International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

Research Article

Impact behaviour of Fibre Reinforced composites with change in Fibre Orientation

Gayatri Vineela. M†*, Gayathri Tadepalli† and A. Krishnaiah†

†Mechanical Engineering Department, CVR College of Engineering, Hyderabad-India
†Department of Mechanical Engineering, University College of Engineering (OU),Hyderabad-India

Accepted 25 Jan 2016, Available online 03 Feb 2016, **Vol.6, No.1 (Feb 2016)**

Abstract

E- Glass/ epoxy polymer composites find widespread applications because of their several advantages like high wear resistance, good strength-to-weight ratio and low cost. They find huge application in the construction of automotive and aviation body structures, in which they are inevitably subjected to sudden impacts during their construction, maintenance and functioning. The study of the damage behaviour of the fibre reinforced polymer composites (FRC) subjected to impact loads has become a crucial area of research. In this paper, the processing, characterization and the effect of the various orientations (0/90; 30/60; 45/90) of E-Glass/epoxy composite plates has been investigated experimentally and analytically using ABAQUS after being impacted with a standard drop weight. The response of these laminates to low velocity impact has been recorded and compared. The study reveals that the impact resistance of cross – ply laminates is more when compared with angle ply laminates.

Keywords: *FRC; E- Glass/ epoxy polymer composites; Impact loads; Fibre orientation; drop weight*

1. Introduction

Composites are multifunctional materials having unprecedented mechanical and physical properties which can be tailored to meet the requirements of a particular application. The development of composite materials and related design and manufacturing technologies is one of the most important advances in the history of materials. Hosseinzadah and Shokreih have investigated the damage behaviour of thin and thick glass/epoxy; carbon/epoxy composites including the sandwich structure of Carbon/Glass/ Epoxy composite experimentally and analytically (ANSYS / LS-DYNA). The carbon/glass/epoxy sandwich structure was proposed as the best optimized material in terms of strength & weight reduction. Ramazan and Erbil studied the impact behaviour of glass/ epoxy laminated composite plates with (0/±θ/90) numerically at equal energy, equal velocity and equal impactor mass. Chandekar Bhushan studied the response of fiber glass epoxy composite laminates under low velocity loading using LS – DYNA and compared the results with the experimental investigations. Richardson showed the damage will be invisible from for low velocity impacts and may cause serious decrease in mechanical strength. Ross and Sierakowski studied the effects of impacts by conical head impactors and observed delamination in glass/epoxy plates by using a power light source. Clark developed a model for delamination of different fiber reinforced plates and showed that the delamination is in the form of stretched or almond shape. Antonio F Avila, Marcelo I Soares and Almir Silva Neto investigated the strength of composites using nano-particles as fillers and compared with conventional composites. In this paper, three different fiber reinforced composite plates of different orientations are studied after being impacted with a standard drop weight. The response of this laminates to low velocity impact has been investigated.

*Corresponding author: **Gayatri Vineela. M**

2. Material Preparation

E- Glass or Electrical grade glass are produced using melt spinning techniques i.e., melting of glass composition into a platinum crown which has small holes for the molten glass to flow. Continuous fibers can be drawn out through the holes and wound onto spindles, which forces molten glass with a typical normal composition of SiO_2 54 wt%, Al_2O_3 14 wt%, CaO + Mg.

Table 1 Properties of E- Glass

S. No	Properties	Values
1	Diameter	8mm
2	Volume Fraction	40%
3	Density	2.54g/cm^3
4	Tensile Strength	3.447Gpa
5	Poisson's Ratio	0.25
6	Young's Modulus	72GPa

The co-polymer 'Epoxy' is made from two different chemicals 'resin' and hardener (Polyamine). Resin(epoxide group) react with amine group (hardener) to form covalent bond. Polymerization also called 'Curing' can be done by controlling temperature, which of resin and hardener.

