Investigation on effect of using rubber as core material in sandwich composite plate subjected to low velocity normal and oblique impact loading.

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Abstract. In this article, the structural performance of composite plate under low velocity impact is studied. Two forms of layup sequence namely jute-epoxy laminate (JE) and jute-epoxy-rubber sandwich (JE-R-JE) are considered for evaluation. Special emphasis is provided for evaluating the influence of normal and oblique loading. The various dynamic parameters such as energy, peak load, and deformation are analysed in detail to study the effect of impact angle on both laminate and sandwich. Stress analysis of both the laminate and sandwich structure is carried out to discuss the effect of introducing rubber as a core material. The results reveal that using rubber as a core material has a significant effect on energy absorption. In addition, it is noticed that increasing the angle of impact yields better performance of the composite plate. The results presented here may serve as benchmark for the effective utilization of composite plates in low velocity impact applications.

Keywords: jute epoxy; low velocity; oblique impact; finite element (FE) simulation; sandwich composite; rubber core

1. Introduction

In the automotive industry, the focus nowadays is shifted towards reducing the weight of the components that indirectly gives economy in fuel consumption. Composites are replacing the conventional metal and alloys in structural and semi structural applications due to their enhanced mechanical properties over conventional materials like aluminium and steel with high sp. strength and stiffness combined with better corrosion resistance.

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Cladding panels are used to protect some of the primary structures in automobiles. Off road and off highway vehicles need to travel more on the gravel surfaces. The components like fuel tank located in the bottom portion of such vehicles during their operation may be subjected to impact loading by the gravel or flying debris. The impact caused by flying debris may result in extensive damage to automobile body and its components. Such damage, if caused to the component like fuel tank may result in leakage of fuel from the tank and if it is not noticed, may be a serious threat. In order to protect the components from such impact, the cladding panels may be incorporated which can resist such impacts and thereby avoids possible damage.

The study carried out by Shah [1] and Michael et al. [2] showed that reinforcing natural fibers in polymer composites has been practiced commonly over the last decade because of the promising properties like high sp. stiffness and lower environmental impacts they provide. An extensive study by Omar et al. [3] and Libo et al. [4] showed that the natural fibers are considered as replacements for manmade glass fibers in structural and semi structural applications which are becoming increasingly common in transportation and sport goods industries. For the purpose of absorbing energy during an impact event polymer matrix composites reinforced with natural fibers are widely studied by Fahmi et al. [5], Andrez et al. [6] and Neng et al. [7].

Natural rubber is a material that is abundantly available in nature and using it as a matrix material provides numerous advantages like low cost, ease of availability, biodegradability. Stelldinger et al. [8] showed that by integrating the rubber layer in a composite laminate, significant improvement in impact damage resistance can be achieved. Structural or semi structural components during their operation are subjected to impact loading ranging from low to high velocity. Kabir et al. [9] said that Projectile induced impacts can be classified as low and high velocity according to projectile mass and velocity. Regimes of velocity classify any velocity up to 10 m/s as low velocity, 100-1000 m/s as high velocity and anything greater than 2 km/s as hyper velocity. There also exists intermediate velocity between 10-100 m/s which some researchers argue belonging to low velocity and some as high velocity. Though many researchers have studied the impact behaviour of composites, still it is not completely comprehended as concluded by Aktay et al. [10] and Brenda et al. [11]. Sjoblom et al. [12] and Shivakumar et al. [13] proposed that low velocity impact events can occur in the range 1–10m/s depending on the target stiffness, material properties, impactor mass and its stiffness. They usually occur during manufacturing and maintenance of the structural or semi structural components due to striking of another part, tool drop or during operation of the part like the striking of gravel, debris, spall from the explosion etc.
Behavior of composites subjected to normal impact loading has been studied by many researchers. However, in real life engineering applications, the components are rarely subjected to normal impacts. Instead, they are subjected to oblique impacts. Rebounding of the projectile can occur depending on the angle at which it impacts the structure or target. Sadeghzadeh et al. [14] studied the effect of impact velocity and impact angles on impact dynamics of graphene nano sheets in collision with metallic nano particles. Based on available literature, it was found that there are hardly any studies available on composites fabricated with low cost naturally available materials subjected to oblique impact loading under low velocity.

