Estimation of Impact Strength of Kevlar/Basalt and Kevlar/Glass Interwoven Composite Laminate after High-Velocity Bullet Impact

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The application of composite materials has increased drastically in the aerospace industry. The impact strength signifies the importance of composite materials when exposed to suddenly applied loads. This paper is focused on describing the behavior of interwoven kevlar/glass-epoxy and kevlar/basalt-epoxy composite laminate under high-velocity bullet impact. The composite lamina of kevlar/glass and that of kevlar/basalt are prepared using three different weaving techniques. The composite laminates are prepared using the compression moulding technique. The laminates have been subjected to high-velocity bullet impact. The velocity range is from 220 m/s to 260 m/s. The impact damage area in the laminate has been assessed through ultrasonic pulse echo submerged nondestructive technique. The impact strength has been calculated using the damaged area derived using the impact energy absorbed by the laminate. The results have shown that the maximum impact which found out to be kevlar/basalt (KB 1 × 1) is 28.24 J/cm².

1. Introduction

The high-velocity impact study has been a major contribution to the aerospace industry ever since Apollo 11 touched down on the moon in the 1960s [1], and the progress has not stopped there. In the aviation sector, the components such as empennage leading edges, windshields, and the intake of engines Nacelles are subjected to high-speed impact loadings; also it was considered that almost 77% of the accidents are caused due to the impact in windshields [2, 3]. In the space sector, the average velocity of debris is 7.5 km/s, and it varies from 0.5 to 16 km/s, which the satellites are supposed to withstand its impact [4, 5]. The military vehicles use organic composites such as kevlar and spectra which absorb energy by deformation of the fiber itself, the same technology is used in formula (1) cars [6]. Kevlar has got its high strength from its interchain bonds and even it is resilient at such low temperatures as −196°C; thus, it has got a wide range of applications in the industry [7].

The kevlar is used in the ballistic application due to its special characteristics such as heat resistance and impact strength. Basalt consists of materials such as olivine, pyroxene, and minerals plagioclase. It has better properties than other fiber materials and the specific strength is three times stronger than that of steel. Shaari and Jumahat, in their work, explained that the addition of kevlar fiber to the glass fiber increases the load-carrying capacity and its resistance to deformation [8]. Velumayil and Palanivel [9] have shown through their experiment that sandwiching kevlar fiber with basalt could yield a maximum impact energy absorption of 8.3 J. Tirillo et al. [10] in their paper carried out ballistic impact on basalt-cabon/epoxy hybrid composite laminate. It is observed from the study that hybridization of basalt has improved the ballistic...
2. Methodology

2.1. Weaving & Preparing Composite Laminate. Weaving in the composite is a process of interlacing warp (fibers in longitudinal direction) and weft (fibers in lateral direction) in a sequence to form a fiber mat. In this research work, weaving is performed in three different types.

2.1.1. Type 01. In type 01, two different kinds of laminas are prepared. One with kevlar/basalt and one with kevlar/glass fibers. Here, every single fiber of basalt [warp] is woven with single fiber of kevlar [weft] and “kb 1 x 1” lamina is prepared [plain weave]. Similarly, every single fiber of glass fiber is interlaced with single fiber of kevlar and “kg 1 x 1” lamina is prepared.

2.1.2. Type 02. In type 02, two different kinds of laminas are prepared. One with kevlar/basalt and one with kevlar/glass fibers. Here, three fibers of basalt is woven after every three fibers of kevlar and “kb 3 x 3” lamina is prepared. Similarly, every three fibers of glass is interlaced after every three fibers of kevlar and “kg 3 x 3” lamina is prepared.

2.1.3. Type 03. In type 03, two different kinds of laminas are prepared. One with kevlar/basalt and one with kevlar glass fibers. Here, five fibers of basalt are woven after every five fibers of kevlar and “kb 5 x 5” lamina are prepared. Similarly five fibers of glass are interlaced after every five fibers of kevlar and “kg 5 x 5” lamina are prepared.

As a result, six different lamina are prepared [kb 1 x 1, kb 3 x 3, kb 5 x 5, kg 1x, kg 3x, and kg 5 x 5]. Then five layers of “kb 1 x 1” lamina with 300 x 300 mm dimension are stacked one over the other and “KB 1 x 1” laminate is prepared, epoxy being the resin. Similarly five composite laminates [KB 3 x 3, KB 5 x 5, KG 1 x 1, KG 3 x 3, and KG 5 x 5] are prepared using the compression moulding method with (300 x 300) mm dimension. Then the laminate is cut into 150 mm x 150 mm dimensions using a vertical band saw cutter to fit in the high-velocity impact fixture.

2.2. High-Speed Ballistic Impact Test. The high-velocity impact test has been carried out using a steel projectile on the interwoven composite laminates. The specification of the projectile is given in Table 1.

