Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 13 Issue 4, April 2024

Low-Velocity Impact Response of Fibre-Reinforced Composite Laminate: Prediction and Verification

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***Abstract*- The Fiber reinforced laminated composites are preferred in many aircraft applications due to low weight, high strength to weight ratio and high stiffness. One of the crucial loads on structural components is the low velocity impact that can produce barely visible impact damage leading to premature failure of components. In this paper, low velocity impact response and tolerance of a composite laminate have been evaluated. The behaviour of composite laminate under low velocity impact has been predicted using numerical simulation and verified by carrying out experimental test. Glass fibre reinforced composite laminate has been fabricated using vacuum assisted resin transfer molding. Experimental low velocity impact test has been performed using ball indentor and the behaviour of the laminate has been recorded. Finite element (FE) modelling and numerical simulation of low velocity impact has been carried out by considering influence of different mesh parameters. Developed FE model is validated against the experimental results. Impact response of laminate for different energy levels has been predicted by FE analysis and the same is verified against data obtained by actual experimental test. Close concurrence observed between prediction and verification establishes a quality methodology for carrying out impact response analysis of composite laminate.**

***Keywords*- Impact response, Finite element analysis, Composite laminate, Numerical simulation terminals.**

I. INTRODUCTION

Composite structures are load-bearing components made of materials that are typically non-metallic, irregular fibre and resin mixtures. In numerous structural applications, including those involving aviation, aerospace, military vehicles, automobiles, civic infrastructure, medical devices, and sporting goods throughout the last few decades, composite materials have increasingly supplanted and replaced metals [1]. Common benefits of composite structures include lighter weight, better performance, and cost-effectiveness. Due to their improved strength, durability, corrosion resistance, resilience to fatigue, and damage tolerance properties, composites have become a more alluring alternative to traditional metals for many structures. Additionally, composites offer more flexibility due to their ability to be adapted to specific design needs and their substantial weight advantages.

The modern-day composite can be defined as any structural material made of two or more combined constituents at a macroscopic level which are insoluble in each other. One constituent is called the reinforcing phase and another one in which it is embedded is called the Matrix. The reinforcing phase material may be in the form of fibers, particles, or flakes.

Fiber-Reinforced Composites can be categorized based on the length of the fibres that make up the matrix structure. continuous fibre reinforcement composites are those with long fibre reinforcements, whereas discontinuous fibre reinforcement composites are those with short fibre reinforcements. In the matrix structure of continuous fibre composites, fibres may be put either unidirectionally or bidirectionally, and they transfer loads from the matrix to the fibre in a very simple and efficient manner.

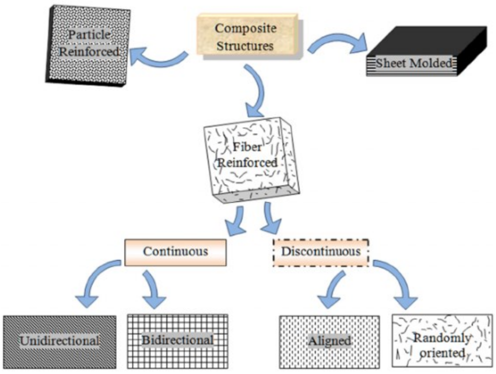


Fig. 1. Classification of composite materials [1]

Among the reinforcing fibres used in polymeric matrix composites (PMC), glass fibres are the most prevalent. Low cost, great tensile strength, good chemical resistance, and excellent insulating qualities are glass fibres main benefits. Among commercial fibres, the drawbacks include relatively low tensile modulus, high density, sensitivity to handling abrasion (which commonly reduces tensile strength), low fatigue resistance, and high hardness (which causes excessive wear on moulding dies and cutting tools). E-glass and S-glass are the two types of glass fibres most frequently used in the fiber-reinforced plastics (FRP) industry.

Several factors, including the kind of fibre, resin, lay-up, specimen thickness, velocity, and type of projectile, might influence failure modes in composites under low velocity impact loading circumstances. While composite laminates mostly absorb energy during elastic deformation, metals absorb energy in both elastic and plastic regions. Since most composites are brittle by nature, damage processes and elastic deformation rather than plastic deformation are the ways in which they might absorb energy.

