Hindawi
Advances in Materials Science and Engineering
Volume 2023, Article ID 8933844, 8 pages
https://doi.org/10.1155/2023/8933844

Research Article

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

J. Jensin Joshua,[1] **Dalbir Singh**,[1] **Y. Murali Krishna**,[1] **P. Sivaprakasam**,[2] **D. Raja Joseph**,[1] and **P. S. Venkatanarayanan**[1]

[1]*School of Aeronautical Sciences, Hindustan Institute of Technology & Science, Chennai, India*
[2]*Department of Mechanical Engineering, College of Electrical and Mechanical Engineering, Center of Excellence-Nanotechnology, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia*

Correspondence should be addressed to P. Sivaprakasam; shiva@aastu.edu.et

Received 25 June 2022; Revised 1 November 2022; Accepted 25 November 2022; Published 20 November 2023

Academic Editor: R. Thanigaivelan

The application of composite materials has increased so 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/cm^2.

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 limit. Aghamohammadi et al. [11] in their paper fabricated a metal hybrid composite laminate with basalt fiber and aluminium 2024 T3. MWCNT was also added in different percentages to study the flexural and high-velocity impact properties. From the study, it was found out that there was an increase in the flexural property alone. The impact property did not have an immense effect. It has been mentioned that the hybridization of high-strength and high-stiffness fibers would yield better characteristics [12–14]. Hybridization of composites can enhance the mechanical and wear properties of the composites [15]. In thermoset and thermoplastics polymers, glass fiber is used as a reinforcing agent because of its high dimensional stability, high tensile strength, chemical resistance, and low cost with good insulating properties, whereas basalt fiber have good chemical resistance, thermal stability (can also be used in wide range temperature of −200°C to 600°C), mechanical stress, string, and durable. It is obtained naturally as mineral fiber and has impressive performance for advantageous price [16]. When comparing the fibers basalt to glass the chemical stability of basalt fiber in acidic environment is better than glass fiber [17], in the mechanical point of view the elastic modulus of basalt fiber strongly depends on chemical composition but the tensile strength and elongation at break are slightly higher when compared to glass fiber [18].

Also, from the experimental work it is evident that increasing the kevlar content could increase the energy absorption of the material [19]. In glass fiber, the weaving angle between 20° and 30° are observed to be absorbing more energy than that of weaving angle of 60°, 70°, 80°, and 90° [20]. Under the nominal temperature, the tensile strength of basalt fiber is greater than that of glass with 2850 MPa and 2450 MPa, respectively, considering it has a better alternative for glass [21]. At high temperatures of 700°C, the strength of basalt has reduced to 50%, whereas the glass has completely lost its strength characteristics. Due to its increase in load with thermal resistance, basalt fiber has been used in carrying the Space Shuttle [22]. Li et al. [23] have expressed in their experiment that the basalt retains its strength even at the lowest temperature of −96°C. Fu et al., [24] has concluded in his investigation that for the sharp projectile, the woven basalt fiber composites (WBFCs) possess very good low velocity impact resistance than that of unidirectional basalt fiber composites (UBFC) also WBFC has better stiffness than UBFC. It is evident that the damage tolerance and the resistance of a material can be increased by 3D stitching the material. It has also been shown that 3D stitching could increase the impact resistance of the material by up to 20% [25].

To improve the strength of the composite laminate either the composite laminate can be prepared by hybridization or by the addition of the nanoparticles [26]. Enough research in weaving of kevlar with basalt and glass for high-velocity impact studies is not available. So, in the current study, a composite laminate is prepared by weaving (hybridization) the fibers of kevlar-basalt [KB] and kevlar-glass [KG] with epoxy being resin in both cases. Hand loom technique is followed to weave the fibers of basalt and glass with kevlar. The novelty in the current study involves weaving of fibers in three different types and carrying out high-velocity bullet impact on it.

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 1×1” lamina is prepared [plain weave]. Similarly, every single fiber of glass fiber is interlaced with single fiber of Kevlar and “kg 1×1” 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 3×3” lamina is prepared. Similarly, every three fibers of glass is interlaced after every three fibers of kevlar and “kg 3×3” 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 5×5” lamina are prepared. Similarly five fibers of glass are interlaced after every five fibers of kevlar and “kg 5×5” lamina are prepared.

