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# Numerical Study on the response of Sandwich Composite Plates with Foam Core and Different Skin Thicknesses to various impact Energy Levels

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***Abstract*** **- This study investigates numerically the impact response of sandwich composite plates with constant core thickness and different skin thicknesses to various impact energy levels. According to the extent of deformation, the damages are classified as Visible Impact Damage (VID) Barely Visible Impact Damage (BVID) and Low-Level Damage (LLD). A unidirectional carbon fiber reinforced polymer and a Rohacell® PMI closed cell foam are used as the skin and core respectively in the sandwich construction. An explicit finite element model is developed for the sandwich plate in ANSYS workbench and in the proposed model the initiation of damage has been predicted using Hashin damage criteria. The various impact parameters like dent depth, contact force, absorbed energy are calculated. Dent depth and absorbed energy show a bilinear relationship with the impact energy. It has been found from the analyses that there are shifts in damage mechanisms, when the energy level changes from LLD to VID. The experimental findings show good agreement with the numerical results.**

*Index Terms* – Sandwich composites, non-crimp fabric, VID, BVID, LLD, Hashin damage criteria, numerical simulation

## INTRODUCTION

A sandwich composite is a special type of composite material in which two thin but stiff skins are attached to a lightweight but thick core [1]. Due to their high stiffness and strength to weight ratios, sandwich composites are used nowadays in marine applications like hulls of ships & boats, frames, keels, mast etc. Sandwich composites with skins made out of Carbon fibre reinforced epoxy are usually used in boat hulls cored with honeycomb or foam. In a sandwich composite structure, in-plane loads and the bending are carried by the face-sheets(skins), whereas core material carries the transverse loads [2]. The sandwich structures will be subjected to high and low velocity impacts during their life time. Even when trivial harm is induced, it may compromise the structural integrity of the applications [3,4]. The writings of Abrate [5], Shipsha et al. [6] and Reid and Zhou [7] have given some insights in to the effects of dynamic loads on sandwich constructions. In recent years a lot of studies have been done in this field. Zenkart et al. [8] studied impact damages on sandwich panels made of CFRP skins and found that even if sharp or blunt impactors are used, the impact damage would reduce the compressive load carrying capacity of the skin and it could be a significant reduction

On the basis of impactor velocity, the impact problems are classified in to low velocity impacts (LVI) and high velocity impacts [9]. If the impactor velocity is between 1 to 10 m/s, (e.g., tool drop) then it can be considered as a low velocity impact [10] and can be replicated using a falling weight apparatus. However high velocity impacts (e.g., runway debris, small arms fire) can be tested using a gas gun. The authors in their previous study [11] investigated the effects of impactor shape and core characteristics on the high velocity impact response of marine sandwich composites

Some of the studies in which the impact response of carbon fibre reinforced composite structures and laminates were done experimentally and numerically are given in [12]-[14]. In these studies, it was observed that fiber rupture, delamination, matrix crushing and matrix cracking were the common methods of failure due dynamic loading on the composite bodies. Sutherland [15] in his review paper presented a lot of works, mostly related to dynamic impact on composite materials in the marine sector.

In their study, Anderson and Madenci [16], found that sandwich composites with honeycomb cores showed significant damage compared to foam cored specimens. Xia et al. [17] studied low velocity impact performance of sandwich composites with foam cores, in combination with several skins such as Kevlar, carbon etc

However, there are only few research papers related to the study of sandwich composites subjected to low velocity impact, and having foam cores and with varying skin thicknesses. These researches are significant in the case of applications like boat and ship hulls, where the skin thickness of the sandwich plates can be varied as per the requirement. Rajput et al. [18] recently has done an experimental study associated to the response of sandwich composite laminates having different skin thicknesses to a range of impact energy levels. In their research, to obtain the low velocity impact response a drop weight impact test apparatus has been used. A Rohacell® core and carbon fiber skins are used in the sandwich construction. They have conducted a pilot study in which the sandwich plates were tested with impactors of various energy levels to recognize when visible impact damage (VID), barely visible impact damage (BVID) and low-level damage (LLD) occurs. The variables like absorbed energy, deflection, peak contact force and dent depth are found out.