To distinguish between low velocity and high velocity impact, composite materials may be divided into two separate groups based on their impact response. Both are based on structural deformation and structural reaction, which are dependent on the impact's velocity, mass, and duration. According to Shivakumar et al[2]. and Sjoblom et al.[3], low velocity impact events may typically be viewed as quasistatic, while a structure's high velocity impact response is primarily determined by the propagation of stress waves through the material. The experimental methodology and the numerical method are the two frequently used methodologies for studying impact issues of composite structures [2]. The experimental inquiry is practical and efficient for gathering the fundamental data needed for subsequent research since it may give immediate vision of the impact phenomena and damage types. Using a drop-weight impact carriage, Mili [4] investigated the impact behaviour of fully-clamped E-glass/epoxy laminate constructions at velocities ranging from 0.54 to 3.1 m/s. A spring-mass model approximation was utilised to predict the maximal impact force using a Hertzian contact law. It was discovered that the impactor velocity had a direct relationship with the impact force and centre deflections. Transverse deformation rises with increasing projectile velocity, according to Aggour and Sun [5], who also performed low velocity impact tests on E-glass/epoxy laminates at various impact velocities. Due to its benefits in eliminating testing, which reduces design costs and time, the numerical approach of research has grown in popularity the majority of researchers have examined the whole impact behaviour of the composite materials using the data from FE simulations. In addition to a thorough investigation of the stress distribution, a FE simulation of a low-velocity impact on a composite material also reveals information regarding scarcely perceptible impact damage, which is hard to see during experimental tests. The finite element (FE) programme LS-DYNA is utilised for this purpose [6, 7]. Employing the commercially available explicit FE programme LS-DYNA, composite plates are used in low-velocity impact simulation models using solid and shell elements. The initial purpose of the shell elements, which have a significantly a smaller number of components than solid elements, was to depict smoothly deformed structures. In terms of the time-force and time-energy histories, the numerical simulation findings of the shell element model are in good agreement with the results of the experiments. The simulation model of the solid element, however, allows for a more accurate prediction of the size and shape of the delamination. [8] K. R. Jagtapa utilised this Effective simulation of the low velocity impact scenario on composite structures using finite element software allows for the precise prediction of failure mechanisms. A successful FE model of an impactor and an 80 x 80 x 2.1 mm carbon/epoxy laminate plate (5 ply) was constructed to analyse the damage caused by a low-velocity impact. LS-explicit DYNA's solver is used to carry out the work validation and convergence investigation.

II. DEVELOPMENT AND VALIDATION OF FINITE ELEMENT MODEL

A. Materials and methods

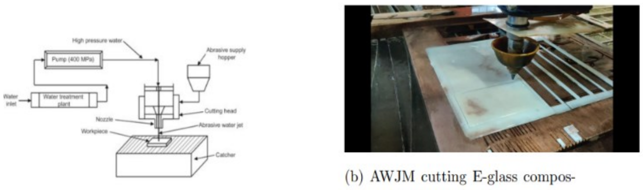
E-glass fibres were used to create composite constructions. Both of these fibres were obtained from Marktech Composites Pvt Ltd., Bangalore, India, and the thermoset polymer epoxy-LY556 (CAS number 25068-38-6) and desired hardener (Aradur HY951) were obtained from Huntsman, Pune, India. The composite had a thickness of 2 mm and varied ply orientations of glass fibres (0, and 90). The Resin transfer moulding technology was used to create composites. The glass fibres were piled into 9 layers throughout the production process. According to the supplier's advice, epoxy solution and the desired hardener were combined at a 6:4 ratio before being applied layer by layer and layered together. The created laminate was 300 X mm 300 mm in size. Using an abrasive-waterjet cutter, it was subsequently reduced to 125 mm X 75 mm.

a) Resign transfer modeling

One of the most effective methods for creating composite parts is resin transfer moulding (RTM). In RTM, a dry preform made of fibre reinforcements is inserted into a mould cavity, the mould is closed, resin is forced into the preform, and the resin is then allowed to cure to create a composite product. Even though the RTM process is fairly simple and only requires a few steps, it has been discovered that the quality of the finished products depends on a number of factors, including injection pressure, vacuum assistance, mould temperature, fibre and resin temperature, curing temperature, fibre architecture, volume fraction, resin viscosity, and more.

b) Abrasive-waterjet machining (AWJM)

The cutting of hard and weakly machinable materials including titanium alloys, ceramics, metal-matrix composites, concrete, rocks, etc. is frequently done using abrasive-waterjet machining (AWJM). In order to increase the machinability of some materials, the technique uses both the impact of a waterjet and the impact of abrasives A configuration for AWJM is sketched out in Fig. 2. The reciprocating pump, which is used to pump clean water at a very high pressure of 4000–6000 bar, is the key component of an abrasive-waterjet arrangement. The waterjet receives the abrasive particles from a hopper in the mixing chamber. Waterjet and abrasives work well together to cut or machine composite materials, Kevlar polymers, hardened steels, and certain ceramic materials.



(a) A configuration for AWJM

(b) AWJM cutting E-glass composite

Fig. 2. Abrasive-waterjet machining

In our research, we used Abrasive-waterjet machining (AWJM) for machining of composite dimensions (125mm X 75 mm)

B. Impact test

The low-velocity impact event was carried out in accordance with ASTM D7136 using a drop-weight testing machine that had an anti-rebound mechanism to prevent numerous collisions and a 0-500 kN load cell to record the history of the contact force as shown in fig 3. The impact force data was acquired using a 16-bit analog-to-digital converter, NI 9222, and the sampling rate was set to be 100 kHz. Four clamps were used to restrict the specimen after it was simply held on the support fixture with a cut-out measuring 125 x 75 mm. The total mass of the impactor consists of impactor head, load cell, connecting rod and weights. The hemispherical impactor heads exhibits the diameter of 17 mm used, to avoid the effect of impact velocity, a constant mass of 6.5 kg was selected for all the impact tests, and the striker was released from different heights to reach different impact energies. The transient impact responses of the specimen included load and energy as function of time. Peak load, time to peak load and absorbed energy also were recorded.