Despite abundant work on impact behaviour of composites and other materials, the opportunity of exploring the potentiality of rubber as an energy absorbing material under low velocity impact is hardly focused upon. The objective of the present study is to investigate the low velocity normal impact and oblique impact behaviour of jute-epoxy laminate (JE) and jute-epoxy-rubber (JE-R-JE) sandwich composite at various oblique angles along with normal impact. Yazdani et al. [15] proposed that due to the high cost and time involved in testing, using numerical method is inevitable and since the present study is a preliminary step aimed at exploring the usage of new material for energy absorption application under low velocity impact, analysis is performed using finite element method (FEM). The study has been carried out for various angles of impact (0⁰, 5⁰, 10⁰, 15⁰, and 20⁰).

2. Validating Analysis Model and Mesh Convergence

This section deals with verifying the methodology adopted for low velocity impact analysis of composite plates. An example of study made by Karas [16] is taken as a reference to validate the finite element (FE) method employed in the present study. The same methodology was employed by Hyunbum [17] to validate his study on graphite-epoxy composite. To this end, the numerical example considered by [16] is reproduced with the aid of present methodology.

2.1 Comparison of analysis results with study made by Karas [16]

A study on low velocity impact behaviour on a steel plate of dimension 0.2 x 0.2 x 0.008 m was carried out by [16] in which the four edges of the plate were fixed and plate is subjected to impact loading at a velocity of 1m/s. The model of the steel plate, the ball used for impacting the plate and their meshing is as shown in Figure 1(a)-(b). The 2D shell element and 3D solid element were used to mesh the plate and ball with 11,680 and 850 elements respectively. In order to carry out the mesh convergence study, three different sizes of mesh were
chosen as 2mm, 1.5mm and 1mm. Figure 2(a)-(b) shows the comparison of the results carried out by [16] and the present study with various mesh sizes of 2 mm, 1.5 mm and 1 mm. It can be concluded by comparing the graphs of contact force against time and deformation against time that the present study closely matches with the study made by [16] for a mesh size of 1 mm. Hence it is concluded that the finite element method applied in this study has validity with a mesh size of 1 mm.

3. Modeling

The numerical simulation of the present study is carried out using ANSYS WORKBENCH commercial software. The procedure adopted in the study of current modelling has been validated with the procedure provided by [16] for normal impact loading and the results of oblique impact loading has been compared with normal impact loading as followed earlier by Meybodi et al. [18].

The schematic representation for the normal and oblique impact of the JE laminate and JE-R-JE sandwich model considered for the present study are shown in Figure 3 and 4, respectively, where all the dimensions represented are in mm. The dimensions of Laminate and sandwich are chosen as 100 mm x 150 mm according to ASTM D7136/D7136M standard. The thickness of the laminate is considered as 12 mm, face sheets as 3 mm each and core as 6 mm in the sandwich. The oblique angle is defined as the angle between axis of the impactor and normal to the plate.

3.1 Finite Element Model

The meshing details and modelling of JE laminate and JE-R-JE sandwich used for both normal and oblique impact analysis is as shown in Figure 5(a)-(e). The size of the element chosen for meshing is 1 mm with a Quad type of mesh for laminate and sandwich and tetrahedral element for impactor. The mesh convergence study was carried out to ensure the mesh refinement was sufficient to obtain the results with reasonable accuracy. The total numbers of elements used for laminate and sandwich are 61,056 and for impactor are 1560. The impactor considered is hemispherical impactor of radius 6.5 mm and is made up of steel citing the work carried out by Balasubramani et al. [19].

Figure 6a shows the meshing of JE laminate and Figure 6b shows the meshing of JE-R-JE sandwich. Figure 6(c) and (d) shows the boundary conditions applied to laminate and sandwich along with impactor respectively. The boundary condition applied to the laminate and sandwich structure is fixed support on the edges of the sandwich structure as well as on the four side faces and the impactor is given a velocity of 10 m/s. The model is
meshed using shell type element. It was assumed that there is a perfect bonding between face sheet and core and surface to surface contact relations were defined at the face sheet core interface using contact conditions. During the contact between impactor and sandwich the friction between impactor and the sandwich was neglected. The impactor was modelled as a rigid body and its motion was governed by the rigid body reference node. The material properties of structural steel used for the impactor and rubber used for core are predefined in commercially available software and is given in Table 1. Hashin’s failure criterion is used for the purpose of analysis. The initial velocity assigned to the impactor is 10 m/s and it is constrained only to move in Z direction. Explicit dynamic analysis type is selected to perform the low velocity impact test on laminate and sandwich structure. The laminate and sandwich structure is defined as flexible material and impactor as rigid material. Based on the work carried out by Balasubramani et a. [19], Stuart [20], Mir et al. [21] and Hossain et al. [22], the material properties of jute-epoxy used for analysis are drawn and tabulated in Table 2.

