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*Research Article*

# Experimental Estimation of Energy Absorbed and Impact Strength of Kevlar/Basalt-Epoxy Interwoven Composite Laminate Added with $Al_2O_3$ Nanoparticles after High-Velocity Bullet Impact

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The use of composites has increased exponentially in most industries, especially in the aerospace industry; the usage of composites has increased by almost 40% in the last 15 years. Aerospace components are often subject to high-impact loads, so it is important to use impact-resistant materials. Kevlar is known for its high-impact resistance and is commonly used as a fiber with various resins to achieve the desired properties. This paper mainly focuses on weaving Kevlar with basalt fiber in plain weave type by the traditional handloom weaving method. The epoxy resin, along with the harder, is then mixed with the aluminum oxide nanoparticles ($Al_2O_3$) in different percentages [1%-KB1, 3%-KB2, and 5%-KB3] to form the matrix. The laminate fabricated is then subjected to the high-velocity bullet impact of around 250 m/s. A steel hemispherical head projectile was used in the testing, and it was found to be penetrated through all the specimens making holes. The impact strength for all the different specimens was then estimated by calculating the bullet damage area and energy absorbed. The plate added with 3% $Al_2O_3$ nanoparticle was found to have improved impact strength when compared with the other two specimens. This plate can be used for bulletproof and other high-velocity impact applications.

## 1. Introduction

A composite is a mixture of two or more chemically different constituent materials combined macroscopically or microscopically to yield a useful material [1, 2]. It is a mixture of fiber/reinforcement and matrix/resin. Composites are categorized based on the type of fiber and resin being used in the fabrication process; they can be naturally occurring or manmade (synthetic). Some examples of natural composites are wood (which contains cellulose fibers and lignin), bone, granite (which has the particulate type of fiber), and manmade composites are concrete, and plywood. [3]. Macro-fiber composite (MFC) is used for energy applications using unimorph and bimorph cantilever beams [4]. Composites have proven as a good replacement for alloys because of their high stiffness/weight ratio which also helps in fabricating lightweight materials [5, 6]. During the flight take-off, cruise, and landing the aircraft surfaces such as wings, engines, turbines, and nose experience high-velocity impact loadings. One of the major impacts is due to the bird strikes because there will be high relative velocities between the birds and the aircraft [7]. The defense industry also uses composite laminated bulletproof armor to prevent the entry of bullets into the protected area; however, armor with multiple fiber layers was also developed in the past few decades which gives improved penetration resistance for the bullet [8]. Today, composites are thought to have outstanding potential applications as primary load-bearing structures in many industries; therefore, studies on the impact behavior of the composites have attracted a lot of attention and become a burning research interest in the field of composite materials [9]. Composite structures are open to different load conditions during their useful life. An important requirement for the effective use of composites as a protective structure is resistance to ballistic impact loads from foreign objects. Such applications require a clear understanding of the damage mechanism associated with the conditions under which the projectile penetrates the composite target. Residual strength after ballistic impact is also an important consideration. Impact loads can be divided into three categories: low-speed impact, high-speed impact, and hyperspeed impact. The reason for this classification is that the energy transfer and damage propagation mechanisms between the projectile and the target change dramatically as the speed of the projectile changes. One way to raise the ballistic limit is to use fiber composites [10].

Kevlar has more fascinating properties than other natural and synthetic fibers, resulting in it being in a key position in various load carrier applications. The most significant important property of Kevlar is its high tensile strength-to-weight ratio, which means that when compared to regular material, it has a higher tensile strength at a lower weight [11]. Kevlar fabric has a tensile strength of 3620 MPa (525,000 psi) and a very low relative density of 1.44, which is suitable for ballistics applications where the strength-to-weight ratio is paramount [12]. As a fibrous polymer, Kevlar has been shown to withstand high temperatures. Its tension/tensile strength depletes by 10–20% at elevated temperatures, which continues to fall within a few hours. When Kevlar is molded, the fibers formed have a tensile strength of approximately 3620 MPa and a relative density of 1.44 [13].

Basalt fibers are prepared from basalt rocks which are obtained from volcanic magma that is solidified in the open air after flowing as a hot fluid. The general composition of basalt rocks is, $SiO_2$ at 51.6–59.3%, $Al_2O_3$ at 14.6–18.3%, $Fe_2O_3$ at 9.0–14.0%, and CaO at 5.9–9.4% [13]. Comparing the thermal properties of glass fiber with the thermal properties of basalt fiber, the tensile modulus of basalt fiber is about $60.4 \pm 18.9$ GPa, and the tensile strength is $568 \pm 267$ MPa [14]. Basalt has several properties that make it an excellent fiber, such as chemical resistance, heat resistance, low water absorption, and heat insulation. When mixed with other matrices, basalt is a very good reinforcement [15]. The mechanical properties of basalt fiber-reinforced composites have been completely investigated [16–18]. The properties of Kevlar and basalt are given in Table 1.

The properties of Kevlar fiber composites are dominant in the axial to the transverse direction. In order to improve mechanical properties even in the transverse direction, hybridization is considered as the way to construct [19]. The transverse mechanical properties can be improved by weaving with other fibers such as basalt, glass, and carbon. [20]. Recently, basalt fibers have acquired particular importance due to their high compound stability, heat resistance, etc. [21]. The purpose of hybridization is to obtain a better-reinforced structure.

Hybrid composites can contain at least two types of fiber aggregates, helping to integrate the properties of the two materials and reducing costs. 3D textile composites, as shown in Figure 1 [22], are well known for their resistance to ballistic forces.