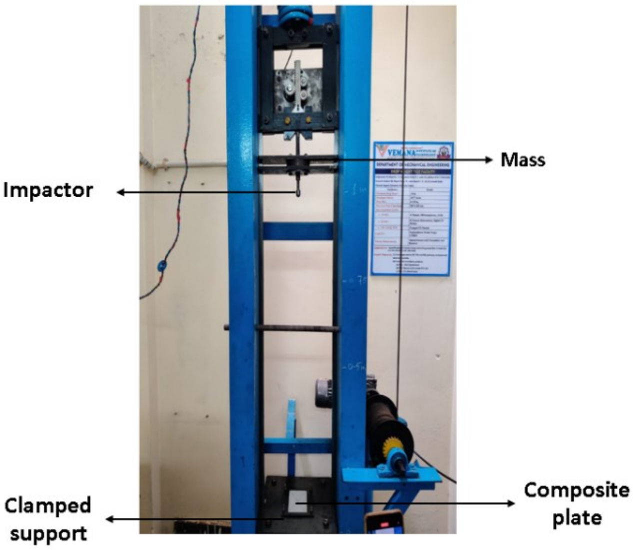


Fig. 3. Drop-weight testing machine

Table 1: Properties of Drop weight test machine

Particulars	**Details**
Maximum Drop height	5.8m
Maximum Velocity	10.77 m/sec
Drop mass	6-120kg
Data acquisition system	
• NI 9222	4 Channel,500 ksamples/sec, 16bit
• NI 9401	8 channel, Bidirectional, Digital I/O
• NIC-CDAQ-9174	Compact I/O module
Load Cell	Semiconductor Strain Gauge, 0-500kN
Velocity Measurements	Optical sensors with transmitter and receiver

C. FE Model development

Numerical techniques, including the finite element method (FEM), discrete element method (DEM), boundary element method (BEM), and finite difference method (FDM), have been employed to address various engineering challenges. Worldwide, programmes like ABAQUS, ANSYS, NASTRAN, and LS-DYNA are used for numerical simulation. The two or three -dimensional element libraries (e.g., Solid, shell, beam, truss, infinite elements) and a material library (e.g., elastic, plastic, hyperplastic, viscoelastic, etc.) are the major components of these commercial software products. Additionally, these programmes are frequently used to solve a variety of engineering issues, including statics, dynamics, heat transport, etc. Different forms of impact analysis, such as normal and oblique impacts, can be studied using the finite element (FE) numerical approach. Additionally, the linear, nonlinear, and damaging reactions brought on by an impact may be efficiently simulated and studied using FE approach.

a) Element

Employing the commercially available explicit FE programme LS-DYNA, composite plates are used in low-velocity impact simulation models using solid and shell elements. The initial purpose of the shell elements, which have a significantly a smaller number of components than solid elements, was to depict smoothly deformed structures. Additionally, the elements' capabilities are increased to model extreme deformations, such as plastic deformations and failures. In terms of the time-force and time-energy histories, the experimental findings and the numerical simulation results of the shell element model correspond well. The overall impact behavior is therefore suitably predicted by the shell element model. It is reasonable to conclude that the shell element model is preferable to the solid element model for an analysis of the impact behavior of a composite plate under a low-velocity impact load.

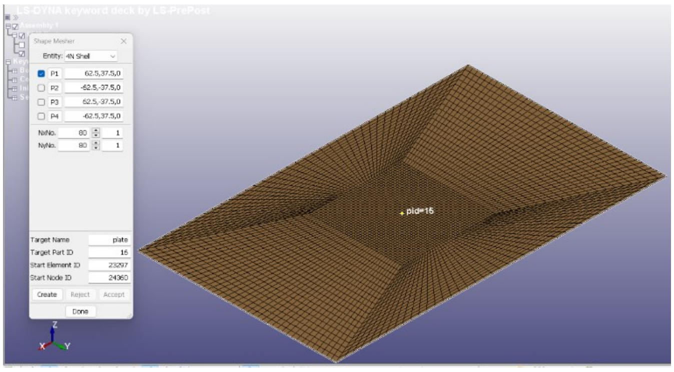
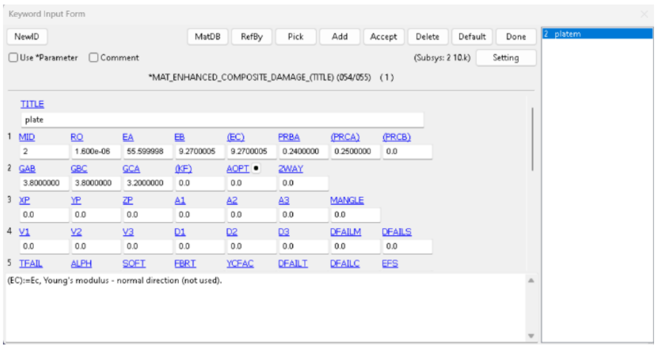

Entity: 4N Shell
☑ P1 62.5,37.5,0
☐ P2 -62.5,-37.5,0
☐ P3 62.5,-37.5,0
☐ P4 -62.5,37.5,0
NxNo. 80 1
NyNo. 80 1
Target Name plate
Target Part ID 15
Start Element ID 23297
Start Node ID 24360

Fig. 4. Shell elements in LS-DYNA

b) Description of element cards

The well-developed numerical code LS-DYNA has a large feature library. A Card in LS-DYNA describes each feature. Different material models are created to fit various materials and application areas. In this research work mainly MAT RIGID and MAT 54/55 (MAT ENHANCED COMPOSITE DAMAGE) are used. In order to simplify the input and create a hard, non-deformable component, a solid impactor composed of MAT 20 (MAT RIGID) was used in the finite element arrangement. The hemispherical tip impactor with radius of 8.5 mm is considered to be made up of steel with a mass of 6.5 kg. The various material properties of the impactor are: Young's modulus, E 210 GPa, Poisson ratio, v = 0.3, density, p = 7800 kg/m³.