Table 2 Epoxy Properties

S. No	Properties	Values
1	Density	1.21g/cm^3
2	Tensile Strength	82.74Mpa
3	Poisson's Ratio	0.12
4	Young's Modulus	3GPa

The hardener used in Epoxy is polyamine. A polyamine is an organic compound having two or more primary amino groups -NH_2.This class of compounds includes several synthetic substances that are important feed stocks for the chemical industry, such as ethylene diamine H2N-CH_2-CH_2-NH_2, 1,3-diaminopropane H_2N-$(CH_2)_3$-NH_2, and hex methylene diamine H_2N-$(CH_2)_6$-NH_2. The amine groups react with the epoxide groups to form a covalent bond. Each NH group can react with an epoxide group, so that the resulting polymer is heavily cross linked, and is thus rigid and strong.

3. Filament Winding (HOOP) Technique

Axi-symmetric laminates is fabricated by Filament Winding Process. The equipment used in the filament winding process is:

1. A modified center lathe with change gears and a VFD.
2. A cylindrical MS drum of Ø 450 x L 1000 mm as mandrel.
3. Resin bath of 1 liter capacity.
4. Fiber dispensing system with variable tensioning arrangement.

Table 3 Winding Parameters

S. No	Parameters	Values
1	Tension in Fiber	1.5Kg
2	Resin : Hardener: Diluent	100: 24: 24
3	Temperature of the resin bath	45^{0}c
4	Pitch for winding	3mm
5	Speed of rotation of mandrel	15RPM
6	Scraper Blade gap	1.25mm

4. Cutting of the Prepeg along the desired Orientation

The Prepeg mat obtained is in rectangular form of dimensions 1380x890 mm. we desire to make an angle-ply [45/90]s glass fiber reinforced epoxy(GFRE) composite laminae of size 300x300. The required laminate orientations are as follows

Table 4 Epoxy Properties

S. No	Orientation	No. of Plies
1	45	5
2	90	5

The 45^0 ply orientated laminae are cut first. Similarly a 90^0 should be obtained in same fashion. The Prepeg mat is cut using a sharp knife or blade and along with the backup polythene sheets. The next step in the process is laying of the laminae in the desired stacking order.

5. Curing Of the Laminate

In the curing process, the plates are kept in oven and the temperature is maintained at 80^{0}c for four hours. During this stage the diluent present in the resin mixture is evaporated and the resin thickens into form of thick gel. This process is called Gelation phase. After this, the temperature in the oven is increased to 170^0 C. During this stage, the hardener present in the resin mixture acts as a initiator or catalyst which breaks down into free radicals .this free radicals initiate the chemical reaction between the monomers present in the resin creating a cross linking between the monomers forming a polymer. This process of cross linking between the monomers is called polymerization. The resin helps to distribute the force uniformly over the fiber reinforcement.

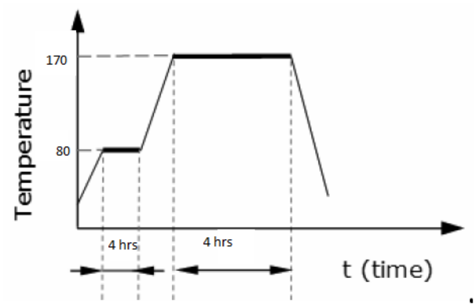


Fig.1 Curing cycle

The above figure represents the time temperature plot of a curing cycle which takes place inside the oven. After the curing cycle it is left to cooled down .then the bolts are removed and the bolts are removed and the fabricated laminate is removed from the mold plates.

6. Finite Element Analysis

FEA is used to predict the stresses and strains induced in the laminate by a low velocity projectile. These stresses and strains can later be used to predict the life span of the composite under various loading conditions. ABAQUS finite element codes are used for the simulations.

Table 5 Material Properties of Glass fiber/Epoxy Composite

Material Specifications	Value (G Pa)
E11	45
E22	12
E33	12
G12	6.5
G13	6.5

G23	2.5
S_{1t}	1.02
S_{2t}	0.04
S_{1c}	0.62
S_{2c}	0.14

Table 6 Material Properties of Glass fiber/Epoxy Composite

Young's modulus (E_1) N/m^2	Poisson's ratio (ν_{12})	Density Kg/m^3
210 x 10^3	0.3	7.8 x 10^3

7. Modelling

A solid square plate of 300mm x 300mm area and 3mm thickness is created in ABAQUS to represent a composite plate fixed. Then a sphere of 40 mm diameter is created and placed at a negligible distance from the composite plate. This sphere represents the steel impactor and it is considered as a rigid body. Fig.2 shows the model in ABAQUS.