Table 2 describes the varying velocity of the projectile during initial and impact conditions. It has been observed that the projectile lost its most of the energy in KB 5 x 5 and KG 5 x 5.

The impacted area of the material is extracted using the C scanning method and Phanthom Cine analysis is used to calculate the residual and impact velocity of the projectile. Further, the impact strength has been estimated by finding the absorbed energy of the material.

2.3. Ultrasonic C Scan. The ultrasonic method of inspection is considered to be the most effective way of checking the quality of the materials [27]. Here, a submerged ultrasonic C
scan method is used to obtain the images of the impacted materials and then the area is calculated using Image J software. Those areas are used to calculate the impact strength of the materials. The system consists of an Ultra-sonic Transducer and a receiver to fetch the results from the transducer.

### 3. Estimation of Absorbed Energy

The study of impact testing is carried out by calculating the absorbed energy from [28, 29]

\[
E_{\text{abs}} = \frac{1}{2} m_p (V_i^2 - V_r^2), \tag{1}
\]

where, \(E_{\text{abs}}\) is the energy absorbed by the material, \(m_p\) is the mass of the projectile, \(V_i\) is the impact velocity of the projectile, and \(V_r\) is the residual velocity of the projectile.

As the projectile strikes the material, the kinetic energy of the projectile is converted into absorbed energy. Thus, the energy which is lost is called absorbed energy [29].

From Table 3, we have acquired the impact and the residual velocities of the projectile for different composite materials. The absorbed energy is calculated from this loss of kinetic energy.

The impact strength could be depicted from the absorbed energy of various composite materials which is given in above Table 3.

Figures 1 and 2 display the front face of the material after the bullet impact and their corresponding C scan images. The specimens KG 1 × 1, KG 3 × 3, and KG 5 × 5 has undergone a lot of damage with the impact area of 37.39 cm², 33.36 cm², 21.16 cm², respectively.

Moyo et al. [30] have stated in their work that absorbed energy is linear to that of damaged area. Thus, impact strength for the composites is.

\[
\text{impact strength} = \frac{(\text{energy absorbed})}{(\text{damaged area})}. \tag{2}
\]

The impact strength of the composite materials is depicted in Table 4. The area is calculated using the Image J software. The impact strength of KB 1 × 1, KB 3 × 3, and KB 5 × 5 are 28.24 J/cm², 7.633 J/cm², and 19.323 J/cm², respectively, while the impact strength of KG 1 × 1, KG 3 × 3, and KG 5 × 5 are 2.494 J/cm², 2.816 J/cm², and 5.340 J/cm², respectively.

### 4. Results and Discussion

The absorbed energy which was calculated from the energy lost equation is found to be greater for KB 5 × 5 and KG 5 × 5. The absorbed energy for the different kevlar basalt and kevlar glass interwoven laminate is shown in Figure 3.

In order to investigate the influence of the different woven composite materials on the impact properties, the damaged area and impact strength are calculated and the results obtained are presented in Figures 4 and 5.

It is evident from Figure 5, the result that the KB 1 × 1 has is more resistant compared to any other fabricated material with an impact strength of 28.24 J/cm² with area of 2.698 cm², followed by KB 5 × 5 which has an impact strength of 19.323 J/cm² with area of 5.99 cm² and the hybrid of glass and kevlar are observed to be having lowest impact strength of 2.494 J/cm² with the area of 37.39 cm². Basalt has got excellent comprehensive performances because of the presence of silica content. In alkali condition, the basalt fiber is more stable than the glass fibers mainly because of the chemical composition. Added basalt also has got greater failure strain properties [24]. Generally, glass fibers have low knit line strength and low elastic modulus which might have led to low impact strength than kevlar basalt weaving. Lower elastic modulus will tend to make the fiber stiffer resulting in the low breakage of the fibers. The carbon reinforced epoxy composite has impact strength of 27 J/cm² [31] which is lesser compared to that of KB 1 × 1. This is because carbon fibers generally have poor impact properties and they are very brittle.

The carbon fiber undergoes delamination even under mild impact loads [32].

### Table 1: Specification of the projectile.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Mild steel</td>
</tr>
<tr>
<td>Mass</td>
<td>7.34 (g) or 0.00734 (kg)</td>
</tr>
<tr>
<td>Length</td>
<td>15.5 (mm)</td>
</tr>
<tr>
<td>Diameter</td>
<td>9.66 (mm)</td>
</tr>
</tbody>
</table>