*MAT_ENHANCED_COMPOSITE_DAMAGE_(TITLE) (054/055) (1)

TITLE: plate

1	MID	RO	EA	EB	(EC)	PRBA	(PRCA)	(PRCB)
	2	1.600e-06	55.599998	9.2700005	9.2700005	0.2400000	0.2500000	0.0
2	GAB	GBC	GCA	(KF)	AOPT ●	2WAY		
	3.8000000	3.8000000	3.2000000	0.0	0.0	0.0		
3	XP	YP	ZP	A1	A2	A3	MANGLE	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
4	V1	V2	V3	D1	D2	D3	DFAILM	DFAILS
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	TFAIL	ALPH	SOFT	FBRT	YCFAC	DFAILT	DFAILC	EFS

(EC):=Ec, Young's modulus - normal direction (not used).

Fig. 5. Description of element cards in LS-DYNA

When it comes to shell elements, there are two main modelling strategies: the stacked shell, where each ply of the laminate is represented by a shell section with a single integration point, and the layered shell, where a single section has the laminate's overall thickness and an equal number of integration points as the number of plies. MAT 54/55 (MAT ENHANCED COMPOSITE DAMAGE), which is only an upgraded version of MAT 22 giving strain and stress limiting parameters, or MAT 22 (MAT COMPO- SITE DAMAGE), might be used to explicitly express it. Since MAT 54/55 uses the Chang-Chang failure criterion to account for four types of failure, including tensile and compressive (both in matrix and in fibre modes), it is unquestionably the material most commonly used to describe a composite through two-dimensional elements defining an orthotropic material. An E-glass composite plate having stacking sequence of [0/90]s with 0.22 mm ply thickness and dimensions of 125 mm x 75 mm x 2mm is modelled for the impact analysis using material card available MAT 54/55 (MAT ENHANCED COMPOSITE DAMAGE) in LS-DYNA software. Table 2 describes the properties of E-glass.

Table 2: Material properties of E-glass

Property	**E-glass/epoxy**
Fiber volume ratio Vf (%) 65.00	65.00
Density q (gr/cm3)	1.83
Longitudinal modulus E1 (GPa)	40.51
Transverse modulus E2 (GPa)	13.96
In-plane shear modulusG12 (GPa)	3.10
Poisson's ratio m12	0.22
Longitudinal tensile strength Xt (MPa)	783.30
Longitudinal compressive strength Xc (MPa)	298.00
Transverse tensile strength Yt (MPa)	64.00
Transverse compressive strength Yc (MPa)	124.00
In-plane shear strength Si (MPa)	69.00
Interlaminar shear strength S12 (MPa)	38.00

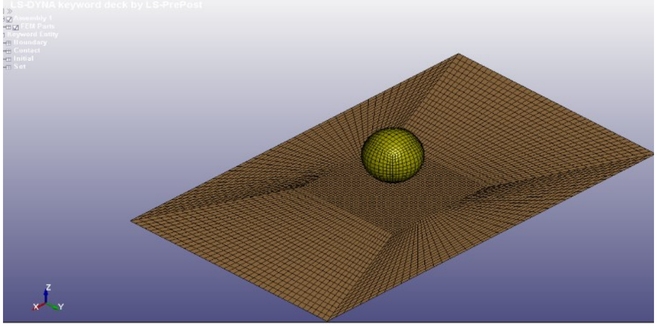


Fig. 6. Virtual representation of impactor and plate

c) Boundary conditions

By running the low velocity impact simulation with varied boundary conditions, it is possible to examine the impact of the boundary conditions on the variation of the stress distribution along the laminate. In this case, the plate is clamped along all four sides and is subject to both translational and rotational forces. In specifying boundary conditions, contacts, limitations, etc. are included. In this instance, there is specified contact between a steel ball and a composite plate. LS-DYNA uses the contact type CONTACT AUTOMATIC NODES TO SURFACE. In LS-DYNA, a contact is specified by specifying which places must be examined for potential slave node penetration through a master segment.