4. Results and Discussion

The current modelling has been validated with the procedure provided by [16] for normal impact loading and the results of oblique impact loading has been compared with normal impact loading as followed earlier [18].

4.1 Contact Force

Peak contact force is of great importance in impact loading as it can control damage initiation. The higher the peak load, the damage initiation is earlier. For all the tested angles (0⁰, 5⁰, 10⁰, 15⁰, and 20⁰) on JE laminate the graph of contact force as a function of time is shown in Figure 7(a) and the same for JE-R-JE sandwich is shown in Figure 7(b). All the curves show same trends where the loading and unloading parts of curve are smooth. The duration for which the impactor is in contact with a sandwich is studied from the graph. Till the point of initiation of damage or peak load, the variation of force with time is linear. The point where the failure is just initiated on the graph is referred to as the maximum load carrying ability. This point was called as incipient point of damage by Siow et al. [23] which is usually a matrix failure. The extent of damage is very little or no visible damage. Due to this there is a drop in the magnitude of force showing reduction in stiffness of the material. Penetration and perforation damages are the results of a combination of such failures. The peak load for JE laminate and JE-R-JE sandwich is tabulated in the Table 3. The tabulated results show that the peak load will be more in laminate when compared to sandwich structure for any given case of loading, indicating earlier damage initiation in laminate compared to the sandwich. The contact force histories also conclude that
with increasing in angle of impact, there is a reduction in peak contact force. The descending part of the unloading is due to continuous loading beyond the peak point where there is a continuous progression of damage to the structure and thus a reduction in the contact force. Therefore the major mode of failure for this impact loading scenario is due bending stress.

4.2 Energy

Gathering knowledge about ability of composite to absorb energy under impact loading is very important and it is the critical parameter studied by most of the researchers. The energy absorbed by the composite is obtained by the difference between initial and final kinetic energy of impactor as given by Eq. (1).

\[ E_a = E_{KE}^I - E_{KE}^R \]  

(1)

The variation of kinetic energy with respect to time for various loading conditions on JE laminate and JE-R-JE sandwich is as shown in Figure 8(a) and (b), respectively. For illustrating the variation of kinetic energy against time during an impact event, the case of normal impact in a laminate is considered. It can be noted from Figure 8(a) that for all types of loading conditions the kinetic energy of impactor reaches zero at some point of time and after that the kinetic energy increases. With the increase in impact angle, the time at which the kinetic energy becomes zero increases and also the residual kinetic energy decreases and hence the residual velocity also decreases. For illustrative purpose, the normal impact loading case in JE laminate is considered. In stage I, kinetic energy (KE) of the impactor is dropping rapidly after contact with laminate, which is transformed into internal energy of the laminate. At stage II, Kinetic energy of the impactor becomes zero at the lowest position. At the same time, internal energy (IE) of the laminate becomes the largest. As impact continues, kinetic energy of the impactor increases again with rebound of the impactor, which is stage (III). At the end of the impact event, the impactor is separate from the laminate with a constant rebound kinetic energy or residual kinetic energy \( E_{KE}^R \). The same concept applies to all the loading conditions in laminate as well as sandwich. The residual velocity of the impactor is calculated using the Eq. (2)

\[ V_R = \sqrt{\frac{2E_{KE}^R}{m}} \]  

(2)

Where \( V_R \) is the residual velocity, \( m \) is the mass of the impactor in Kgs. The volume of the impactor is found to be 3.62x10^{-5} m^3. Using the volume, according to Eq. (3), the mass of the impactor is calculated as 0.28 Kg.
\[ m = \rho \times \text{vol} \quad (3) \]

It can be seen from the energy history curve with respect to time that as the impact angle increases, the final energy of impactor i.e. residual kinetic energy decreases. This means that the growth of impact angle leads to increase in energy absorption. The initial kinetic energy, residual kinetic energy, residual velocity of the impactor and the energy absorbed by the laminate are tabulated in Table 4.