In the current study, the authors numerically investigate how the response varies when sandwich composites with varying skin thicknesses and constant core thickness undergo low velocity impact. The experimental set up used in [18] are numerically simulated using ANSYS software. Finally, comparison of the experimental and numerical results is done and conclusions are made from the findings

## MATERIAL SPECIFICATIONS

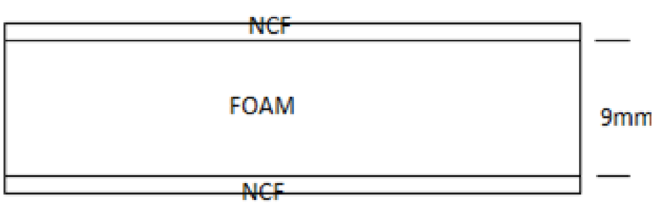


FIGURE 1

SCHEMATIC DIAGRAM OF THE SANDWICH COMPOSITE

The schematic illustration of the composite plate is given in figure 1. In the present study the core material used is having a constant thickness but the skin(face-sheet) thickness differs. In the current study three types of skin thicknesses are used. The face-sheet is manufactured using uni-weave carbon fiber non-crimp fabric (NCF) and the face-sheet lay-up is $[0/45/90/-45]_n$, where n = 2, 3 or 4. The epoxy, which is the resin used, functions also as an adhesive among the skin & the core. And the core is constructed with a Rohacell® Polymethacrylimide(PMI) closed cell foam material. For the tested specimens, all the samples are having a 9mm thick core at the middle but there are three different skin thicknesses i.e., 1.6, 2.4 and 3.1 mm. The three different sandwich types used for testing will be referred as S1(1.6/9/1.6), S2(2.4/9/2.4) and S3(3.1/9/3.1) hereafter. From previous studies [18,19] the material properties of the composites are collected.

The material properties of the NCF skin and Rohacell® core are displayed in tables I & II respectively.

TABLE I

MATERIAL PROPERTIES OF NCF COMPOSITE

| | |
|---|---|
| Density (Kg/m$^3$) | 1560 |
| E1 (GPa) | 136 |
| E2 (GPa) | 9.30 |
| E3 (GPa) | 9.30 |
| $\mu_{XY}$ | 0.28 |
| $\mu_{YZ}$ | 0.28 |
| $\mu_{XZ}$ | 0.28 |
| G1 (GPa) | 4.40 |
| G2(GPa) | 3.40 |
| G3(GPa) | 3.40 |
| $X^T$ (MPa) | 1790 |
| $X^C$ (MPa) | 631 |
| $Y^T$ (MPa) | 29 |
| $Y^C$ (MPa) | 130 |

TABLE II

MATERIAL PROPERTIES OF ROHACELL CORE

| | |
|---|---|
| Density (Kg/m$^3$) | 205 |
| Tensile modulus (MPa) | 389 |
| Compressive modulus (MPa) | 350 |
| Shear modulus (MPa) | 109 |
| Compressive strength (MPa) | 7.1 |
| $\mu$ | 0.3 |

The composite specimen size for the numerical study is 150 mm X 100 mm. The particulars of the tests are shown in table III

TABLE III

TEST DETAILS

| Composite configuration |
|---|
| S1(1.6/9/1.6) |
| S2(2.4/9/2.4) |
| S3(3.1/9/3.1) |

The steel impactor used in all the cases is having a hemispherical shape at the end and is 16 mm in diameter. The total impactor mass remains constant at 3.04 Kg

## ENERGY LEVELS OF IMPACT

In the present study, 0.15 mm residual indentation dent depth is taken as low-level damage (LLD), 0.30 mm as the barely visible impact damage (BVID) & 0.60 mm as the visible impact damage (VID) as per [18]. For the numerical simulation impact energies ranging from 3 to 5J i.e., impact velocities of 1.5 to 4.2 m/s are used

## NUMERICAL SIMULATION

*I. Failure model*

For numerical studies the most commonly used material model for composite materials has been proposed by Hashin [19,20]. The damage initiation criteria proposed by Hashin for composites are given below