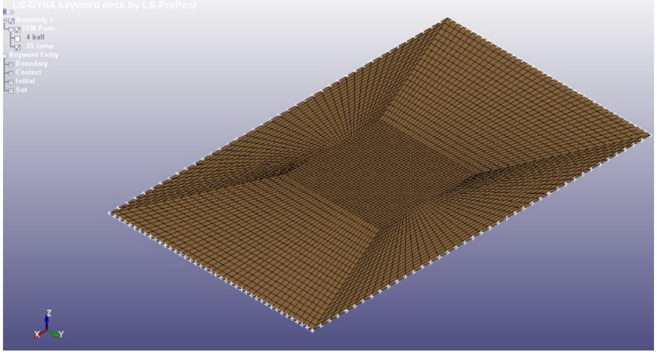


Fig. 7. Boundary condition

d) Meshing

In structural engineering, models of specified structures must be made in order to examine their mechanical behaviour. This is accomplished by dissecting the model into a mesh of individual parts. The pieces join together into nodes to form a continuous space. The model is also given the material attributes, the restraints, and the loading scenario. In its nodes, each element is examined independently. After then, all components are put together to create a full set of equations (stiffness matrix). In order to obtain a displacement field, the system of equations is solved while accounting for the acting load. The displacement field may be used to determine other quantities, such as internal forces, reactions, and stresses. Many structural design software programmes come with modules that can create FE meshes automatically. A high-quality mesh is required to deliver acceptable findings when an analysis is performed. An examined model may be misinterpreted, which might cause further flaws in the solution. There are no specific standards for defining a mesh's quality, though. It is a relative phrase that is always based on a particular issue. It is also important to realise that FEA only offers approximations for solutions. Therefore, the correctness of the analysis cannot be ensured by quality alone. Generally speaking, if the quality of the final solution is good, the mesh quality is good as well.In this paper, considering four different mesh cases which are listed below.

- Case: 1 has 32 elements in the impactor and 800 elements on the plate with dimensions of 20 (length) x 20 (width) x 2 (height).
- Case:2 has 32 elements in the impactor and 3200 elements in the plate, calculated as 40 (length) x 40 (width) x 2 (height).
- Mesh 3 has 256 elements in the impactor and 12,800 elements on the plate with dimensions of 80 (length) x 80 (width) x 2 (height).
- Case: 4 has 256 elements in the impactor and the computing time was reduced by introducing different mesh size/density in different regions of the FE model, from 1 mm X 1 mm elements in the impacted zone.

A. **B.**	**Mesh Size**	**C.** **D.**	**FEM Simulation Peak Impact Load (kN)**	**E.**	**Experimental Simulation Peak Impact Load (kN)**
G.	Case 1	H.	3.2		4.02
	Case 2	K.	3.31		4.02
M	Case 3	N.	3.36	O.	4.02
	Case 4	Q.	3.89	R.	4.02

Table 2: : Comparison of FEM and Experimental Peak force

An analysis is performed on a steel plate with rigid impactor with various mesh densities for both the plate and the impactor.Therefore, it has been discovered that accuracy improved along with density.

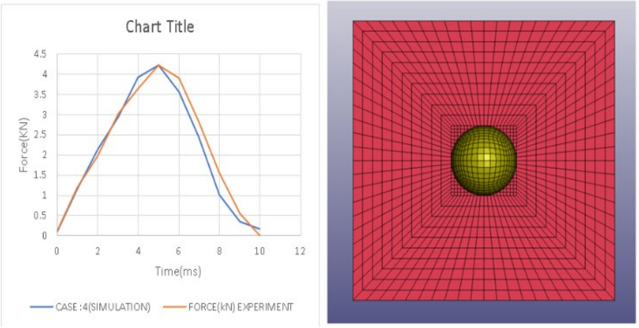


Fig. 8. Comparision of mesh density

e) pre and post processing.

In current analysis LS-PREPOST is used as main pre-processor which has options for adding the cards for preparation of the code for processing in LS-DYNA which is the processor and LS-POST as the post processor.

f) Assigning material in Ls-dyna

The LS-DYNA 4.3 version pre-processor is used to mesh composite plate models. The material model chosen for assigning to the plate is MAT 54/55 (MAT ENHANCED COMPOSITE DAMAGE) composite damage out of a large choice of material models in Ls-dyna. The composite plate is modelled using Belytschko-Tsay shell components. Hughes-Liu solid elements are used to model the rigid sphere; the material model assigned is MAT 20 MAT RIGID, and the elements selected are solid elements.

g) Defining Control time step

The smallest stable time steps in every deformable finite element in the mesh are used to calculate the time step of an explicit analysis. The following equation provides the time step for the shell element:

$$\Delta t = \frac{Ls}{c} \qquad (1)$$

Where, Ls is the characteristic length and c is the sound speed Time step for shell element can also be prevented by the equation as shown below:

$$\Delta t \leq \frac{\Delta x}{c} \qquad (2)$$

Where, Δx = Characteristic length, E = Young's modulus, ρ = Density of the material.

h) Defining Database Binary Option

Plotting information is contained in the D3PLOT, D3PART, D3DRLF, and INTFOR files, allowing data to be plotted across the model's three-dimensional geometry. With LS-PREPOST, this database may be visualized. The D3THDT file includes global information as well as time history data for element subsets. To get output files containing the results information, ASCII output files (also known as database files), are optional but required. Some of the output flies that are mentioned are listed below:

- GLSTAT: This file contains global information. Kinetic energy, internal energy, total energy, ratio, stone-wall energy, spring and damper energy, hourglass energy, sliding interface energy, external effort, and X, Y, and Z-direction velocities are the output components for this file.

- MATSUM: The individual material energies are output by this file. This file's output components include X, Y, Z-direction momentum, X, Y, Z-direction rigid body velocity, kinetic energy, internal energy, and hourglass energy for each individual component as well as overall kinetic, internal, and hourglass energy.
- NODOUT: This file contains information on the nodal points. It is possible to acquire output such as displacement in the X, Y, and Z directions, velocities in those directions, acceleration values in those directions with rotation in the X, Y, and Z directions, as well as rotational velocities and acceleration.
- RCFORC: This file contains the resulting interface forces in the X, Y, and Z axes, which are utilised for impact issues. The resultant interface force is simply the contact force.

