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# Finite Element Analysis of Low Velocity Impact on Woven Type GFRP Composite Laminates

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**Abstract: In this work, numerical investigation isperformed to study the behaviour of a composite laminates under low velocity impact. Woven type Glass Fibre Reinforced Polymer [GFRP] composite plates having two different thicknesses of 2 mm and 4 mm has been considered, the specimens were subjected to low velocity impact at different velocities and the impact simulation has been performed on composite plate using explicit finite element analysis software LS-DYNA. Finite element simulation has been done to calculate impact energy and maximum impact force on the laminated composite plates. Various parametric studies are performed includes boundary conditions, thickness of the laminates, lay-up sequence, mass and velocity of the impactor on the composite plate. An attempt also made to calculate the impact energy and maximum impact force using analytical methods to validate the numerical predictions.**

**Keywords— Boundary conditions, Laminate, Mass, Velocity, Impactor, lay-up sequence, LS-DYNA and Impact energy.**



## INTRODUCTION

A composite material is a macroscopic combination of two or more distinct materials, having a recognizable interface between them. Composite laminate is a combination of fiber and resin mixed in proper form. One of the unique properties of composite laminate is that, it has high specific strength. Composites are being utilized instead of metallic materials in structures where weight is a major consideration, example aerospace structures, high speed boats and trains [1]. The use of composites has evolved commonly to incorporate a structural fiber and plastic, this is known as Fiber Reinforced Plastics (FRP). Fibers provides structure and strength to the composite, while a plastic polymers holds the fiber together, common types of fibers used in FRP composite includes: Glass fiber, Aramid fiber, Carbon fiber, Boron fiber, Basalt fiber, Natural fiber etc., in case of fiber glass, thousands of tiny glass fibers are compiled together and held rigidly in place by plastic polymer resin. Common plastic resins used in composites includes: Epoxy, Polyester, Vinyl ester, Polyurethane and Polypropylene etc.

Impact is defined as “the striking of one component against another with force instantly”; it involves the collision of two bodies: the impactor and the target. During collision, an impactor indents the target and makes indentation on the plate. The knowledge of dynamic response of structure and its damage resistance is much needed to optimize the structure requiring high safety like aircraft structural applications. The majority of impact test has been carried out on a flat plate with either simply supported or clamped boundaries. The inability to visualize the internal damage of composites makes the research community to focus on the low-velocity impact phenomena stringently. Impact phenomenon is a very complicated process in which the performance depends on many parameters like duration of the impact, kinetic energy, velocity of the impactor, properties of target and the impactor materials [2].

The experimental analysis is often used to study loading, deformation and damage of composite plates. However, this method is expensive, time consuming, and requires multiple standardized test prototypes, equipment, and strongly regulated test settings [3]. A significant advantage of finite element analysis is that an advanced preliminary study can be carried out by using a virtual prototype in a virtual environment which can substantially cut costs, reduce the development time and substantially optimize the overall development process. The main objective of this paper is to investigate the behaviour of the composite plate under three different velocities by using finite element analysis software LS-DYNA. An analysis result has been compared against available experimental results from the literature survey [4].

## ANALYTICAL PROCEDURE

The Mathematical model used for present work from reference [5] is used to find maximum impact force and impact energy at different velocities is given by the equations (1) and (2) respectively.

$$\frac{1}{2} m_i v_i^2 = \left(\frac{1}{2}\frac{F_{max}^2}{K}\right) + \left(\frac{2}{5}\frac{F_{max}^{5/3}}{n_o^{2/3} R_i^{1/3}}\right) \quad (1)$$

$$\text{Energy} = \frac{1}{2} m_i v_i^2 \quad (2)$$

$$n_o = \frac{4}{3} E_2 \quad \text{for } E_i \geq E_2$$

Where,

$E_i$ = Modulus of impactor.
$E_2$ = Modulus of plate in thickness direction.
$F_{max}$ =Maximum impact force.

$m_i$=Mass of the impactor.
$v_i$=Velocity of the impactor.
$R_i$=Radius of the impactor.
K=Flexural stiffness of the plate.