Table 1: Properties of Kevlar and basalt.

| Properties | Kevlar | Basalt |
|---|---|---|
| Density ($g/cm^3$) | 1.44 | 2.66 |
| Tensile modulus (GPa) | 124 | 93 |
| Tensile strength (MPa) | 3620 | 4500 |
| Elastic modulus (GPa) | 76 | 57 |
| Elongation at break (%) | 2.0 | 3.1 |

The mechanical properties of hybrid composites such as basalt-carbon have been studied under ballistic impact. The results of these experiments demonstrate that the hybridization of basalt with Kevlar fibers significantly improves the performance of reinforced composites [23]. Bandaru and others studied the behavior of Kevlar–basalt composites under low-velocity impact. The basalt sample was found to have the highest peak force, and it was also found that the hybrid samples absorbed more energy than the individual samples [24].

In many studies, researchers have explored traditional fibers such as carbon-based polymer composites, glass, and Kevlar fibers using computational and experimental methods to characterize the properties of composite materials. The energy absorption, ballistic impact performance, and penetrating behavior of these conventional fiber-based polymer composites when subjected to dynamic or impact loads have been investigated. Delamination, fiber-matrix compression damage, matrix cracking, and tensile failure of yarns have been recognized as the primary failure mechanisms under impact load [25].

Therefore, based on all these observations, in this present study, the properties of the basalt hand woven with Kevlar in a plain weaving $[1 \times 1]$ manner composite in fiber form with epoxy resin were investigated. A traditional handloom weaving process is used to hybridize Kevlar and basalt fibers, which, although this is a time-consuming but cost-effective process, can reduce production costs. Due to the attractive mechanical properties, optimum adhesion, strong chemical resistance, and wide range of coatings, epoxy resins are often used in producing polymer-based composites [26].

## 2. Materials and Methods

*2.1. Nanofillers ($Al_2O_3$).* Recent trends demonstrate the use of dispersed nanoparticles in polymers to improve polymer performance, and these composites are called polymer nanocomposites. Various nanofillers such as aluminum, graphene, and titanium, are used as fillers inside polymeric epoxies and other polymers. Compared with pure polymers, polymer-based nanocomposites exhibit unique properties due to their structure. This has led to the widespread use of polymer-based nanocomposites in various engineering fields [27].

The inclusion of different concentrations of alumina nanoparticles ($Al_2O_3$) into the polymer matrix increased both final stress parameters and percent elongation. The existence of nanoparticles in nanocomposites acts as a bridge

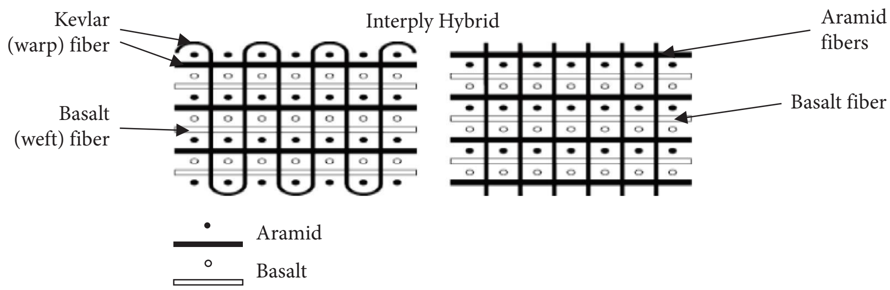



Figure 1: Plain interwoven basalt/aramid hybrid composite [22].

between different polymer molecules to come closer together to build a similarity index between them [28]. Yang et al. [29] proved that the presence of up to 10% (threshold value) by weight of distributed nano-$Al_2O_3$ particles in the polymer matrix plays an important role in improving the chemical and thermal properties of the nanopolymer composites obtained. According to the study, $Al_2O_3$ nanofillers improve the mechanical properties, but the hardening effect is gradually reduced for $Al_2O_3$ content higher than 10% (above a threshold value) by weight. Zhou et al. [30], in their results, found that the thermal conductivity and mechanical properties increased, and the material increased with the addition of 80% alumina nanopowder, but the mechanical properties started to decrease by 55%, i.e., above the threshold value. So, based on all the previous observations, nanoparticles, especially $Al_2O_3$, are known to increase the mechanical and thermal properties of composites. Therefore, in this study, the nanoalumina powder was chosen as filler in the fabrication of Kevlar/basalt and epoxy composite and examined the subsequent changes in properties. Figure 2 shows the alumina nanoparticles, and Figure 3 shows the processing methods and testing of composites.

Most studies have carried out impact testing for Kevlar/basalt composites, the content of nanoparticles plays a vital role in the mechanical properties of a composite, but this aspect is least bothered, so in this study, nanoalumina powder ($Al_2O_3$) was added with different percentages into different samples because it can reduce the porosity, and the density of the material increases dramatically with a small percentage of the addition of nanosized alumina particles, tensile strength also increased although there was no difference in the ductility of the material is recorded [31]. The mechanical properties, flexural strength, tensile strength, and Young's modulus or stiffness of the material will be increased. If the alumina content is too low, the intermolecular distances will increase, reducing the impact strength, while if the alumina content is too high, the close stacking of molecules can lead to the fragile property of the material [32].

*2.2. Fabrication of Laminate by Weaving.* The traditional weaving process takes place on a loom. This process requires two types of yarns or fibers: warp and weft. Here the warp threads are Kevlar, and the weft threads are basalt fibers, the warp running along the length of the fabric, and the weft running across the length of the warp. The woven fabrics are shown in Figure 4.

*2.3. Hand Layup Process.* The production of a composite laminate is carried out by the traditional hand layup method shown in Figure 5. Epoxy resin and HY951 hardener are used in the fabrication process. Three different laminates are prepared by mixing aluminum oxide nanoparticles in three different percentages viz. 10.6 g of alumina powder, 32 g of alumina powder, and 55 g of alumina powder [1%, 3%, and 5%].

After curing, the resulting composite panels (samples) will have a thickness of 3 mm (which can be achieved by adjusting the thickness of the mold), which is a mandatory requirement for high-speed impact testing, and samples are cut into $150 \times 160$ mm. Three test samples were obtained, namely, KB1 (with 10.6 g of alumina powder), KB2 (with 32 g of alumina powder), and KB3 (with 55 g of alumina powder).