D. Comparison of results

a) Force-displacement curves

Force-displacement curves are given in Fig. 9, and experimental and numerically predicted curves are compared. As the impact event progresses, there is a similar slope until the maximum impact force is attained, which is more consistent with rising impact energy. In contrast, the composite plate unloads less quickly and fully than predicted, particularly in the case of the 10 J impact, which has the lowest energy level, as shown in Fig. It should be emphasized that in the experiment, the measured displacement matches that of the impactor that is rebounding, but the numerical value is derived from the midpoint of the plate's rear face. This variation together with other elements, such as the posited friction coefficient between the projectile and plate, may have an impact that causes numerical forecasts to suggest a faster plate recovery than that observed empirically.

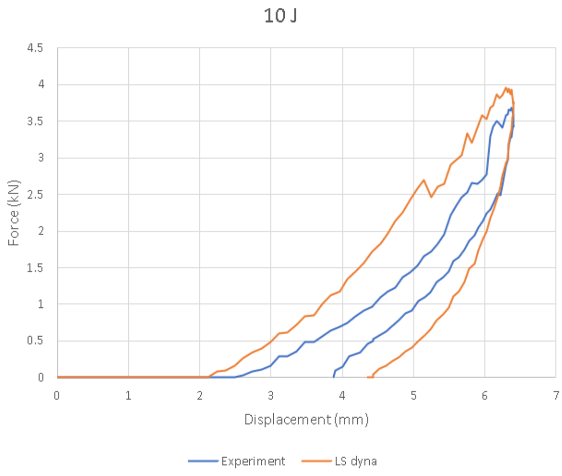


Fig. 9. Comparison of Force-displacement curves

b). Force-displacement curves

The numerical result and the experimental result correspond well, especially as the load increases. The experimental maximum force roughly matches the numerical value. When the peak load is reached and the impactor begins to rebound, the numerical result displays a little larger load value than the experimental and takes longer to reach zero. This phenomenon might be caused by contact forces between the delaminated plies. During the load phase, the numerical analysis provides a solid forecast, and the anticipated maximum force is, which is just slightly lower than the test measurement. Figure 10, depict the Force-time plots for the models and tests. Again, the numerical outcomes of the shell element model are more accurate than the outcomes of the experiments.

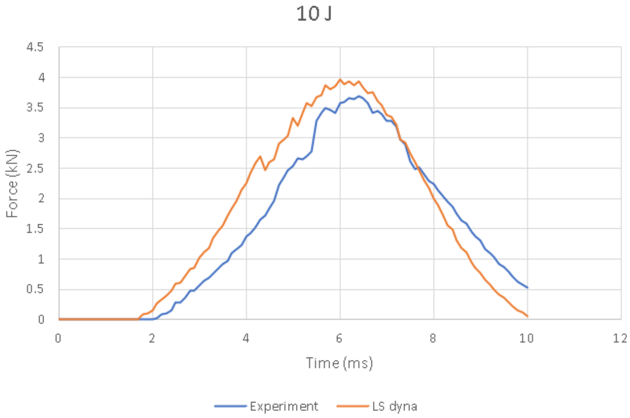


Fig. 10. Comparison of Force-Time curves

c). Energy-time

Once the impactor's velocity is zero, all of its kinetic energy is transmitted to the plate. After this, the impactor bounces back due to the transfer of elastic energy from the plate back to the impactor. Finally, as a result of the damage and friction, the energy absorbed by the composite achieves a steady value. The final absorbed energy anticipated by the numerical model is around 9.59 J for the impact energy of 9.95 J, which is roughly 2.8% lower than the experimental result in Fig.

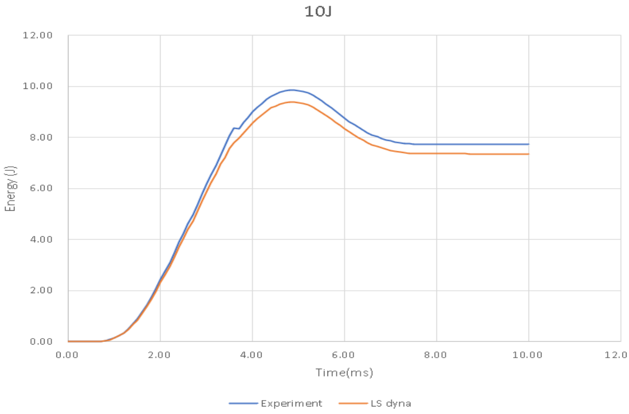


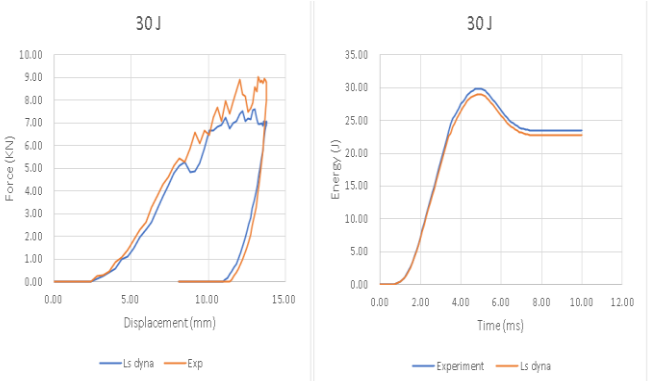
Fig. 11. Comparison of Energy-Time curves