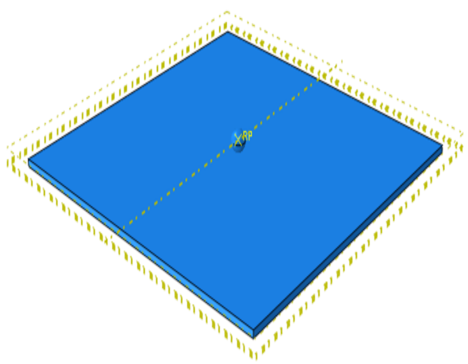


Fig.2 Solid model

The finite element model is developed by meshing the model in ABAQUS. C3D8 element type is used to mesh the model. The meshed model is shown in the fig.5.2. The nodal components of the PLATE and IMPACTOR are created for the reference of the ABAQUS options.

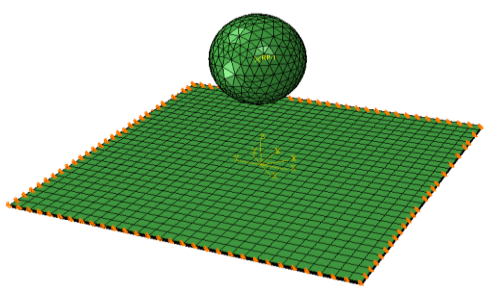


Fig.3 Finite element modeling of Composite plate and Impactor

All the degrees of freedom are constrained for the circumferential surface. The impactor is given an initial velocity of 4.5m/s and acceleration of gravity 9.81 m/s^2 is applied by defining array parameters for time and acceleration values in the solution. The loaded model seems as in the fig.3.

8. Analysis

The loaded finite element model is ready to solve our problem. The model is solved for three different ply sequences and varying the impact velocities taken from experimental data. The type of analysis employed here is dynamic analysis. The results of the solution can be reviewed using the ABAQUS viewer. We can list or plot the results like deformation, stresses, energy, velocities etc at nodes or elements for a single load file.

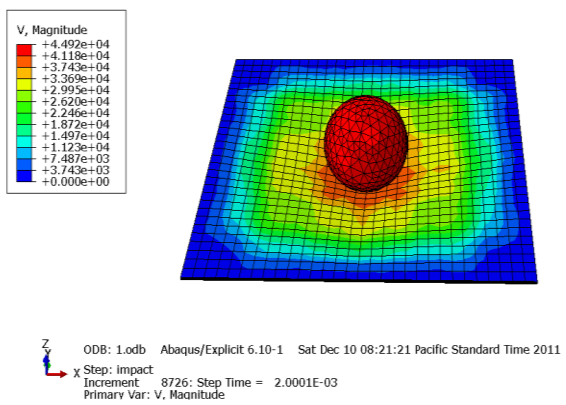


Fig.4 Deformation of composite by the Impactor

9. Experimental Setup

For studying the damage behavior of composite plates subjected to drop weight impacts we are fabricating drop weight impact machine. A supporting frame is used to support the composite laminate as shown in figure. An interface frame was mounted between clamps and plates for making clamping force on the composite laminates uniform.

Fig.5 Drop box setup

The tests were performed using an instrumented falling weight testing machine with no energy storage device: the maximum impact energy is limited by the adjustable falling height and the fixed mass of 2.5kg of the impactor. The impactor mass together with the height of drop determines the energy of impact. With an increase in mass and height the potential energy (P.E=mgh) of the impactor will increase and thus on releasing the tool holding assembly the potential energy is converted to kinetic energy (K.E=1/2mv^2). Falling weight impact test setup is shown in Fig.6. The impactor material used was Mild Steel.

Fig.6 Impact test setup

In accordance with ASTM D 3029 standard[15-18] a batch of square, Area (300-300 mm side, 2.4mm thick) specimens is clamped on a supporting frame with L-Clamps , which are slotted to easy removal of laminates and to placing also. The L-Clamps provides the required clamping force. In this L-clamps were used. The impactor has a spherical head of 80 mm diameter; the impactor is hanged through a wire rope, which is passed through the two pulleys. The two pulleys are fixed to the horizontal beam in such a way that make them has free rotating without friction.