*2.4. High-Speed Bullet Impact Test.* High-speed impact tests are typically performed by a projectile that will be ejected from a high-pressure pneumatic accelerator [33, 34]. A similar configuration was used in this study, and a mild steel hemispherical projectile with details is shown in Table 2. The projectile strikes the composite samples at 200–230 m/s.

The schematic test setup for the bullet (projectile) impact test is shown in Figure 6. Additionally, the high-speed camera was set to an appropriate frame rate to capture several frames at impact. The impact velocities and the residual velocities (velocity of the projectile after striking the specimen) are calculated from the recorded videos with the aid of phantom cine viewer software.

Table 3 shows the different velocities of the projectile before and after impact. It has been observed there is more loss of velocity or energy in KB3. The bullet impact before and after in composite are shown in Figures 7–9.

## 3. Damage Evaluation of Composite Samples Using Immersion Ultrasonic Testing

Ultrasonic scanning is the most popular nondestructive testing (NDT) technique principally used for flaw detection in different materials such as composites, plastics, and metals. The widely used formats for ultrasonic scanning are A-scan, B-scan, and C-scan [35]. In this work, an ultrasonic C-scan was used since it is the accurate and best method for the detection of impact in composite materials [36].

*3.1. Evaluation of Absorbed Energy.* The energy drawn up by the composites is given by the following equation [37]:


Figure 2: Alumina powder.

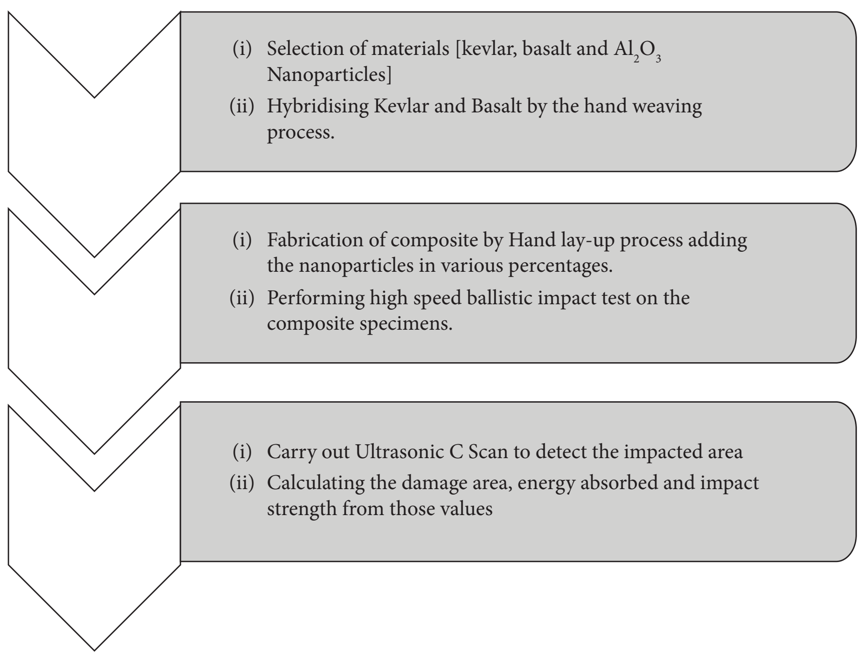
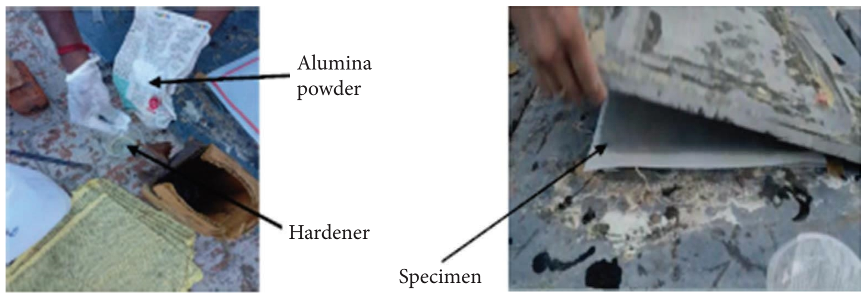



Figure 3: Flow chart for fabrication process and testing of Kevlar/basalt-epoxy interwoven composite.

Figure 4: Woven fiber.




(a) (b)

Figure 5: Hand layup process: (a) mixing of hardener and alumina powder and (b) fabricated composite laminates.

Table 2: Details of the projectile.

| Parameters | Details |
|---|---|
| Material | Mild steel |
| Mass | 7.34 (g) or 0.00734 (kg) |
| Length | 15.5 (mm) |
| Diameter | 9.66 (mm) |

$$E_{abs} = 0.5 * m_p * \left(V_i^2 - V_r^2\right), \quad (1)$$

where $E_{abs}$ is the energy absorbed by the composite. $m_p$ is the mass of the projectile or bullet. $V_i$ is the impact velocity of the projectile or bullet. $V_r$ is the residual velocity of the projectile or bullet.

The fiber layers of the composites resist the penetration of the bullet through it converting most of its kinetic energy to absorbed energy [37]. The absorbed energy of composites is presented in Table 4. The values of $V_i$and $V_r$ can be obtained from Table 3, and the mass of the projectile is 0.00734 kg (from Table 3). The impact energy is given by equation (2), and the residual energy is given by equation (3).

$$\text{Impact energy} = 0.5 * m_p * V_i^2, \quad (2)$$

$$\text{Residual energy} = 0.5 * m_p * V_r^2. \quad (3)$$

*3.2. Calculating Impact Strength of the Composite Specimens.* The impact strength of the materials can be calculated by using the following equation [38]:

$$\text{Impact strength} = \frac{(\text{Energy absorbed})}{\text{Damaged area}}. \quad (4)$$

The damaged area can be predicted from ultrasonic-C scan images of the specimens, and the impact area can be calculated with the aid of Image J software.