III. PREDICTION OF IMPACT RESPONSE OF COMPOSITES

Due of the complicated damage state and simple assumptions, analytical methods created to predict the low velocity impact behaviour of fiber reinforced composite have limitations. We were able to resolve these difficulties with precise boundary conditions due to finite element techniques. Finite element techniques' capacity to predict composites' progressive damage and nonlinear behaviour has also been improved by the creation of interlaminar and intralaminar damage models in conjunction with continuum damage mechanics, the theory of plasticity, and fracture mechanics. The majority of the published progressive damage models for composites are based on shell elements and ignore the out of plane components (normal and shear). Under LVI, damage modelling is broken down into four main categories: models based on failure criteria, continuum damage mechanics, fracture mechanics, and theory of plasticity or yield surface. The failure envelope of damage initiation is defined in failure criteria-based models using polynomial formulas based on stress or strain. This method, however, is unable to pinpoint the location, size, and progression of fractures in composite materials. This method may be used in conjunction with 50 fracture mechanics and failure criteria to forecast progressive damage in composites. However, it needs trustworthy test results as an input.

A. Verification

Finite element analysis of the E-glass plate specimen was performed with different energy levels to predict the failure the plate. At 29.7J the failure of the laminated plate occur. From numerical simulation data, the experiment is conducted at 30J.Force-displacement curves are given in Fig.12, and experimental and numerically predicted curves are compared. As the impact event progresses, there is a similar slope until the maximum impact force is attained, which is more consistent with rising impact energy.



a) Force-Displacement b) Energy-time curve

Fig. 12. Verification

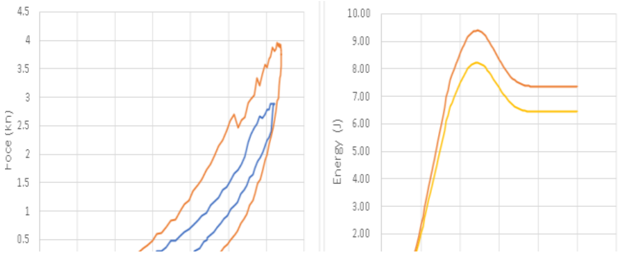
The numerical result and the experimental result correspond well, especially as the load increases. The experimental maximum force roughly matches the numerical value. When the peak load is reached and the impactor begins to rebound, the numerical result displays a little larger load value than the experimental and takes longer to reach zero.

IV. IMPACT TOLERANCE OF COMPOSITE LAMINATES

The impact tolerance of composite laminates depends on the type of composite material used, the number of layers, and the orientation of the layers. Generally, composite laminates with higher fiber content and more layers are more impact tolerant.

A. Change in ply orientation

In general, the low velocity impact of the laminates revealed that the stacking sequence had a substantial effect on the impact damage response of the laminate. The laminates absorbed energy progressively reduced after reaching the maximum energy value. This explains why the laminates' elastic potential energy is converted into impactor kinetic energy, lowering the absorbed energy. This indicates that some energy is required. Changing the ply orientation in an impact test can have a significant effect on the results. The orientation of the plies can affect the stiffness, strength, and energy absorption of the material. The impact response of cross-ply and angle-ply glass/epoxy laminates was examined in this work. The stacking sequence $[0^{\circ}/90^{\circ}]_9$ was used for cross-ply lamination and $[\pm45^{\circ}_2, 0^{\circ}/90^{\circ}_2]s$ for angle-ply lamination. The impact behaviours of the laminates at varying ply orientations and stacking sequences are shown in Figures. Figure.13 shows the energy -time and force–displacement curve for the laminates at a ply orientation of $[0/90]_9$ and $[\pm45^{\circ}_2, 0^{\circ}/90^{\circ}_2]s$.



a) Force-Displacement b) Energy-time curve

Fig. 13. Change in ply orientation

The laminates with ply orientations of $[0^{\circ}/90^{\circ}]_9$ had more energy absorption than those with ply orientations of $[\pm45^{\circ}_2, 0^{\circ}/90^{\circ}_2]s$. This condition is further explained by the fact that energy in a composite laminate may easily pass from one ply to the next if both have the same stacking sequence. When laminates with various stacking sequences are exposed to a higher stress, they have a poorer energy transfer rate and rupture.

B. Change in material properties

The effect of fibre properties was studied by comparing E-glass with carbon fibre/epoxy. By using numerical simulation, the energy-time behaviour of the carbon/epoxy laminate and E-glass/epoxy laminates were compared with each other.

Table 3: Material properties of Carbon/epoxy

Property	Carbon/epoxy
Fiber volume ratio Vf (%) 65.00	65.00
Density q (kg/m3)	1600
Longitudinal modulus E1 (GPa)	153
Transverse modulus E2 (GPa)	6.00
In-plane shear modulusG12 (GPa)	3.7
Poisson's ratio m12	0.22
Longitudinal tensile strength Xt (MPa)	2537
Longitudinal compressive strength Xc (MPa)	1580
Transverse tensile strength Yt (MPa)	82.00
Transverse compressive strength Yc (MPa)	236.00
In-plane shear strength Si (MPa)	79.00
Interlaminar shear strength S12 (MPa)	90.00

As a consequence, the composite behaviour during impact deformation is explored, and the damage energy is computed. The most influential relationships Figure 14, show the energy and time of the impactor. After the investigation of the impact effect of low-energy falling impactor on the laminar composites it has been determined that the portion of the absorbed energy in carbon / epoxy composites increased by 17.5%.