As a result, six different lamina are prepared [kb 1×1, kb 3×3, kb 5×5, kg 1x, kg 3x, and kg 5×5]. Then five layers of “kb 1×1” lamina with 300×300 mm dimension are staked one over the other and “KB 1×1” laminate is prepared, epoxy being the resin. Similarly five composite laminates [KB 3×3, KB 5×5, KG 1×1, KG 3×3, and KG 5×5] are prepared using the compression moulding method with (300×300) mm dimension. Then the laminate is cut into 150 mm × 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 5×5 and KG 5×5.

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

Table 1: Specification of the projectile.

Particulars	Specification
Material	Mild steel
Mass	7.34 (g) or 0.00734 (kg)
Length	15.5 (mm)
Diameter	9.66 (mm)

Table 2: Inlet and residual velocity of the projectile.

Material	Average inlet velocity in m/s	Average residual velocity in m/s
KB 1 × 1	225.67	173.67
KB 3 × 3	225	196
KB 5 × 5	250.5	176.67
KG 1 × 1	256	200.33
KG 3 × 3	253	196
KG 5 × 5	249	176.67

scan method is used to obtain the images of the impacted materials and then the area is calculated using Image J software. Then those areas are used to calculate the impact strength of the materials. The system consists of an Ultrasonic 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]

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

where, E_{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 cm^2, 33.36 cm^2, 21.16 cm^2, 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.

$$\text{impact strength} = \frac{(\text{energy absorbed})}{(\text{damaged area})}. \quad (2)$$

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/cm^2, 7.633 J/cm^2, and 19.323 J/cm^2, respectively, while the impact strength of KG 1 × 1, KG 3 × 3, and KG 5 × 5 are 2.494 J/cm^2, 2.816 J/cm^2, and 5.340 J/cm^2, 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/cm^2 with area of 2.698 cm^2, followed by KB 5 × 5 which has an impact strength of 19.323 J/cm^2 with area of 5.99 cm^2 and the hybrid of glass and kevlar are observed to be having lowest impact strength of 2.494 J/cm^2 with the area of 37.39 cm^2. 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/cm^2 [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 3: Absorbed energy of composite materials.

Material	Impact velocity (m/s)	Impact energy (J)	Residual velocity (m/s)	Residual energy (J)	Absorbed energy (J)
KB 1 × 1	225.67	186.902	173.67	110.692	76.21
KB 3 × 3	225	185.794	196	140.987	44.807
KB 5 × 5	250.5	230.293	176.67	114.549	115.744
KG 1 × 1	256	240.517	200.33	147.285	93.232
KG 3 × 3	253	234.913	196	140.987	93.926
KG 5 × 5	249	227.544	176.67	114.549	112.995