Figure shows the specimen clamping apparatus, specifically designed in order to assure the constancy of the clamping force, through the pre-loading of eight L-clamps. Illustrations of the photograph of the impactor and the specimen mounted on the base plate. A fixed impactor weight of 24.5 N with the impactor was released from varying heights; 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1and 1.2 m according to the energy and velocity of impact required based on the laminate thickness. Scanning of the each laminate before the impact and after the impact will be done. Scanning will be done through NDT (Non-destructive testing) techniques. Here the laminates are scanned by using Ultra-sonic (C-scan) method.

Fig.7 Sample laminate before and after Impact

10. Test Results

The test results of all the 3 specimen laminates are compared and tabulated

Table 7 Comparison based on Ply Angle

Orientations	Frequency Before Impact(db)	Frequency After Impact(db)
[30/60]5	40-50	36-43
[45/90]5	33-45	28-40
[0/90]5	42-48	38-45

In Ultrasound scan, Imperfections between the transmitter and receiver reduce the amount of sound transmitted, thus revealing their presence. C-scan of the laminates reveals very less deformation for the given low velocity impacts for all orientations. The scan images show that there is not much variation in damage area for low velocity impacts. [30/60]$_5$ laminate showed more damage resistance compared to other laminates. The same is validated by the deformation contours obtained using ABAQUS.

10.1 *Ultra Scan Results*

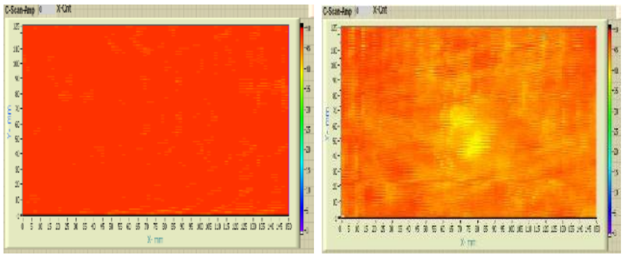


Fig.8 [30/60]$_5$ orientation before and after Impact

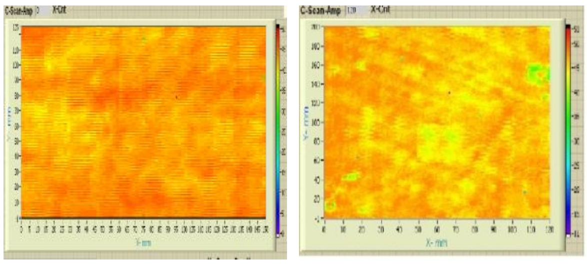


Fig.9 For [0/90]$_5$ orientation before and after Impact

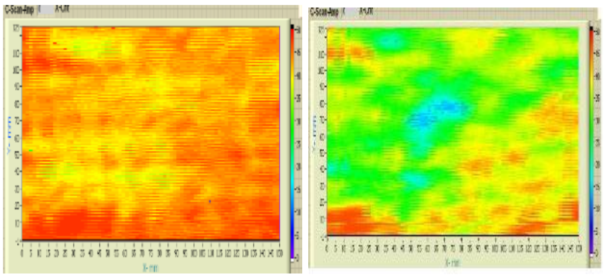
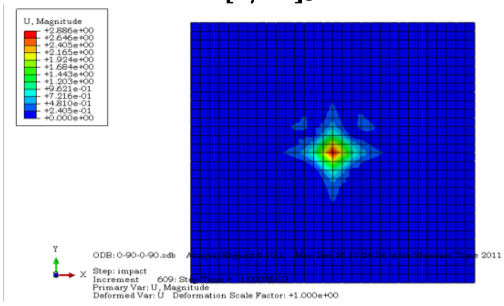