*Fiber tension ($\sigma_{11} \geq 0$)*

$$\left(\frac{\sigma_{11}}{X^T}\right)^2 + \alpha\left(\frac{\sigma_{12}}{S^L}\right)^2 = 1 \qquad (1)$$

*Fiber compression ($\sigma_{11} < 0$)*

$$\left(\frac{\sigma_{11}}{X^c}\right)^2 = 1 \qquad (2)$$

*Matrix tension ($\sigma_{22} \geq 0$)*

$$\left(\frac{\sigma_{22}}{Y^T}\right)^2 + \left(\frac{\sigma_{12}}{S^L}\right)^2 = 1 \qquad (3)$$

*Matrix compression ($\sigma_{22} < 0$)*

$$\left(\frac{\sigma_{22}}{2S^T}\right)^2 + \left[\left(\frac{Y^c}{2S^T}\right)^2 - 1\right]\left(\frac{\sigma_{22}}{Y^c}\right) + \left(\frac{\sigma_{12}}{S^L}\right)^2 = 1 \qquad (4)$$

Here $X^T$ and $X^C$ are the longitudinal tensile and compressive strengths in the fibre direction, respectively, and $\sigma_{ij}$ is the effective stress tensor. The transverse tensile and compressive strengths in the matrix direction are $Y^T$ and $Y^C$, respectively, while the longitudinal and transverse shear strengths are $S^L$ and $S^T$, respectively, and the contribution of shear stress in the fibre tension criterion is described by $\alpha$

*II. Finite element impact model*

In ANSYS workbench, a finite element low velocity impact (LVI) model is generated for each of the three composite plate configurations. Ansys Composite Prep Post (ACP), a dedicated tool for composite layup modelling and failure analysis, is used for generating the different layers of the sandwich composite plate model. The bottom and top skins consist of 0.1mm thick individual plies arranged as bundles to arrive at the skin thicknesses required. Plies are arranged at 0/45/90/-45 angles. The impactor shape is hemispherical and is modelled with discrete rigid elements. A meshed view of the bullet hitting the target is shown in figure 2. At the tip of the projectile fine meshes are used to accurately simulate the impact problem. Mesh independent study is conducted to arrive at the optimum mesh size. Figure 3 shows the plate deformation during the impact.

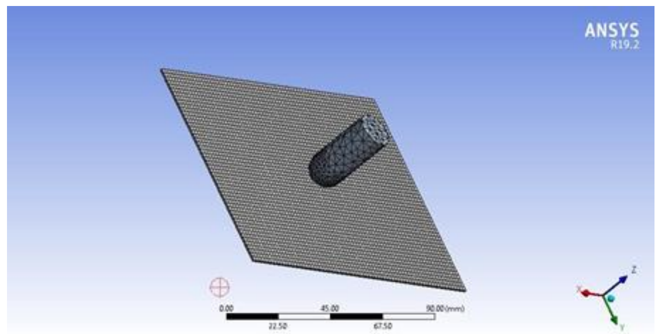


FIGURE 2
MESHED VIEW OF THE PROJECTILE AND THE TARGET

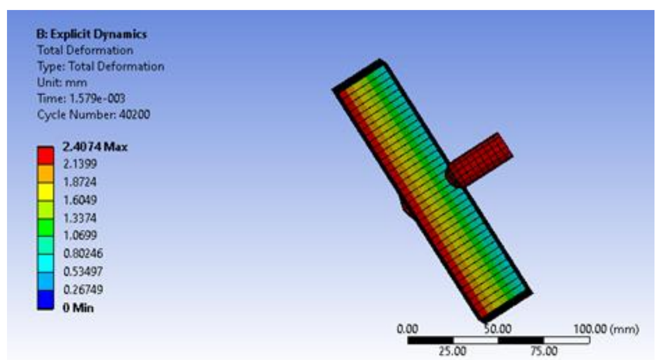


FIGURE 3
PLATE DEFORMATION DURING THE IMPACT

## RESULTS AND DISCUSSION

Table IV shows the various test configurations and the corresponding impact test results. The impact of various parameters will be addressed in the following parts.