The initial kinetic energy, residual kinetic energy, residual velocity of the impactor and the energy absorbed by the sandwich are tabulated in Table 5. As the angle of impact increases, the residual kinetic energy and residual velocity of impactor decreases and the energy absorbed by laminate and sandwich increases. Thus, it can be concluded that as the impact angle increases the energy absorption increases and also JE-R-JE sandwich absorbs more energy compared to JE laminate which can be due to the presence of rubber core which makes the sandwich less brittle compared to laminate.

**4.3 Total Deformation**

Figure 9(a) shows the total deformation against time graph for JE laminate and Figure 9(b) shows the same for JE-R-JE sandwich. Due to the impact at the velocity 10 m/s, the maximum deformation obtained in JE laminate are 3.15 mm, 2.89 mm, 2.47 mm, 2.06 mm and 1.11 mm respectively, for normal impact and oblique impact with 5°, 10°, 15° and 20° loading and for the JE-R-JE sandwich the same is found to be 3.81 mm, 3.66 mm, 3.35 mm, 2.18 mm and 1.32 mm respectively. The maximum deformation is noticed at the centre of JE laminate and at the centre of the top face sheet and minimum deformation at the edges as the four side faces of the sandwich are constrained in all the cases. The maximum deflections of sandwich occur when the impact force becomes equal to zero. During the impact event, the travelling of the impacted surface is indicated by the displacement. Since, drop height of the impactor is same in all the cases, the amount of energy it delivered on the laminate and sandwich will be same according to Remennikov et al. [24]. The laminate or sandwich which can resist maximum load will undergo least displacement as load and displacement depends on the amount of energy dissipated by sandwich. It can be concluded from the Table 6 that as the oblique angle under consideration increases, the deformation reduces. Sandwich and laminate with 20° loading condition can take more load compared to normal loading condition.

**4.4 Stress Analysis**

The stress profiles leading to damage in both JE laminate and JE-R-JE sandwich subjected to normal and various oblique impact loading conditions are shown in Figure 10. In case of JE laminate the occurrence of
damage is observed in both top and bottom faces. It can also be seen that as the angle of incidence with respect to normal increases, the bands of damage get reduced, indicating that the intensity of damage is being reduced and damage is passed to the bottom surface of laminate due to the brittleness of the JE laminate. This is schematically represented in Figure 11(a).

By comparing the stress pattern under different loading condition, it is conclusive that there is no much difference in the nature of damage from normal impact and oblique impact with 5\(^\circ\) impact angle. With further increase in the oblique angle, it can be seen that the damage zone 2 caused due to the effect of zone 1 gradually reduces and moves away from zone 1. The size of damage zone 2 gradually becomes smaller with an increase in oblique angle due to the reduced intensity of the load. For oblique impact at 20\(^\circ\), it can be seen that the zone 2 has been completely vanished and only zone 1 exists.

In case of JE-R-JE sandwich, the top face sheet is damaged under all types of impact loading. The damage on the top surface of the core was observed only for normal, 5\(^\circ\) and 10\(^\circ\) degree impact loading conditions, whereas the bottom face sheet is unaffected in all the cases. This can be due to the presence of rubber core. The elastic recovery nature of rubber arrests the strain energy resulting in prevention of damage to proceed further. This is schematically represented in Figure 11(b). Also in JE-R-JE sandwich the two zones of damage are observed, Zone 1 which is the primary zone of damage and zone 2 which is the secondary zone of damage. The secondary zone of damage gradually reduces as the angle of incidence of impact increases. Also the intensity of damage reduces. When the damage pattern in JE laminate is compared with JE-R-JE sandwich, it is conclusive that the damage in the sandwich is less compared to the laminate of the same thickness. The presence of rubber as a core material which is elastic in nature is the cause for the same. This argument is supported by comparing the absorbed energy of laminate and sandwich in Table 4 and Table 5. Results tabulated in Table 5 shows sandwich deforms more compared to laminate which means that sandwich absorbs more energy than laminate.