*3.2.1. Ultrasonic-C Scan.* This analysis aimed to find out the extent of bullet damage on composite specimens. Two separate tubes for channeling and receiving pulses are spaced equally on opposite faces of the composite sample, as shown in Figure 10. The echoes received from the high-quality region are taken as the threshold value such that the receiver can detect any signal below the threshold value. In general, the pulse energy of damaged regions is small compared with good regions.

The test setup of the Immersion ultrasonic testing system and transmission setup is shown in Figures 11 and 12.

*3.2.2. Estimation of Damage Area through C-Scan.* The impacted specimen is scanned with ultrasonic C scan nondestructive evaluation to estimate the damaged area. Impact or damaged area can be predicted using Image J software.

The impact strengths of KB1, KB2, and KB3 are 2.75 J/cm$^2$, 4.28 J/cm$^2$, and 3.63 J/cm$^2$, respectively, shown in Table 5 and Figure13. Table 6 shows C-scan, front and back side images of all the samples.

(i) It is evident from the values obtained that the impact strength of KB2 (4.28 J/cm$^2$) is higher than KB1 (2.75 J/cm$^2$) and KB3
(ii) In the case of KB1, the addition of alumina powder is very low (i.e., 1% or 10.6 gm); if the alumina content is too low, the intermolecular distances will increase, resulting in the low impact strength [32]
(iii) In the case of KB3, the alumina powder content is very high (i.e. 5% or 55 gm); if the alumina content is too high, the close stacking of molecules can lead to the fragile property of the material, so the impact strength of the specimen is again low
(iv) But in the case of KB2, due to the moderate addition of the alumina powder (i.e., 3% or 32 gm), the resultant impact strength is higher [32, 38]

## 4. Results and Discussion

(i) After the high-velocity impact test, the results are as follows:
(ii) The bullet impact test revealed that the bullet pierced smoothly through the composite specimens in all three cases
(iii) Delamination, fiber-matrix compression damage, matrix cracking, and tensile failure of yarns have been recognized as the primary failure mechanisms under impact load [25]

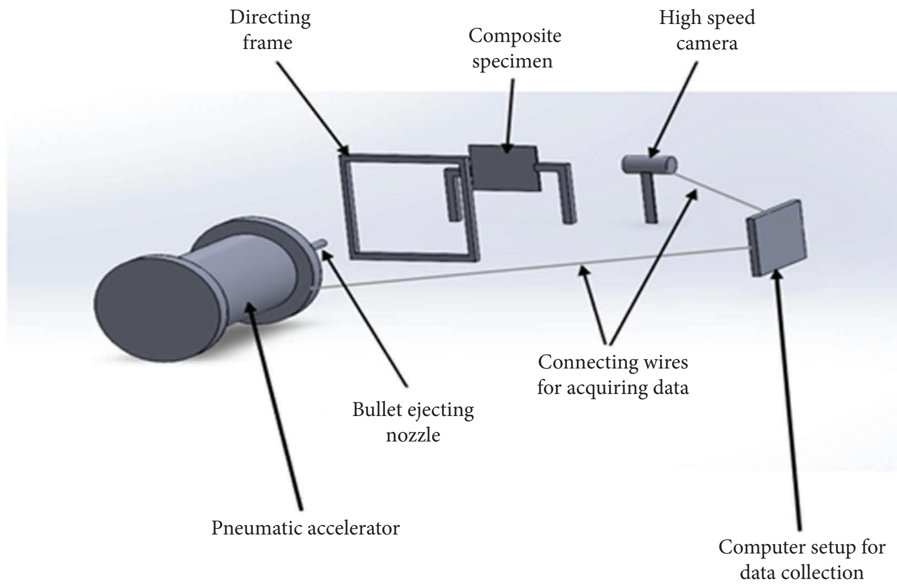



Figure 6: Schematic setup of bullet impact test.

Table 3: Velocities of the projectile.

| Material | Average initial impact velocity of projectile (m/s) | Average residual velocity (m/s) |
|---|---|---|
| KB1 | 222.33 | 206.66 |
| KB2 | 230 | 208.33 |
| KB3 | 224.33 | 199 |

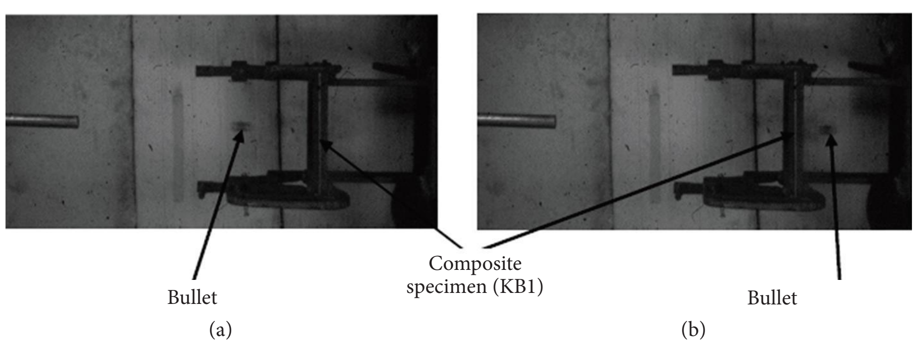



Figure 7: KB1 placed for testing: (a) KB1 before the impact and (b) KB1 bullet after the impact.

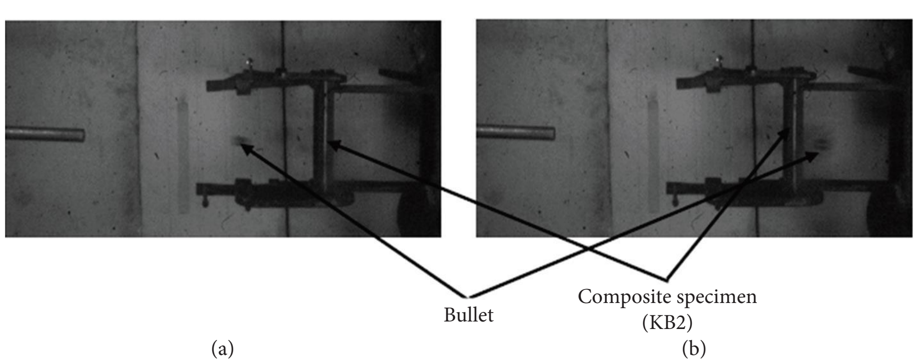



Figure 8: KB2 placed for testing: (a) KB2 before the impact and (b) KB2 bullet after the impact.