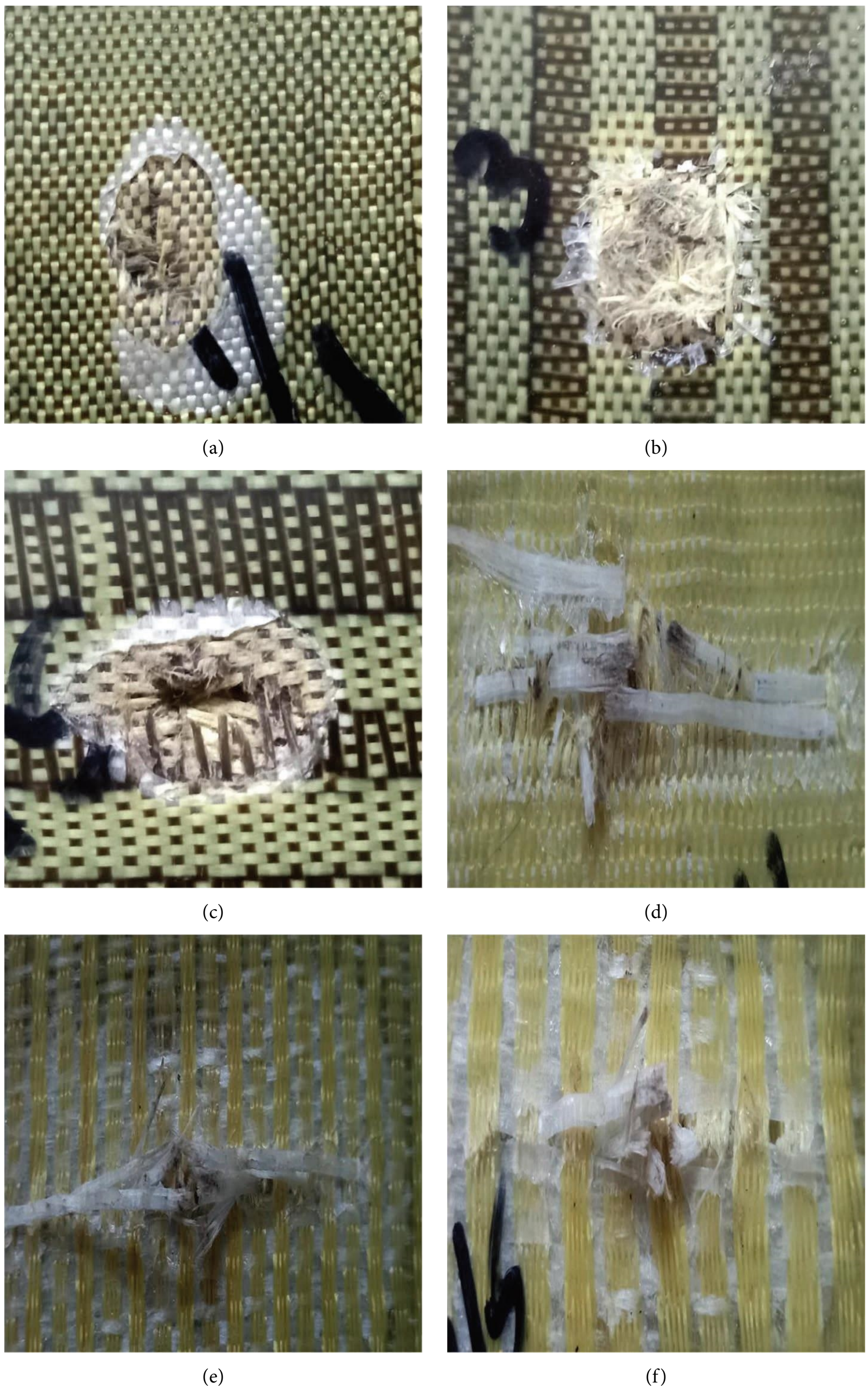

Figure 1: Front face of the impacted specimen (a) KB 1 × 1, (b) KB 3 × 3, (c) KB 5 × 5, (d) KG 1 × 1, (e) KG 3 × 3 and (f) KG 5 × 5.