### Table 2: Inlet and residual velocity of the projectile.

<table>
<thead>
<tr>
<th>Material</th>
<th>Average inlet velocity in m/s</th>
<th>Average residual velocity in m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>KB 1 × 1</td>
<td>225.67</td>
<td>173.67</td>
</tr>
<tr>
<td>KB 3 × 3</td>
<td>225</td>
<td>196</td>
</tr>
<tr>
<td>KB 5 × 5</td>
<td>250.5</td>
<td>176.67</td>
</tr>
<tr>
<td>KG 1 × 1</td>
<td>256</td>
<td>200.33</td>
</tr>
<tr>
<td>KG 3 × 3</td>
<td>253</td>
<td>196</td>
</tr>
<tr>
<td>KG 5 × 5</td>
<td>249</td>
<td>176.67</td>
</tr>
</tbody>
</table>
Table 3: Absorbed energy of composite materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Impact velocity (m/s)</th>
<th>Impact energy (J)</th>
<th>Residual velocity (m/s)</th>
<th>Residual energy (J)</th>
<th>Absorbed energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KB 1\times1</td>
<td>225.67</td>
<td>186.902</td>
<td>173.67</td>
<td>110.692</td>
<td>76.21</td>
</tr>
<tr>
<td>KB 3\times3</td>
<td>225</td>
<td>185.794</td>
<td>196</td>
<td>140.987</td>
<td>44.807</td>
</tr>
<tr>
<td>KB 5\times5</td>
<td>250.5</td>
<td>230.293</td>
<td>176.67</td>
<td>114.549</td>
<td>115.744</td>
</tr>
<tr>
<td>KG 1\times1</td>
<td>256</td>
<td>240.517</td>
<td>200.33</td>
<td>147.285</td>
<td>93.232</td>
</tr>
<tr>
<td>KG 3\times3</td>
<td>253</td>
<td>234.913</td>
<td>196</td>
<td>140.987</td>
<td>93.926</td>
</tr>
<tr>
<td>KG 5\times5</td>
<td>249</td>
<td>227.544</td>
<td>176.67</td>
<td>114.549</td>
<td>112.995</td>
</tr>
</tbody>
</table>

Figure 1: Front face of the impacted specimen (a) KB $1\times1$, (b) KB $3\times3$, (c) KB $5\times5$, (d) KG $1\times1$, (e) KG $3\times3$ and (f) KG $5\times5$. 
Figure 2: Ultrasonic C scan images (a) KB 1 x 1, (b) KB 3 x 3, (c) KB 5 x 5, (d) KG 1 x 1, (e) KG 3 x 3 and (f) KG 5 x 5.
5. Conclusion

The ballistic impact testing on the interwoven kevlar-basalt/epoxy and kevlar-glass/epoxy composite laminates were carried out and the impact strength for all the laminates was determined.

Following were the observations made from the study:

1. The impact strength of the impacted specimens is as follows: KB 1×1 > KB 5×5 > KB 3×3 > KG 5×5 > KG 3×3 > KG 1×1. The weaving pattern has direct influence on the impact strength of the material as KB 1×1 possesses more impact strength than that of KB 5×5.

2. The damaged area for all the kevlar/glass weaving patterns was higher than the kevlar/basalt weaving pattern. This behavior could be due to the predominant fiber breakage and fibers pull out in the kevlar/glass laminates.

3. Also, the first few layers of the kevlar/glass have undergone a large amount of damage in the lengthwise direction.

Table 4: Impact strength of composite materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Area in cm²</th>
<th>Absorbed energy (J)</th>
<th>Impact strength (J/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KB 1×1</td>
<td>2.698</td>
<td>44.807</td>
<td>28.24</td>
</tr>
<tr>
<td>KB 3×3</td>
<td>5.87</td>
<td>115.744</td>
<td>7.633</td>
</tr>
<tr>
<td>KB 5×5</td>
<td>5.99</td>
<td>93.232</td>
<td>19.323</td>
</tr>
<tr>
<td>KG 1×1</td>
<td>37.39</td>
<td>93.926</td>
<td>2.494</td>
</tr>
<tr>
<td>KG 3×3</td>
<td>33.36</td>
<td>112.995</td>
<td>2.816</td>
</tr>
<tr>
<td>KG 5×5</td>
<td>21.16</td>
<td>112.995</td>
<td>5.340</td>
</tr>
</tbody>
</table>
(4) The interwoven laminate of kevlar and basalt which showed improved results can be used in making bullet proof armours. Though the weaving of the laminates can be time consuming the usage of basalt along with kevlar will bring down the cost.

(5) This research can be further extended by adding different nanoparticles in different percentages and testing for the impact strengths.

Data Availability
The data used to support the findings of this study are included in the article.

Conflicts of Interest
The authors declare that they have no conflicts of interest.

Authors’ Contributions
J. Jensin Joshua performed planning, design, experimentation, data collection, and initial draft preparations. Dalbir Singh performed figure preparation and reviewing and editing. Y. Murali Krishna performed experimentation and data collection. P. Sivaprakasam performed data analysis, manuscript editing, and reviewing. D. Raja Joseph performed data collection and analysis. P. S. Venkataranayanan performed reviewing and editing.

References