## NUMERICALPROCEDURE

A woven fabric composite plate having stacking sequence of 0/90/0/90/0/90/0/90/0/90 with bi-directional configuration, having a ply thickness of 0.2mm is considered for impact analysis using explicit finite element analysis software LS-DYNA [5]. In Figure 1, Let x be the variable that describes the position of the projectile. The impact energy was calculated by using the formula:

$E = 1/2\, m_i\, v_i^2$

Where, $m_i$ is mass of the impactor, thickness of the composite plate is taken as h and$v_i$ is the impact velocity measured before impact event.

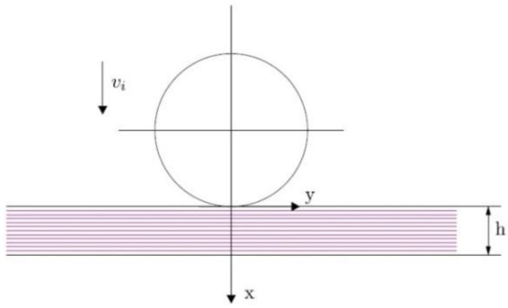


Fig. 1:Impactor and target configuration setup

The number of layers on both 2 mm and 4 mm thicknesscomposite plate is as shown in table 1. The values were adopted from experimental data used as per the work presented in reference [1]. The failure mechanism of the GFRP composite laminates under low velocity impact depends on several factors such as strength of the composite plate, velocity and mass of the impactor, boundary conditions which are applied to the model.

TABLE 1: DIMENSIONS AND NUMBER OF LAYERS

| Material | Dimension of the component in mm | No. of Laminates | |
|---|---|---|---|
| | | 2mm thickness | 4mm thickness |
| GFRP | 150×50 | 10 | 20 |

## FINITE ELEMENT SIMULATION

The finite element simulation was done to analyse the impact phenomenon. The glass fiber reinforced polymer composite laminates were modelled and meshing by using software known as HYPERMESH. All the four sides of the specimen were fixed in x, y and z directions and orthotropic material was selected for modelling the material, the laminates were impacted at the centre of the composite plate by a steel impactor having a spherical tip of 10 mm in diameter and a weight of 15.69 N has been used. The material properties of the impactor and composite plate are as shown in table 2 and 3 respectively.

Table 2: Impactor properties

| Young's modulus | Poisson's ratio | Density |
|---|---|---|
| 210 GPa | 0.3 | 7800 Kg/$mm^3$ |

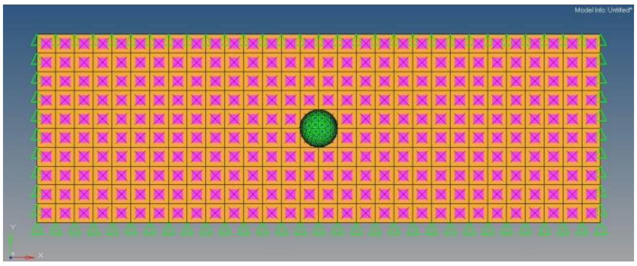

Fig.2: HYPERMESH model

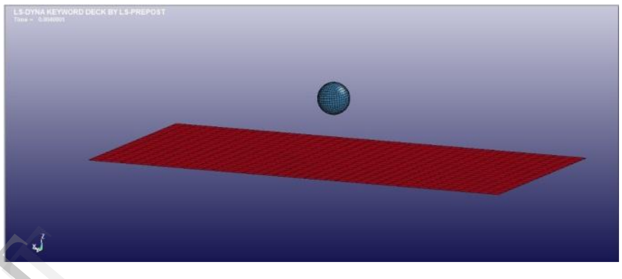

Fig. 3: LS-DYNA Simulated model

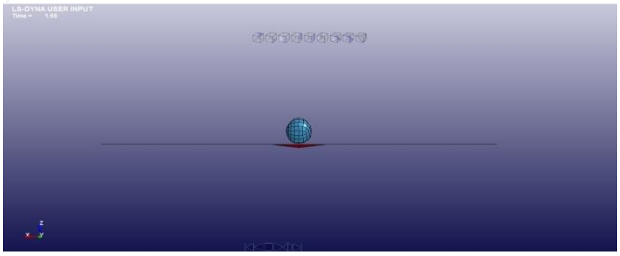

Fig. 4: LS-DYNA deformed model

The impactor is allowed to move only in z direction and treated as a rigid body. An automatic surface to surface contact condition is assigned between the composite target and impactor to accommodate impact initiation and progress. Time step is one of the most important parameter, which normally causes divergence in non-linear finite element analysis. By choosing an adequate time step value simulation has been done [7]. By taking an example of composite plate of 2 mm thickness and was subjected to a velocity of 3.132 m/s is as shown in Figure 2 and was prepared by using pre-processing software known as HYPERMESH. Here LS-DYNA program manager was used as a processor to solve the problem and LS-PrePost was used as post processing software, where we can see the displacements, stress results and deflection animations [8]. Figure 3 shows the simulated model of impact analysis and figure 4 shows the deformed shape of the composite plate.