*I. Dent depth against impact energy*

How the dent depth changes with impact energy are exhibited in figure 4. The figures 4(a), 4(b) and 4(c) display the variation of dent depth as impact energy changes for the configurations S1, S2 and S3 respectively. As expected, the dent depth is increased with the increment in energy of impact. A bilinear relationship is evident in all the three cases between dent depth and impact energy. It can be inferred from the graphs that, at BVID energy level the onset of excessive damage starts. So, after BVID dent depth increases rapidly with increase in impact energy. Also, the energy required to produce the equal dent depth varies amongst the sandwich arrangements since they have different face-sheet thicknesses.

TABLE IV

IMPACT TEST RESULTS

| Sandwich Configuration &Identified energy levels | Impact energy [J] | Impact velocity [m/s] | Dent depth [mm] | Maximum contact force [kN] | Energy absorbed [J] |
|---|---|---|---|---|---|
| S1(1.6/9/1.6) | | | | | |
| LLD | 4.100 | 1.642 | 0.15 | 6.64 | 1.59 |
| | 5.160 | 1.842 | 0.21 | 6.52 | 2.10 |
| BVID | 6.900 | 2.131 | 0.30 | 6.86 | 2.60 |
| | 8.070 | 2.304 | 0.48 | 7.04 | 3.70 |
| VID | 9.000 | 2.433 | 0.60 | 7.38 | 4.82 |
| S2(2.4/9/2.4) | | | | | |
| LLD | 5.310 | 1.869 | 0.15 | 9.19 | 2.23 |
| | 8.320 | 2.340 | 0.23 | 9.24 | 3.04 |
| BVID | 11.10 | 2.702 | 0.30 | 9.39 | 3.27 |
| | 13.00 | 2.924 | 0.45 | 9.60 | 4.87 |
| VID | 14.20 | 3.056 | 0.58 | 10.38 | 5.61 |
| S3(3.1/9/3.1) | | | | | |
| LLD | 8.170 | 2.318 | 0.17 | 11.46 | 6.93 |
| | 13.20 | 2.947 | 0.22 | 12.60 | 7.59 |
| BVID | 18.10 | 3.451 | 0.25 | 13.19 | 8.2 |
| | 21.00 | 3.717 | 0.46 | 14.13 | 9.91 |
| VID | 23.00 | 3.890 | 0.70 | 14.48 | 11.35 |

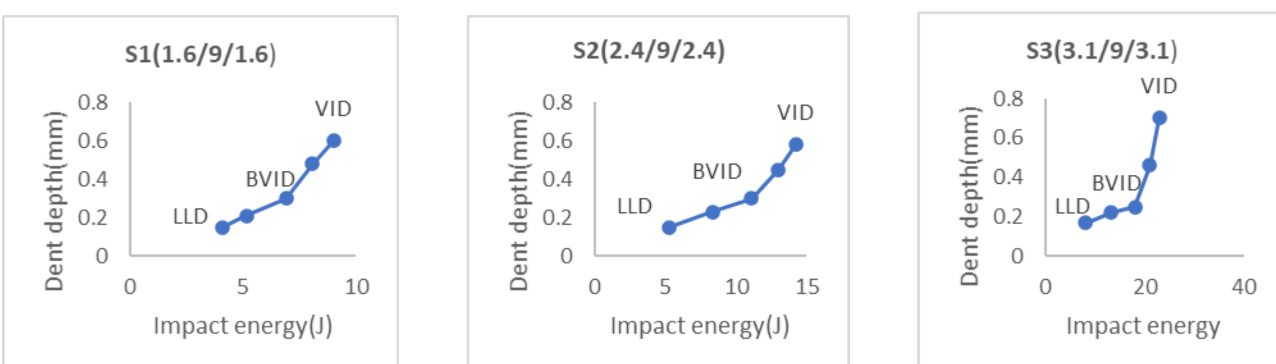


FIGURE 4(a) FIGURE 4(b) FIGURE 4(c)

FIGURE 4
DENT DEPTH AGAINST IMPACT ENERGY

*II. Significance of skin thickness on absorbed energy*

The variation of peak absorbed energy with respect to the impact energy is displayed in figure 5. The figures 5(a), 5(b) and 5(c) show the variation of absorbed energy for the configurations S1, S2 and S3 respectively. Delamination, core crushing, matrix destruction and fiber breakage consume a large portion of the energy absorbed. When the impact energy increases, absorbed energy also increases. Also, the energy absorbed displays a bilinear trend, like in the case of dent depth versus impact energy graphs. At BVID level this shift happens and it is clearly evident in the graphs. It appears that, after BVID level more severe damage occurs. More over comparing S1, S2 and S3, it is obvious that the amount of absorbed energy increases with respect to the skin thickness increment. That means to reach LLD, BVID and VID more energy is required when the thickness of the skin increases from S1 to S2 and then from S2 to S3.