5. Conclusions

In this study, low velocity impact response under normal and oblique impact loading for JE laminate and JE-R-JE sandwich composite is investigated with four different oblique angles of 5\(^\circ\), 10\(^\circ\), 15\(^\circ\) and 20\(^\circ\). The sandwich composite plate consists of two Jute/ Epoxy face sheets with the rubber core material. The FE analysis was carried out to analyze the effect of impact angle on the crucial impact parameters: energy, contact force, deformation and stress patterns. Peak contact load will be more in laminate when compared to sandwich structure for any given case of loading, indicating earlier damage initiation in laminate compared to the
sandwich. The contact force histories also conclude that with increasing in impact angle, the peak contact force decreases. The force at which the point of first damage occurs is approximately 30% more in case of JE laminate compared to JE-R-JE sandwich under normal loading condition. The same in case of oblique loading are 27% more for 5°, 20% more for 10°, 25% more for 15° and 21% more for 20° oblique impact loading. It can be concluded from the energy history curve with respect to time that as the impact angle increases, the final energy of impactor i.e. residual kinetic energy and residual velocity decreases. This means that the growth of impact angle leads to increase in energy absorption. JE-R-JE sandwich absorbs more energy compared to JE laminate which can be due to the presence of rubber core which makes the sandwich less brittle compared to laminate. The JE-R-JE sandwich absorbs 6.2% more energy than JE laminate during normal impact and this drastically increases to 18% for 5°, 23% for 10°, 33% for 15° and 35% for 20° oblique impact loading. From the total deformation plot, it can be concluded that as the impact angle increases the total deformation reduces which means the laminate or sandwich with the highest impact angle of loading resists maximum load. Also, when we compare laminate with sandwich it can be concluded that sandwich absorbs more energy compared to laminate for corresponding loading conditions. For the same thickness of laminate and sandwich, it can be concluded that the damage caused in the sandwich is less than that of laminate. The presence of rubber as a core material avoids the further progression of damage. This can be due to the elastic nature of rubber. It can also be concluded that during normal impact, the damage caused is more as compared to oblique impact.

References


**Biography**

**Vishwas M** received his Bachelor of Engineering degree in Mechanical Engineering and Master of Technology degree in Product Design and Manufacturing in 2007 and 2011 respectively from Visvesvaraya Technological University, Belagavi, Karnataka, India. He is currently working as Research Scholar in the Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal, Mangalore, India. His research interests include composite materials and impact dynamics. He has published and presented many papers in international journals and conferences.

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<th>Properties</th>
<th>Structural Steel (Impactor)</th>
<th>Rubber (Core)</th>
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<tr>
<td>Density (Kg/m$^3$)</td>
<td>7,850</td>
<td>1,000</td>
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<tr>
<td>Modulus of Elasticity (MPa)</td>
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<td>Poisson’s Ratio</td>
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<td>0.5</td>
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<td>Bulk Modulus (MPa)</td>
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<td>Shear Modulus (MPa)</td>
<td>76,900</td>
<td>0.3</td>
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<tr>
<td>Equation of State</td>
<td>Linear</td>
<td>Linear</td>
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**Table 2.** Properties of Material Jute Epoxy (JE) [19-22]

<table>
<thead>
<tr>
<th>Young's Modulus (MPa)</th>
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<tbody>
<tr>
<td>$E_{11} = E_{22}$</td>
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<td>$E_{33}$</td>
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<table>
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<tr>
<th>Shear Modulus (MPa)</th>
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<tr>
<td>$G_{12}$</td>
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<tr>
<td>$G_{23} = G_{13}$</td>
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<tr>
<th>Poisson’s ratio</th>
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<tr>
<td>$\mu_{12}$</td>
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<tr>
<td>$\mu_{13} = \mu_{23}$</td>
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<table>
<thead>
<tr>
<th>Density (Kg/m$^3$)</th>
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<th>Tensile strength (MPa)</th>
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<tbody>
<tr>
<td>$X_T = Y_T$</td>
</tr>
<tr>
<td>$Z_T$</td>
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<table>
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<tr>
<th>Shear strength (MPa)</th>
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<tbody>
<tr>
<td>$S_{12} = S_{13} = S_{23}$</td>
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</table>
Compressive strength (MPa)

\[ X_C = Y_C = 95 \]
\[ Z_C = 102 \]