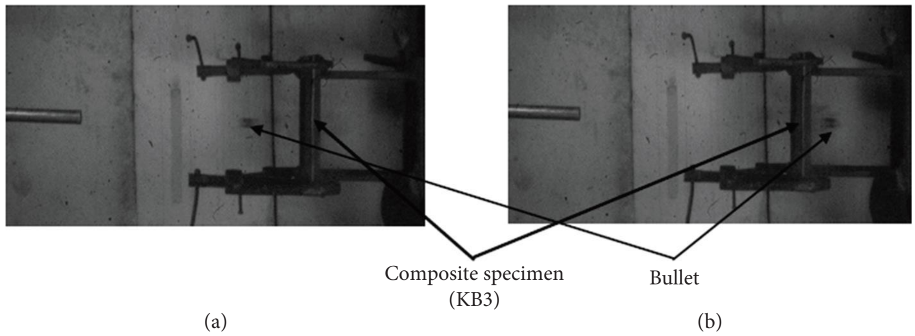



Figure 9: KB3 placed for testing: (a) KB3 before the impact and (b) KB3 bullet after the impact.

Table 4: Absorbed energy of the composite samples.

| Material | The impact velocity of projectile (m/s) | Impact energy (J) | The residual velocity of the projectile (m/s) | Residual energy (J) | Absorbed energy (J) |
|---|---|---|---|---|---|
| KB1 | 222.33 | 181.41 | 206.66 | 156.73 | 24.67 |
| KB2 | 230 | 194.14 | 208.33 | 159.28 | 34.85 |
| KB3 | 224.33 | 184.68 | 199 | 146.8 | 39.34 |

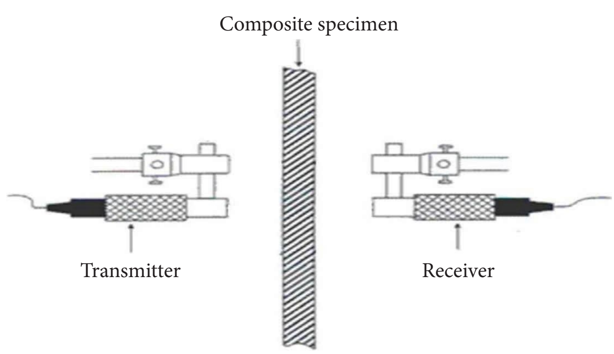



Figure 10: Simplified diagram of the immersion scan system.


Figure 11: Immersion ultrasonic testing system.

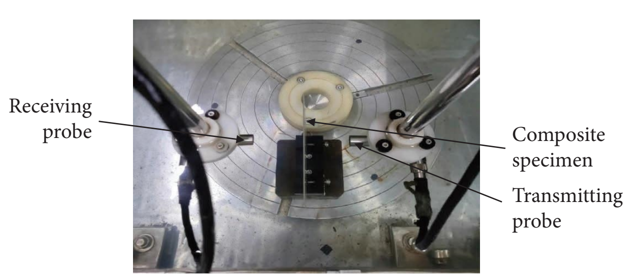



Figure 12: Through transmission setup with the sample.

Table 5: Impact strength of the samples.

| Materials | Impact area ($cm^2$) | Absorbed energy (J) | Impact strength ($J/cm^2$) |
|---|---|---|---|
| KB1 | 8.94 | 24.67 | 2.75 |
| KB2 | 8.13 | 34.85 | 4.28 |
| KB3 | 10.82 | 39.34 | 3.63 |

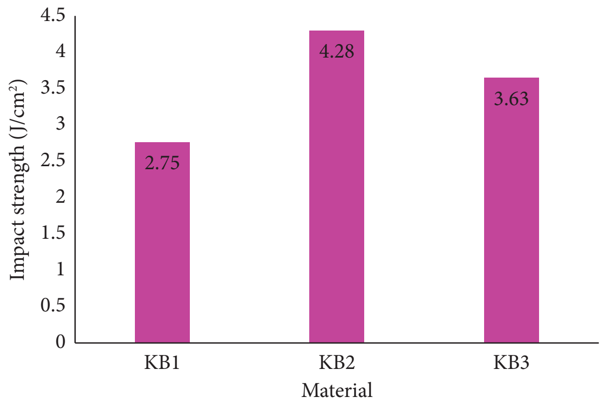
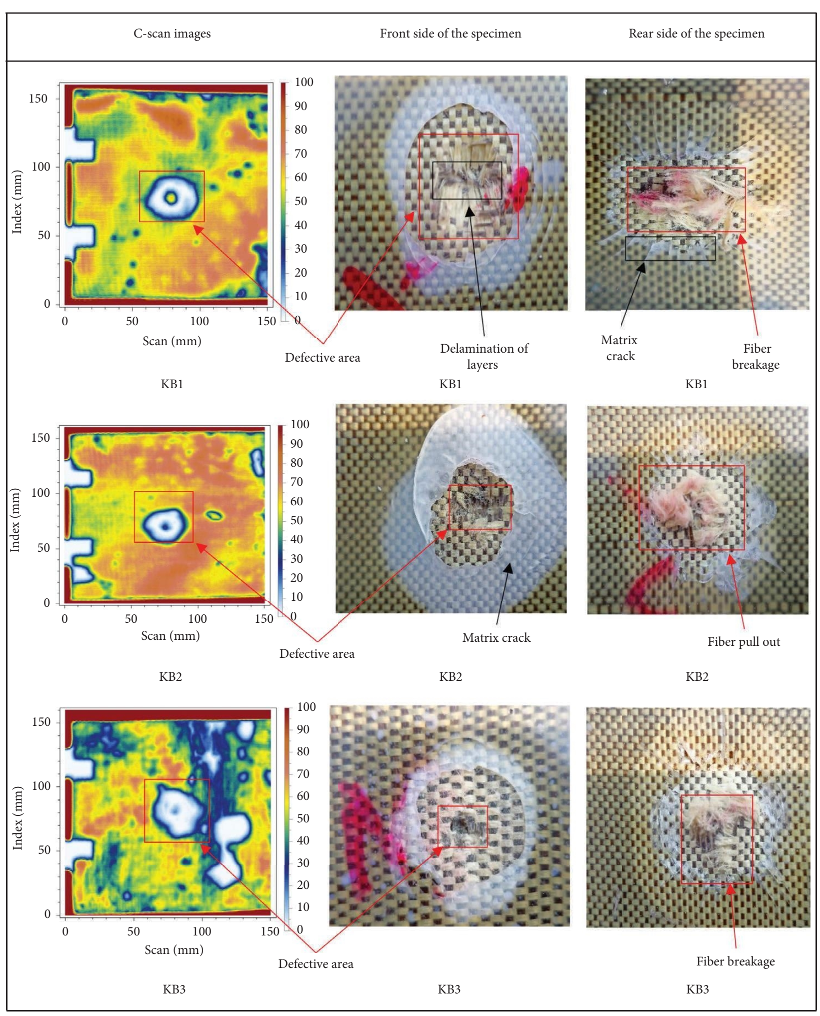