Fig.10 For [45/90]$_5$ orientation before and after Impact

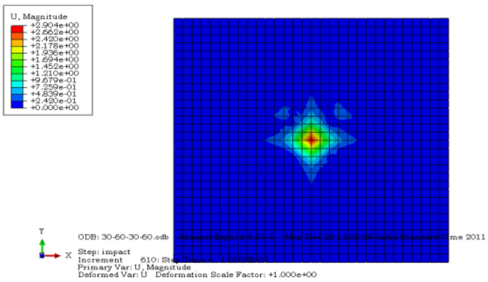
11. FEA Results

11.1 Deformation Contours

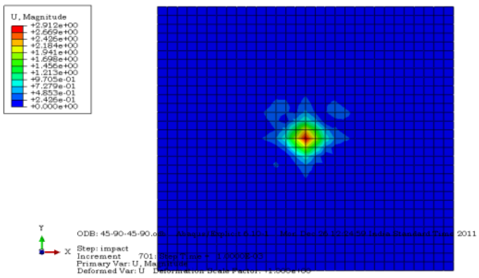
[0/90]$_5$



[30/60]$_5$



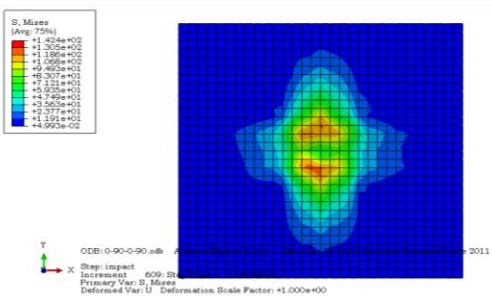
[45/90]$_5$



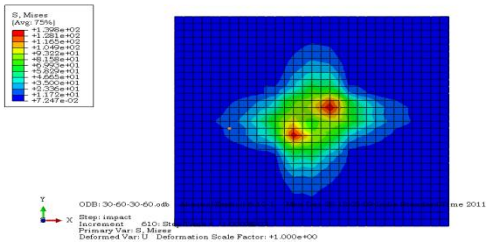
11.2 Stress Contours

The Vonmises stress contours for the laminates as obtained from the analysis in ABAQUS are given below. Stress concentration in [0/90]$_5$ and [45/90]$_5$ laminates is slightly more and stress concentration area is also more in the above two laminates compared to [30/60]$_5$ laminate. The maximum Vonmises stresses are of the order of 1.424e0.02, 1.39e0.02 and 1.558e0.02 for [0/90]$_5$, [30/60]$_5$ and [45/90]$_5$ respectively.

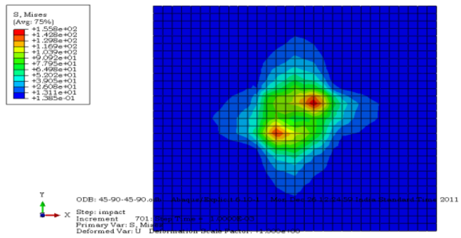
[0/90]$_5$



[30/60]$_5$

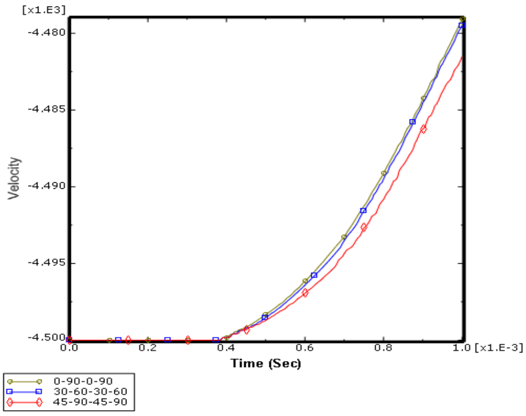


[45/90]$_5$

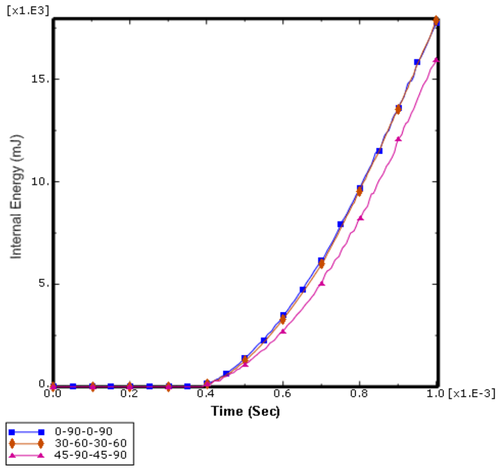


To understand the behaviour of E-Glass/Epoxy laminates with respect to time the comparison plots of Velocity, Internal Energy, Kinetic Energy and the total energy of the plate and sphere Vs Time are given below.