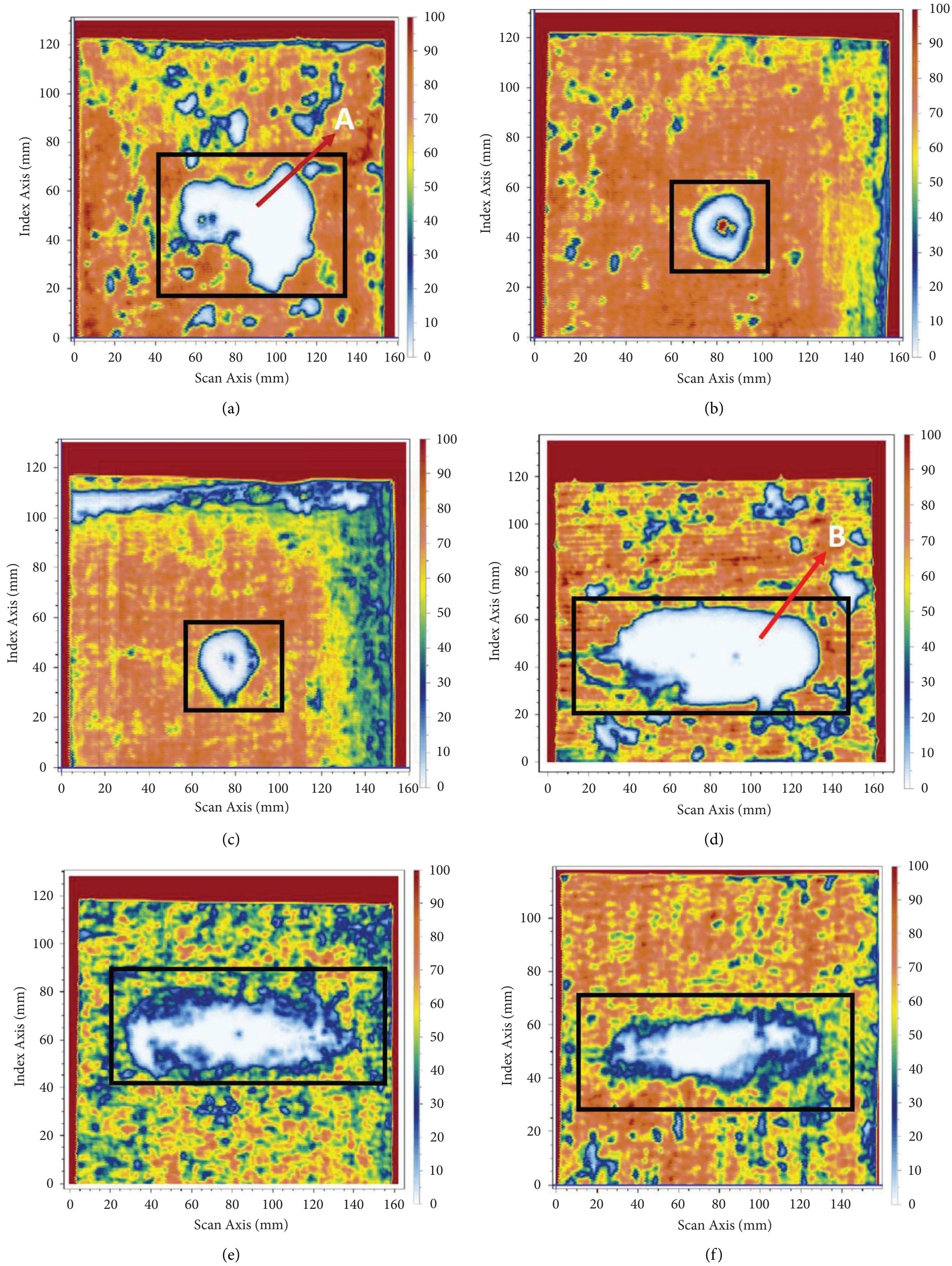

Figure 2: Ultrasonic C scan images (a) KB 1×1, (b) KB 3×3, (c) KB 5×5, (d) KG 1×1, (e) KG 3×3 and (f) KG 5×5.

Table 4: Impact strength of composite materials.

Material	Area in cm^2	Absorbed energy (J)	Impact strength (J/cm^2)
KB 1×1	2.698	76.21	28.24
KB 3×3	5.87	44.807	7.633
KB 5×5	5.99	115.744	19.323
KG 1×1	37.39	93.232	2.494
KG 3×3	33.36	93.926	2.816
KG 5×5	21.16	112.995	5.340

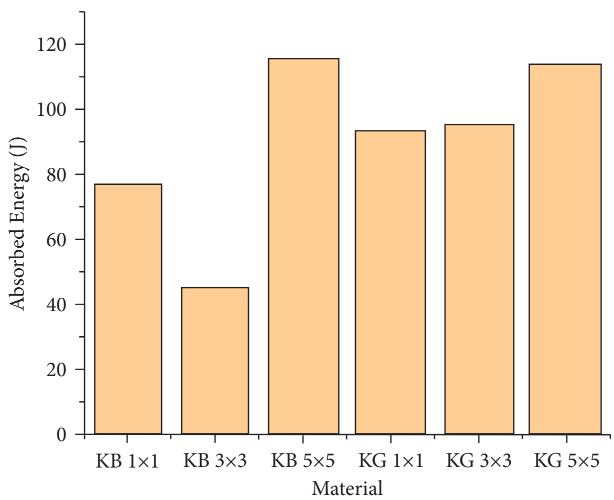

Figure 3: Energy absorbed vs. composite material.

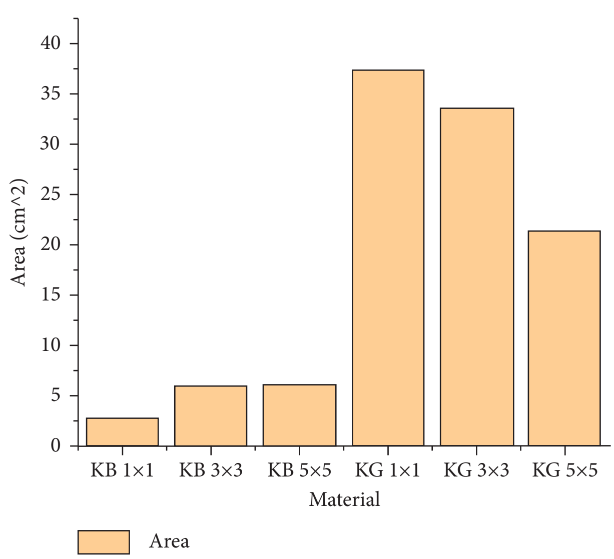

Figure 4: Area vs. composite material.