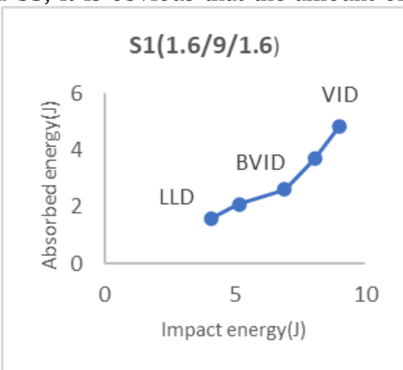


FIGURE 5(a)

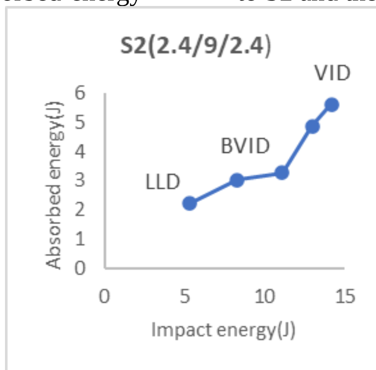


FIGURE 5(b)

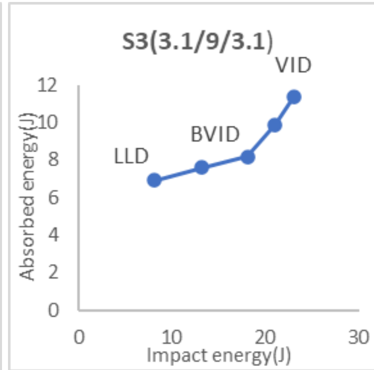


FIGURE 5(c)

FIGURE 5
ABSORBED ENERGY AGAINST IMPACT ENERGY

*III. Peak contact force and impact energy*

The figure 6, figure 7 and figure 8 show the force vs time response of certain impact events from the S1 configuration.