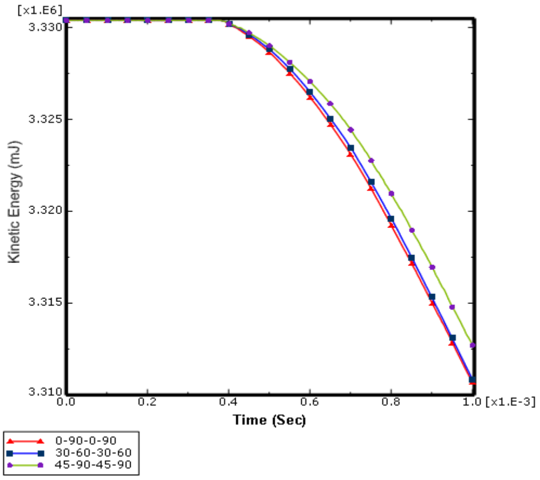
11.3 Velocity



11.4 Internal energy



11.5 Kinetic energy



Conclusion

From the results obtained from the C SCAN we can conclude the 30/60 laminate has more damaged resistance than the other orientations Damage resistance is in the order of **45^0-90^0 < 0^0-90^0 <30^0-60^0**

Three types of Glass/Epoxy composite plates were tested, subjected to drop weight impact of 80mm diameter mild steel sphere. The plates were clamped and the spherical weight is made to impact at the centre of the plates. The composite plates were tested before and after impact first by visual inspection and by using NDT scanning technique The damage area was identified and marked. It was observed at such low velocities and energy due to change in fiber orientation, there was no significant damage reported for all the plates. The damage might be considerably more for high velocity impacts. However, from the results obtained from the C SCAN we can conclude the 30/60 laminate has more damaged resistance than the other orientations Damage resistance is in the order of **45^0-90^0 < 0^0-90^0 <30^0-60^0**

To support the above test results the laminates and the impactor were modeled using ABAQUS .The deformation contours, stress contours and variation of the Velocity of the ball after impact, the change in kinetic energy and the amount of internal energy absorbed after impact were obtained. The damage area obtained by visual inspection is approximately same as that obtained from the analysis software. However, with a good experimental setup backed with accessories to measure the impact force, energy and velocity, the impact characteristics for low, medium and high velocity impacts can be studied, validated with ABAQUS tool to find an optimum ply angle sequence with good impact resistance which can be an advantageous for many industrial applications.

References

Ramin Hosseinzadeh, Mahmood M Shokrieh and Larry Lessard (2006), Damage behaviour of Fiber reinforced composite plates subjected to drop weight impacts; Comp. Sci. Tech. 66

Ramazan Karakuzu, Emere Erbil and Mehmet Aktas (June 2010). Damage prediction in glass/epoxy laminates subjected to impact loading; Indian Journal of Composites & Material Sciences Vol. 17.

Gautam S. Chandekar, Bhushan S. Thatte, and Ajit D. Kelkar. (2010), On the Behavior of Fiberglass Epoxy Composites under Low Velocity Impact Loading; Hindawi Publishing Corporation Advances in Mechanical Engineering Vol 2010.

Richardson MOW, Wisheart MJ (1996). Review of Low Velocity Impact properties of Composite Materials. Compos Part A – Appl. Sci. Manuf;27A.

Ross C A, Sierakowski R L (1973), Studies on the Impact Resistance of Composites Plates. Composites 4.

Clark G (1989), Modelling of Impact Damage in Composite Laminates. Composites; 20

N K Naik, Y Chandrashekar, Shailendra Meduri Damage in Woven Fabric Composites subjected to Low-Velocity Impact.

Antonio F Avila, Marcelo I Soares *et.al* (2005), An Experimental Investigation on Nanocomposites under impact loading, WIT Transactions on Engineering Sciences

Mechanics of Composite Materials by Robert M. Jones

Handbook of composites, Department of Defense

www. compositesworld.com

www.wikipedia.org