Equation of State

EOS Orthotropic

Table 3: Contact force variation at various loading conditions

<table>
<thead>
<tr>
<th>Type of Loading</th>
<th>JE Laminate</th>
<th>JE-R-JE Sandwich</th>
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<tbody>
<tr>
<td>Max. Contact Force at Incipient Point of Damage (N)</td>
<td>1865.36</td>
<td>2805.31</td>
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<tr>
<td>Peak Contact Force (N)</td>
<td>2805.31</td>
<td>2157.9</td>
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<tr>
<td>Max. Contact Force at Incipient Point of Damage (N)</td>
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<tr>
<td>Peak Contact Force (N)</td>
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Table 4: Kinetic energy and Internal energy at different loading conditions for JE laminate

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<thead>
<tr>
<th>Type of Loading on Laminate (JE)</th>
<th>Initial Kinetic Energy (J)</th>
<th>Residual Kinetic Energy (J)</th>
<th>Energy Absorbed (J)</th>
<th>Residual Velocity (m/s)</th>
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<td>Normal (0°)</td>
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<td>7.57</td>
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</tr>
<tr>
<td>5°</td>
<td>7.95</td>
<td>6.05</td>
<td>7.53</td>
<td></td>
</tr>
<tr>
<td>10°</td>
<td>7.76</td>
<td>6.24</td>
<td>7.44</td>
<td></td>
</tr>
<tr>
<td>15°</td>
<td>7.27</td>
<td>6.73</td>
<td>7.20</td>
<td></td>
</tr>
<tr>
<td>20°</td>
<td>7.12</td>
<td>6.88</td>
<td>7.13</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Contact force variation at various loading conditions

<table>
<thead>
<tr>
<th>Type of Loading</th>
<th>JE Laminate</th>
<th>JE-R-JE Sandwich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Contact Force at Incipient Point of Damage (N)</td>
<td>1865.36</td>
<td>2805.31</td>
</tr>
<tr>
<td>Peak Contact Force (N)</td>
<td>2805.31</td>
<td>2157.9</td>
</tr>
<tr>
<td>Max. Contact Force at Incipient Point of Damage (N)</td>
<td>1434.9</td>
<td></td>
</tr>
<tr>
<td>Peak Contact Force (N)</td>
<td>2157.9</td>
<td></td>
</tr>
</tbody>
</table>
### Table 5: Kinetic energy and Internal energy at different loading conditions for JE-R-JE sandwich

<table>
<thead>
<tr>
<th>Type of Loading on Sandwich Structure (JE-R-JE)</th>
<th>Initial Kinetic Energy (J)</th>
<th>Residual Kinetic Energy (J)</th>
<th>Energy Absorbed (J)</th>
<th>Residual Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal (0°)</td>
<td>7.66</td>
<td>6.34</td>
<td>6.34</td>
<td>7.40</td>
</tr>
<tr>
<td>5°</td>
<td>6.86</td>
<td>7.14</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>10°</td>
<td>6.28</td>
<td>7.72</td>
<td>6.70</td>
<td></td>
</tr>
<tr>
<td>15°</td>
<td>5.04</td>
<td>8.96</td>
<td>6.00</td>
<td></td>
</tr>
<tr>
<td>20°</td>
<td>4.70</td>
<td>9.30</td>
<td>5.80</td>
<td></td>
</tr>
</tbody>
</table>

### Table 6: Total deformation for various loading conditions for JE laminate and JE-R-JE sandwich

<table>
<thead>
<tr>
<th>Total Deformation in mm</th>
<th>Normal (0°)</th>
<th>5°</th>
<th>10°</th>
<th>15°</th>
<th>20°</th>
</tr>
</thead>
<tbody>
<tr>
<td>JE Laminate (mm)</td>
<td>3.15</td>
<td>2.89</td>
<td>2.47</td>
<td>2.06</td>
<td>1.11</td>
</tr>
<tr>
<td>JE-R-JE Sandwich (mm)</td>
<td>3.81</td>
<td>3.66</td>
<td>3.35</td>
<td>2.18</td>
<td>1.32</td>
</tr>
</tbody>
</table>