Figure 13: Impact strength vs. composite material.

Table 6: C-scan, front and back side images of all the samples.



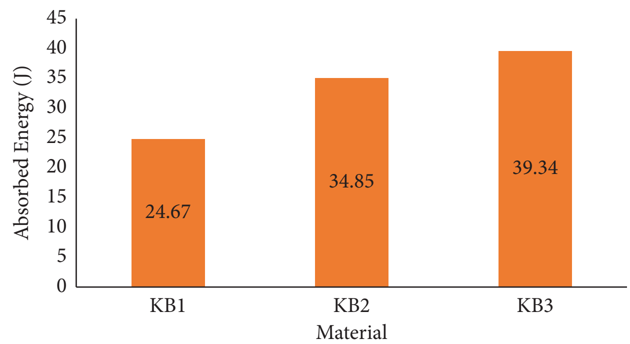



Figure 14: Absorbed energy vs. composite materials.

(iv) Composite failure is due to the high-velocity impact of the projectile, which generates a compression wave through the thickness of the sample and is reflected as a tension wave, causing fiber delamination or detachment between the lamina layers [39]

(v) When the warp and weft threads break in the collision zone, friction between the projectile and target becomes the primary mechanism, continuing to slow the projectile [39]

(vi) The impact area, impact velocity, and residual velocities were predicted using the Image J and Cine viewer software

(vii) Adding nanoparticles to composite materials results in astonishing changes in mechanical properties [25]

(viii) The hybrid samples absorb more energy than individual samples [26]

(ix) It was found that the affected area of KB3 (10.82 $cm^2$) was larger, i.e., more damaged composite panel; this was because the addition of a higher percentage of alumina powder resulted in a small intermolecular gap resulting in a series of alumina particles in one place causing the epoxy bond to break and lead to brittle nature of the material [32].

(x) As the nanopowder content increases, the impact energy increases, and as the impact energy increases, so does the absorbed energy, so the KB3 (39.34 J) composite sample absorbs more energy than the other two samples, as shown in Figure 14 [20, 41]

(xi) In the case of KB1, the alumina content is too low (1%), so the distance between the molecules is too small, which does not help to create stronger bonds between the epoxy molecules, so the impact strength is reduced [40]

(xii) The impact damage area is low in KB2 (8.13 $cm^2$) because of the strong polymeric bond, closely packed structure, and the dense nature obtained by adding nanofillers [31, 41]

(xiii) KB2 (4.28 $J/cm^2$), as shown in Figure 13, gives good impact strength compared to KB1 (2.75 $J/cm^2$) and KB3 (3.63). The mechanical properties of KB2 got heightened due to the modest content of alumina powder that provided proper dispersion of alumina powder which in turn provided more useable area for epoxy to create a strong bond between the molecules which increases the impact strength of the material [41]

(xiv) The presence of alumina particles gives a connection between the epoxy molecules creating a polymer bond that gives resistance to the impact loads [28]

(xv) The percentage of alumina (3%) present in KB2 helped in overcoming the viscous nature of the epoxy molecules and helped to create a strong polymeric chain that increased the impact strength of the specimen [41]

(xvi) The impact strength increases by two times if the content of alumina powder is moderate (KB2), and the impact strength of the composite starts degrading once the nanopowder volume goes beyond the threshold value (KB3)

(xvii) From the conclusions and results made from [28–31], every material has its threshold value in bearing the nanoalumina powder; the mechanical properties of the material increase up the threshold value and then start gradually decreasing and finally leading to the brittle behavior of the material

(xviii) From the tests performed and the results obtained, it is clear that a high percentage of alumina powder can cause higher content of porosity and dispense of alumina particles, and the formation of microcracks [42]

## 5. Conclusion

In this work, the effects of different percentages of nanoalumina powder on the impact strength of Kevlar/basalt and epoxy composites were investigated experimentally and numerically. The fiber layers are made with the help of the weaving process, and the fabrication of the composite is performed by the hand layup method. The ballistic study has been carried out to understand the behavior of the Kevlar/basalt polymer composite with the addition of the alumina nanoparticles. Ultrasonic-C scan was used to find the damage in the subsurface layers and also to find the extent of the damage.