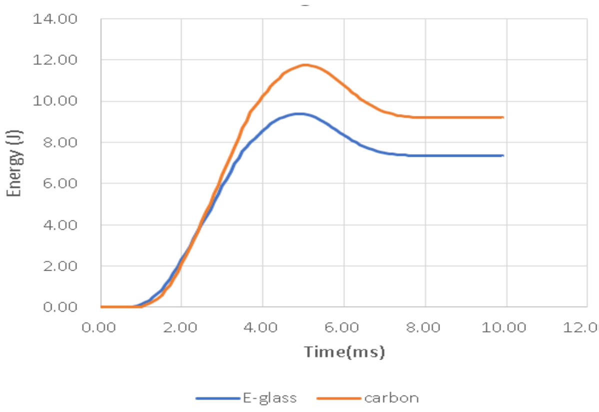


Fig. 14 Comparison of energy-time of E-glass and carbon

V. CONCLUSIONS

In this paper, a drop weight impact response of laminated glass plates was studied under the lower velocity category by using the analytical and numerical methods. Based on the published literatures, the range of the low-velocity drop weight impacts was identified as 0 – 10 m/s. The major goal of this work was to use Finite Element software to model the impact response of a thin composite target and to investigate the effects of various factors. Research was done on a composite laminate to see how it would react to impacts of various energy. Before submitting a Finite Element model to LS-DYNA, a key-file was built, updated, and loaded with boundary conditions and loads. In LS-PREPOST, the outputs were inspected, necessary results were plotted, and graphs were created. After it was discovered that the validation findings and the experimental data had a strong association, parametric investigations were carried out.

Due to their orthotropic structure, composites have a different failure criterion than metals. Different physical, thermal, and material characteristics are present in the composite materials. This may account for the impact damage and sudden loss of structural integrity. The resin that holds the fibres together is an isotropic substance that is fragile by nature. Principal stress, crush failure, and shear failure cause matrix cracking and fibre failure. Lower velocities showed a stronger tendency for delamination as the energy distribution changed with velocity.

ACKNOWLEDGEMENT

The authors would like to acknowledge B.M.S. College of Engineering, Bengaluru, India for providing necessary support and resources to conduct this study.

REFERENCES

[1] E.R.H. Fuchs, F.R. Field, R.Roth, R.E. Kirchain "Strategic materials selection in the automobile body: economic opportunities for polymer composite design". Composite Science and Technology, Vo. 69, No. 9, pp 1989-2002, 2008.
[2] Shivakumar KN, Elber W, Illg W. Prediction of low-velocity impact damage in thin circular laminates. AIAA Journal. 1985;23(3):442-9. 25.
[3] Sjoblom PO, Hartness JT, Cordell TM. On low-velocity impact testing of composite materials. Journal of Composite Materials. 1988;22(1):30-52. the mechanical equivalent of heat. Philosophical Transactions of the royal Society of London. 1850 Dec 31(140):61-82.
[4] Mili F. Effect of the Impact Velocity on the Dynamic Response of E-Glass/Epoxy Laminated Composites. Arabian Journal for Science and Engineering. 2012;37(2):413-9.
[5] Aggour H, Sun CT. Finite element analysis of a laminated composite plate subjected to circularly distributed central impact loading. Computers and Structures. 1988;28(6):729-36.
[6] Herup EJ, Palazotto AN. Low-velocity impact damage initiation in graphite/epoxy/nomex honeycomb-sandwich plates. Compos Sci Technol 1997; 57:1581-98.
[7] Hou SJ, Ren LL, Dong D, Han X. Crashworthiness optimization design of honeycomb sandwich panel based on factor screening. J Sandw Struct Mater 2012; 14(6):655-78.
[8] K. R. Jagtapa , S. Y. Ghorpadea , A. Lalb , B. N. Singhc "Finite Element Simulation of Low Velocity Impact Damage in Composite Laminates" Materials Today: Proceedings 4 (2017) 2464–2469
[9] Mehmet Aktas, Cesim Atas, Ramazan Karakuzu "An experimental investigation of the impact response of composite laminate" Composite Structures 87 (2009) 307-313.
[10] Seung JK, Kuk HJ, Seung HP. Numerical simulation of mechanical behavior of composite structures by supercomputing technology. Adv Compos Mater. 2008;17(4):373–407.
[11] Furqan A, Fethi A, Myung KP, et al. Numerical investigation to evaluate effect of fiber orientation on penetration-resistance of an aircraft composite material. Mech Adv Mater Struct. 2018. DOI:10.1080/15376494.2018.144422.
[12] Cantwell WJ, Morton J. Comparison of the low and high velocity impact response of CFRP. Composites. 1989;20(6):545-51
[13] Liu D, Malvern LE. Matrix crolsson R. Mass criterion for wave-controlled impact response of composite plates. Composites Part A: Applied Science and Manufacturing. 2000;31(8):879-87.acking in impacted glass/epoxy plates. Journal of Composite Materials. 1987;21(7):594-609
[14] LS-DYNA material volume 1& 2 (2006).