Table 3: Composite plate properties

| | | |
|---|---|---|
| Young's Modulus in GPA | $E_{11}$ | 20.8 |
| | $E_{22}$ | 20.8 |
| | $E_{33}$ | 8.7 |
| Shear Modulus in GPa | $G_{12}$ | 3.92 |
| | $G_{23}$ | 4.2 |
| | $G_{31}$ | 4.2 |
| Poisson's Ratio | $\gamma_{12}$ | 0.173 |
| | $\gamma_{23}$ | 0.28 |
| | $\gamma_{13}$ | 0.28 |
| Density in Kg/$m^3$ | $\rho$ | 1750 |

## RESULTS AND DISCUSSION

Analytical calculations and numerical analysis has been done to a Glass Fibre Reinforced Polymer [GFRP] laminates havinga two different thickness of 2 mm and 4 mm were subjected to low velocity impacts at three different velocities(3.132, 4.429 and 5.425 m/s). The obtained results were compared against experimental values.The Comparison between them is illustrated in Table 4 and Table 5.

Table 4: Result comparison on 2 mm thickness plate

| Max. force in Newton's | | | Impact Energy in Joules | | |
|---|---|---|---|---|---|
| Analytical | Numerical | Exp. | Analytical | Numerical | Exp. |
| 1780 | 1760 | 1822.5 | 7.85 | 7.9 | 7.696 |
| 1920 | 1890 | 1755 | 15.7 | 14.01 | 13.01 |
| 2129 | 2040 | 2016 | 23.54 | 21.07 | 22.275 |

Table 5: Result comparison on 4 mm thickness plate

| Max. force in Newton's | | | Impact Energy in Joules | | |
|---|---|---|---|---|---|
| Analytical | Numerical | Exp. | Analytical | Numerical | Exp. |
| 2189 | 2190 | 2245.5 | 7.85 | 8.9 | 7.729 |
| 3480 | 3389 | 3550.5 | 15.7 | 16.13 | 15.547 |
| 4019 | 4209 | 4113 | 23.54 | 24.94 | 23.352 |

Validation of results was demonstrated by comparing numerical, analytical and experimental values are plotted in a graph is as shown in figure 5 and 6.

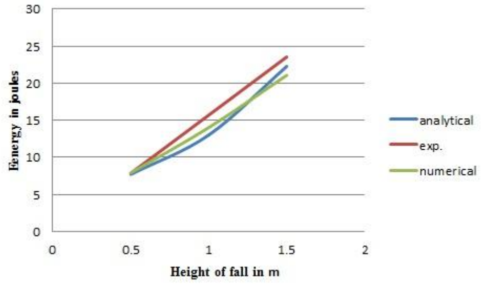


Fig. 5: Plotted results for 2mm thickness plate

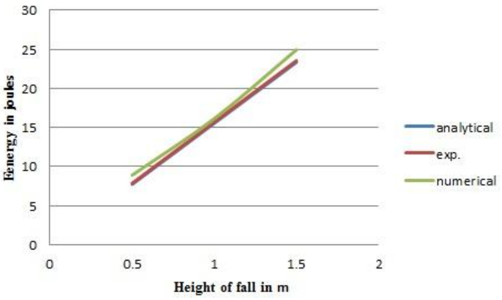


Fig. 6: Plotted results for 4mm thickness plate

## CONCLUSION

Numerical analysis was performed to study the behaviour of glass fibre reinforced polymer composite laminates under low velocity impact using explicit finite element analysis software LS-DYNA. Numerical and analyticalresults were comparedagainst available experimental results from the literature survey in terms of maximum impact force and impact energy. The difference between the numerical, experimental and analytical results were less than 10%, thus results were within a reasonable range of prediction. It is further concluded that thickness of the composite plate plays an important role on the deflection of the plate.



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