As discussed, the impact area is low in KB2 (8.13 $cm^2$) compared to KB1 (8.94 $cm^2$) and KB3 (10.82 $cm^2$). However, KB3 absorbed more energy (39.34 J) due to the gradual increase of impact strength from the threshold value of alumina powder. As per the results obtained, the impact strength started increasing with the increment of alumina content, and once the percentage increased above the threshold value (i.e., 3% in this study), the mechanical properties started declining. Hence the impact strength is higher in KB2 (4.28 J/$cm^2$), and less in KB3 (3.63 J/$cm^2$), and also the impact area is less in KB2 (8.13 $cm^2$) but more in KB3 (10.82 $cm^2$), this implies KB2 is more resistant to the high-speed ballistic loads due to the modest content of $Al_2O_3$ particles.

Several experiments and tests are still being carried out to explore the various benefits of introducing different nanoparticles to composite materials. Therefore, it is not recommended to use too high alumina powder content (above a threshold value) if the aim is to achieve high-impact resistance; a moderate amount of alumina powder can provide high-impact resistance. Alternatively, the woven Kevlar–basalt/epoxy composites can be spiked with other types of nanofillers available in various proportions, and the resulting changes can be investigated after the impact test.

## 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 regarding the publication.

## References

[1] A. Wondimu, M. Kebede, and S. Palani, “Trash pineapple leaf fiber reinforced polymer composite materials for light applications,” in *Bio-Fiber Reinforced Composite Materials*-Springer, Singapore, 2022.

[2] Y. Sinshaw, B. SirahbizuY, S. Palani, and U. PrakashJ, “Mechanical property analysis of glass particulates reinforced Aluminum matrix composites,” *Materials Today Proceedings*, vol. 62, pp. 488–494, 2022.

[3] S. W. Mekonen, S. Palani, B. Ravi, S. M. Atnaw, M. Desta, and Y. Regassa, “Mechanical properties of Bone particulate and E-glass fiber reinforced hybrid polymer composite,” *Advances in Materials Science and Engineering*, vol. 2022, Article ID 5902616, 7 pages, 2022.

[4] M. P. Saravanan, K. Marimuthu, and P. Sivaprakasam, “Modeling and analysis of dynamic structure with macro fiber composite for energy harvesting,” *Materials Today Proceedings*, vol. 33, pp. 3481–3485, 2020.

[5] K. Kalai Thendral and D. Abraham Antony, “Ballistic Impact analysis of 2D woven Kevlar/Basalt reinforced composite,” *IOP Conference Series: Materials Science and Engineering*, vol. 912, Article ID 052023, 2023.

[6] P. O. Sjoblom, J. T. Hartness, and T. M. Cordell, “On low-velocity impact testing of composite materials,” *Journal of Composite Materials*, vol. 22, no. 1, pp. 30–52, 1988.

[7] S. Safri, M. T. H. Sultan, N. Yidris, and F. Mustapha, “Low velocity and high-velocity impact test on composite materials - a review,” *International Journal of Engineering Sciences*, vol. 3, pp. 50–60, 2014.

[8] B. Tunaboylu, A. G. Elsabagh, A. K. Sari, and R. Akdeni, “Simulation and experimental tests of ballistic impact on composite laminate armor,” *Advances in Materials Science and Engineering*, vol. 2018, Article ID 4696143, 12 pages, 2018.

[9] E. A. Duodu, J. Gu, W. Ding, and S. Tang, “Performance of composite structures subjected to high-velocity impact,” *Journal of Researches in Engineering*, vol. 16, no. 4, 2016.

[10] N. K. Naik, “Composite structures under ballistic impact,” *Composite Structures*, vol. 66, no. 1–4, pp. 579–590, 2004.

[11] A. N. Nair, S. Sundharesan, and I. S. M. Al Tubi, “Kevlar-based composite material and its applications in body armour: a short literature review,” *IOP Conference Series: Materials Science and Engineering*, vol. 987, Article ID 012003, 2003.

[12] R. Stopforth and S. Adali, “Experimental study of bullet-proofing capabilities of kevlar of different weights and number of layers, with 9 mm projectiles,” *Defence Technology*, vol. 15, no. 2, pp. 186–192, 2019.

[13] E. Kowsari and J. Hemmat, “Aramid fibers composites to innovative sustainable materials for biomedical applications,” *Materials for Biomedical Engineering*, Elsevier, Amsterdam, Netherlands, 2022.

[14] K. Pareek and P. Saha, “Basalt fiber and its composites: an overview,” in *Proceedings of the National Conference on Advances in Structural Technologies (CoAST2019)*, Silchar, India, February 2019.

[15] T. Czigány, “Special manufacturing and characteristics of basalt fiber reinforced hybrid polypropylene composites: mechanical properties and acoustic emission study,” *Composites Science and Technology*, vol. 66, no. 16, pp. 3210–3220, 2006.

[16] R. Anjabin and H. Khosravi, “Property improvement of a fibrous composite using functionalized carbon nanofibers,” *Polymer Composites*, vol. 40, no. 11, pp. 4281–4288, 2019.

[17] N. Jamali, H. Khosravi, A. Rezvani, and E. Tohidlou, “Mechanical properties of multiscale graphene oxide/basalt fiber/epoxy composites,” *Fibers and Polymers*, vol. 20, no. 1, pp. 138–146, 2019.

[18] N. Jamali, A. Rezvani, H. Khosravi, and E. Tohidlou, “On the mechanical behavior of basalt fiber/epoxy composites filled with silanized graphene oxide nanoplatelets,” *Polymer Composites*, vol. 39, no. S4, Article ID E2472, 2018.

[19] Y. Swolfs, R. M. McMeeking, I. Verpoest, and L. Gorbatikh, “The effect of fibre dispersion on initial failure strain and cluster development in unidirectional carbon/glass hybrid composites,” *Composites Part A: Applied Science and Manufacturing*, vol. 69, pp. 279–287, 2015.

