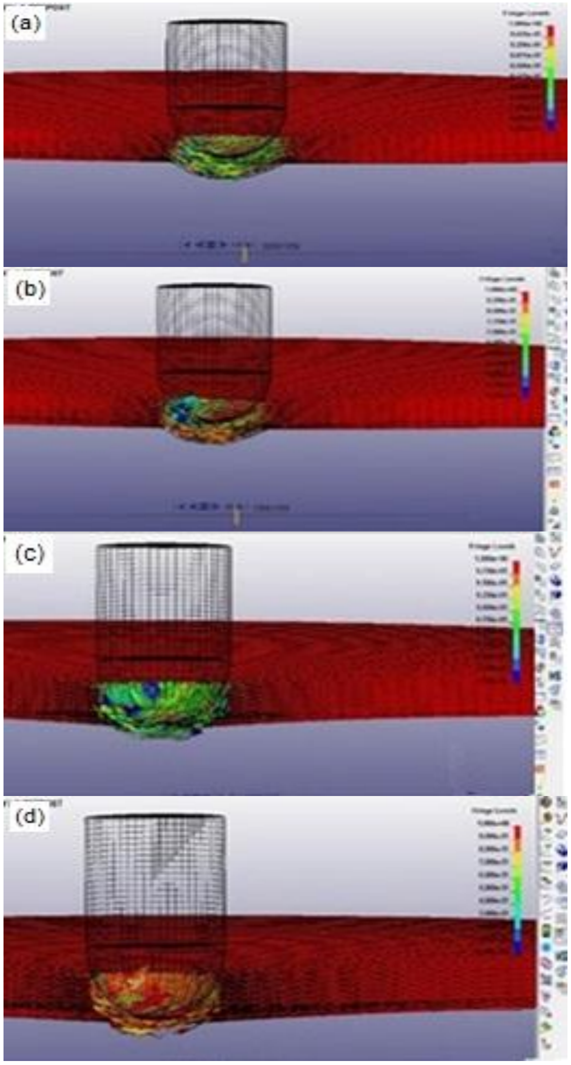

Fig. 5. Penetration pattern for laminate (a) symmetrical without pre-crack (b) asymmetrical laminate without pre-crack (c) symmetrical with pre-crack (d) asymmetrical laminate with pre-crack.

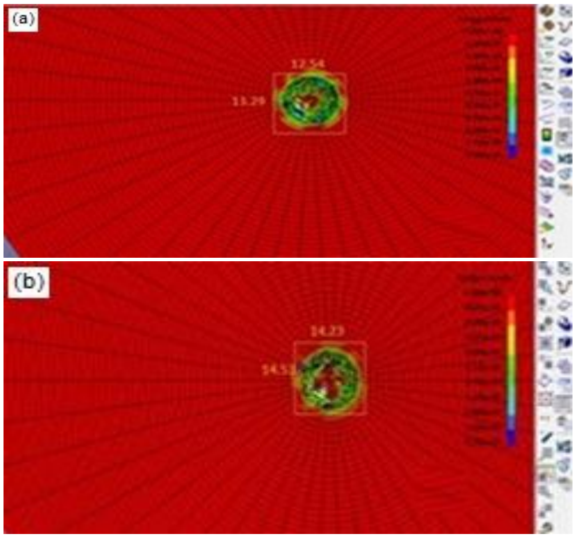

Fig. 6. Rectangular damage area for laminate without pre-crack (a) symmetrical (b) asymmetrical laminate.

Conclusion

The damage behavior of GFRP laminate (symmetrical and asymmetrical layup) with and without pre-crack in two middle layers have been investigated using LD-DYNA. Numerical study justified the influence of ply orientation which plays a crucial role in energy absorption during low-velocity impact, investigated parameters finding can be concluded as: The stress generated during impact was found less in the case of symmetrical laminate design in both cases with and without pre-crack comparatively. No fiber damage was detected at 12 J impact energy in the case of the symmetrical and asymmetrical laminate without pre-crack while samples with pre-crack have fiber damage in both cases and maximum fiber damage occurred in asymmetrical laminate with pre-crack. Maximum impactor penetration occurs in the case of asymmetrical laminate with pre-crack where the maximum damage was also observed. Rectangular damage area for the asymmetrical design with pre-crack was 206.76 mm^2; it is 24.06 % higher as compared to the damage in symmetrical laminate design contains pre-crack in the midplane.

Acknowledgements

Any Funding Program did not support this work.

References

1. Singh, K. K.; Singh, R. K.; Chandel, P. S.; Kumar, P.; *Polym. Compos.*, **2008**, *29*, 1378. **DOI:** 10.1002/pc.20422
2. Singh, K. K.; Singh, N. K.; Jha. R; *J. Compos. Mater.*, **2015**, *50*, 1853. **DOI:** 10.1177/0021998315596594
3. Sarasini, F.; Tirillò, J.; Ferrante, L.; Valente, M.; Valente, T.; Lampani, L.; Gaudenzi, P.; Cioffi, S.; Iannace, S.; Sorrentino, L.: *Composites, Part B.*, **2014**, *59*, 204. **DOI:** 10.1016/j.compositesb.2013.12.006
4. Angrizani, C. C.; Cioffi, M. O. H.; Zattera, A. J.; Amico, S. C.; *J. Reinf. Plast. Compos.*, **2014**, *33*, 472. **DOI:** 10.1177/0731684413517519
5. Chai, G. B.; Zhu. S.: *Proc. Inst. Mech. Eng., Part L.*, **2011**, *225*, 207. **DOI:** 10.1177/1464420711409985
6. Davis, D. C.; Wilkerson, J. W.; Zhu, J.; Hadjiev, V. G.; *Compos. Sci. Technol*., **2011**, *71*, 1089. **DOI:** 10.1016/j.compscitech.2011.03.014
7. Siegfried, M.; Tola, C.; Claes, M.; Lomov, M. V.; Verpoest, I.; Gorbatikh, L.; *Compos. Struct.*, **2014**, *111*, 488. **DOI:** 10.1016/j.compstruct.2014.01.035
8. Agarwal, S.; Singh, K. K.; Sarkar, P. K.; *J. Compos. Mater.*, **2014**, *48*, 317. **DOI:** 10.1177/0021998312472217
9. Reid, S. R.; Zhou, G. (Eds.); Impact Behaviour of Fiber-Reinforced Composite Matericals and Structures; Woodhead: UK, **2000**. **ISBN:** 1855734230
10. Singh, N. K.; Singh, K. K.; *Polym. Compos*. **2014**, *36*, 1786. **DOI:** 10.1002/pc.23064
11. Rawat, P.; Singh, K. K.; *Polym. Compos*., **2015**. **DOI:** 10.1002/pc.23573.
12. Ghasemnejad, H. ; Furquan, A. S. M. ; Mason. P. J.; *Mater. Des*., **2010**, *31*, 3653. **DOI:** 10.1016/j.matdes.2010.02.045