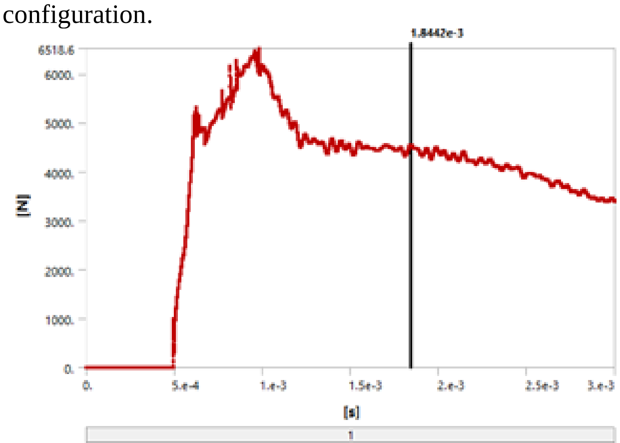


FIGURE 6
FORCE AGAINST TIME FOR LLD

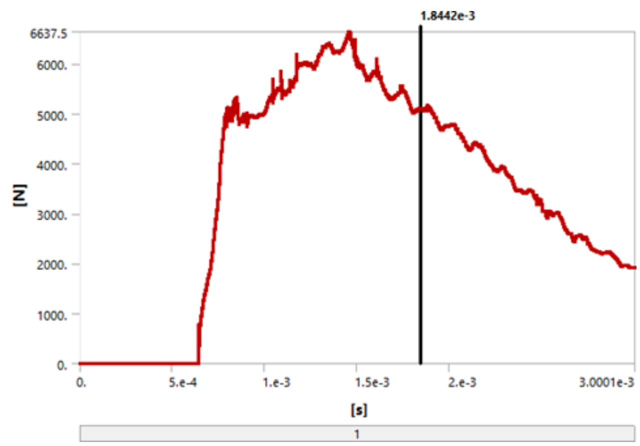


FIGURE 7
FORCE AGAINST TIME FOR BVID

Fig.6 shows the variation of force with respect to time for an LLD impact event, fig.7 shows for a BVID impact event and fig.8 shows the same response for a VID damage case. Only graphs of S1 configuration are shown here. Nearly elastic response can be seen in all the three cases selected. Maximum contact force increases from LLD to VID. For other configurations also, the trend is the same as evident from table 4.

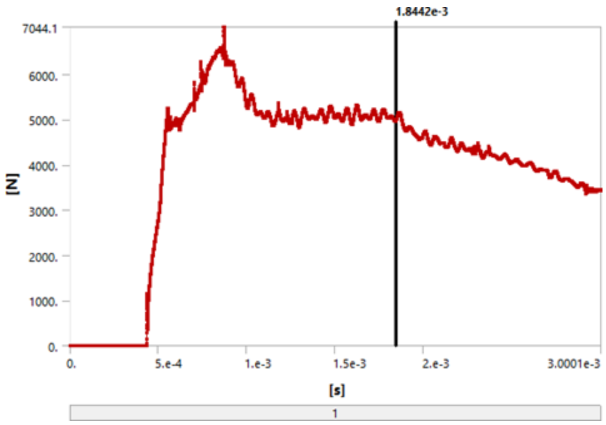


FIGURE 8
FORCE AGAINST TIME FOR VID

*IV. Comparison of experimental and numerical findings*

The comparison of experimental findings from [18] and numerical results from the current study are done in this section. Figure 9 and Figure 10 show the comparison between experimental and FEM values of dent depth and absorbed energy for the selected cases. Only S1 case is shown here. Other configurations are also showing the same trend. From fig.9 and fig.10 it is clear that generally numerical and experimental values are showing a good agreement.

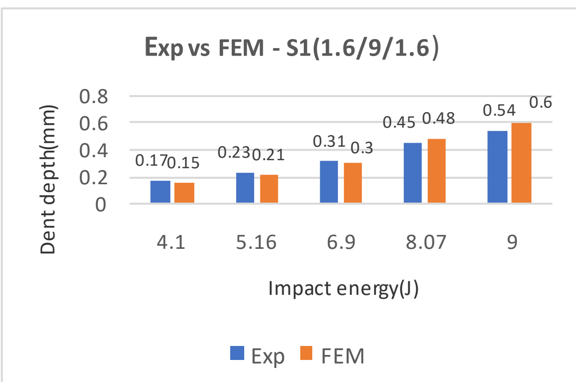


FIGURE 9
DENT DEPTH- EXP. VS FEM

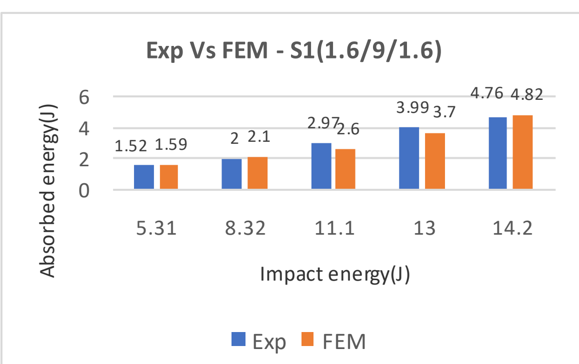


FIGURE 10
ABSORBED ENERGY- EXP. VS FEM

## CONCLUSION

A finite element low velocity impact model is developed incorporating various damage criteria and the impact parameters absorbed energy, dent depth and contact force are found out numerically. It is observed that there is a shift in the level of damage at BVID impact level and excess damage starts at BVID level. It is observed that during impact, energy is absorbed in the form of cracks, delaminations, fiber damage and core crushing. But after BVID energy level, the degree of core crushing and fiber damage are more predominant. This explains the bilinear nature of the dent depth and absorbed energy graphs. The numerical model used in the study predicts the impact phenomenon quite well and there for can be used for further parametric studies

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