[20] M. R. Karamooz, H. Rahmani, and H. Khosravi, “Hybrid effects of basalt and kevlar fibers on low-velocity impact behavior of epoxy-based composites,” *Fibers and Polymers*, vol. 21, no. 11, pp. 2590–2598, 2020.

[21] V. Lopresto, C. Leone, and I. De Iorio, “Mechanical characterisation of basalt fibre reinforced plastic,” *Composites Part B: Engineering*, vol. 42, no. 4, pp. 717–723, 2011.

[22] A. Kunal Singha, “Short review on basalt fiber,” *International Journal of Textile Science*, vol. 1, no. 4, pp. 19–28, 2012.

[23] J. Tirillò, L. Ferrante, F. Sarasini et al., "High velocity impact behaviour of hybrid basalt-carbon/epoxy composites," *Composite Structures*, vol. 168, pp. 305–312, 2017.

[24] A. K. Bandaru, S. Patel, Y. Sachan, R. Alagirusamy, N. Bhatnagar, and S. Ahmad, "Low velocity impact response of 3D angle-interlock Kevlar/basalt reinforced polypropylene composites," *Materials & Design*, vol. 105, pp. 323–332, 2016.

[25] A. Chaurasia, R. S. Mulik, and A. Parashar, "Polymer-based nanocomposites for impact loading: a review," *Mechanics of Advanced Materials and Structures*, vol. 29, 2021.

[26] X. Zhao, S. Lu, W. Li et al., *Epoxy as Filler or Matrix for Polymer Composites*, IntechOpen, London, UK, 2022.

[27] V. Mahesh, D. Harursampath, and V. Mahesh, "An experimental study on ballistic impact response of jute reinforced polyethylene glycol and nano silica based shear thickening fluid composite," *Defence Technology*, vol. 18, 2022.

[28] R. Mukherjee and S. De, "Adsorptive removal of nitrate from aqueous solution by polyacrylonitrile–alumina nanoparticle mixed matrix hollow-fiber membrane," *Journal of Membrane Science*, vol. 466, pp. 281–292, 2014.

[29] C.-C. Yang, S.-J. Chiu, W.-C. Chien, and S.-S. Chiu, "Quaternized poly(vinyl alcohol)/alumina composite polymer membranes for alkaline direct methanol fuel cells," *Journal of Power Sources*, vol. 195, no. 8, pp. 2212–2219, 2010.

[30] W. Zhou, S. Qi, C. Tu, H. Zhao, C. Wang, and J. Kou, "Effect of the particle size of Al2O3 on the properties of filled heat-conductive silicone rubber," *Journal of Applied Polymer Science*, vol. 104, no. 2, pp. 1312–1318, 2007.

[31] B. Sadeghi, M. Shamanian, F. Ashrafizadeh, P. Cavaliere, and A. Rizzo, "Influence of Al2O3 nanoparticles on microstructure and strengthening mechanism of Al-based nanocomposites produced via spark plasma sintering," *Journal of Materials Engineering and Performance*, vol. 26, 2022.

[32] S. Mallakpour and E. Khadem, "Recent development in the synthesis of polymer nanocomposites based on nano-alumina," *Progress in Polymer Science*, vol. 51, pp. 74–93, 2015.

[33] J. P. Johnston, J. M. Pereira, C. R. Ruggeri, and G. D. Roberts, "High-speed infrared thermal imaging during ballistic impact of triaxially braided composites," *Journal of Composite Materials*, vol. 52, 2022.

[34] A. Amirian, H. Rahmani, and H. Moeinkhah, "An experimental and numerical study of epoxy-based Kevlar-basalt hybrid composites under high velocity impact," *Journal of Industrial Textiles*, vol. 51, pp. 804S–821S, 2021.

[35] M. F. Raiminor Ramzi, F. M. Mahmod, and A. B. Elmi, "Immersion ultrasonic inspection system for small scaled composite specimen," *Journal of Engineering and Applied Sciences*, vol. 10, no. 22, 2022.

[36] S. Arhamnamazi, N. Bani, N. B. M. Arab, A. R. Oskouei, and F. Aymerich, "Accuracy assessment of ultrasonic C-scan and X-ray radiography methods for impact damage detection in glass fiber reinforced polyester composites," *Journal of Applied and Computational Mechanics*, vol. 5, 2018.

[37] V. Mahesh, S. Joladarashi, and S. M. Kulkarni, "Damage mechanics and energy absorption capabilities of natural fiber reinforced elastomeric based bio composite for sacrificial structural applications," *Defence Technology*, vol. 17, no. 1, pp. 161–176, 2021.

[38] M. Moyo, K. Kanny, and R. Velmurugan, "Performance of kenaf non-woven mat/PLA biocomposites under medium velocity impact," *Fibers and Polymers*, vol. 21, no. 11, pp. 2642–2651, 2020.

[39] A. K. Bandaru, V. V. Chavan, S. Ahmad, R. Alagirusamy, and N. Bhatnagar, "Ballistic impact response of kevlar reinforced thermoplastic composite armors," *International Journal of Impact Engineering*, vol. 89, pp. 1–13, 2016.

[40] S. Zhang, X. Y. Cao, Y. M. Ma, Y. C. Ke, J. K. Zhang, and F. S. Wang, "The effects of particle size and content on the thermal conductivity and mechanical properties of Al2O3/high density polyethylene (HDPE) composites," *Express Polymer Letters*, vol. 5, no. 7, pp. 581–590, 2011.

[41] In-Y. Jeon and J.-B. Baek, "Nanocomposites derived from polymers and inorganic nanoparticles," *Materials*, vol. 3, no. 6, pp. 3654–3674, 2010.

[42] N. Srivastava and G. P. Chaudhari, "Microstructural evolution and mechanical behavior of ultrasonically synthesized Al6061-nano alumina composites," *Materials Science and Engineering A*, vol. 724, pp. 199–207, 2018.