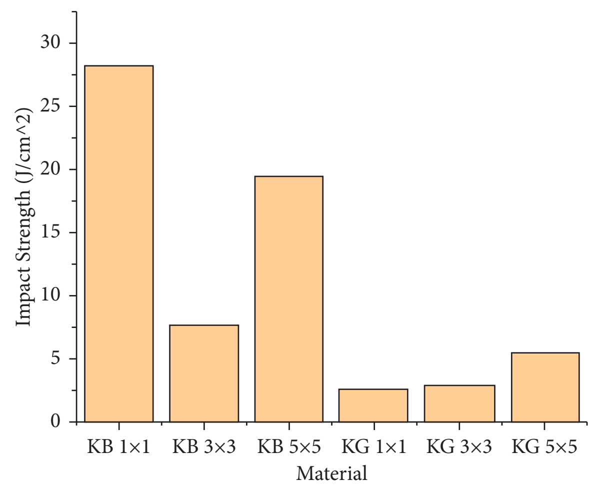

Figure 5: Impact strength vs. composite material.

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 $1 \times 1 >$ KB $5 \times 5 >$ KB $3 \times 3 >$ KG $5 \times 5 >$ KG $3 \times 3 >$ 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.

(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. Venkatanarayanan performed reviewing and editing.

References

[1] Y. Sun, C. Shi, Z. Liu, and D. Wen, "Theoretical research progress in high-velocity/hypervelocity impact on semi-infinite targets," *Shock and Vibration*, vol. 2015, Article ID 265321, 15 pages, 2015.

[2] S. N. A. 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 Science*, vol. 3, pp. 50–60, 2014.

[3] I. Mohagheghian, Y. Wang, J. Zhou et al., "Deformation and damage mechanisms of laminated glass windows subjected to high velocity soft impact," *International Journal of Solids and Structures*, vol. 109, pp. 46–62, 2017.

[4] H. Sylvestre and V. R. R. Parama, "Space debris: reasons, types, impacts and management," *Indian Journal of Radio and Space Physics*, vol. 46, pp. 20–26, 2017.

[5] W. P. Schonberg, "Studies of hypervelocity impact phenomena as applied to the protection of spacecraft operating in the MMOD environment," *Procedia Engineering*, vol. 204, pp. 4–42, 2017.

[6] P. J. Hogg, "Composites in armor," *Science*, vol. 314, pp. 1100-1101, 2006.

[7] M. Hisham, M. Fahaduddin, M. A. Khan, B. C. Ashok, and P. K. Shrivastava, "A research on kevlar and hybrid kevlar composites; A report," *International Journal of Recent Technology and Engineering*, vol. 8, no. 2S3, pp. 830–833, 2019.

[8] N. Shaari and A. Jumahat, "Unhole and open hole compressive behaviours of hybrid Kevlar/glass fibre reinforced silica nanocomposites," *Materials Research Express*, vol. 5, no. 6, Article ID 065009, 2018.

[9] R. Velumayil and A. Palanivel, "Hybridization effect on mechanical properties of basalt/kevlar/epoxy composite laminates," *Polymers*, vol. 14, no. 7, 2022.

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

[11] H. Aghamohammadi, R. F Eslami, and A. Tcharkhtchi, "The effect of multi-walled carbon nanotubes on the mechanical behavior of basalt fibers metal laminates: an experimental study," *International Journal of Adhesion and Adhesives*, vol. 98, Article ID 102538, 2020.

[12] M. Damghani, N. Ersoy, M. Piorkowski, and A. Murphy, "Experimental evaluation of residual tensile strength of hybrid composite aerospace materials after low velocity impact," *Composites Part B: Engineering*, vol. 179, Article ID 107537, 2019.

[13] A. Wondimu, M. Kebede, and S. Palani, "Trash pineapple leaf fiber reinforced polymer composite materials for light applications," in *Bio-Fiber Reinforced Composite Materials*, pp. 13–30, Springer, Singapore, 2022.

[14] A. Divya Sadhana, J. Udaya Prakash, P. Sivaprakasam, and S. Ananth, "Wear behaviour of aluminium matrix composites (LM25/Fly ash)–A Taguchi approach," *Materials Today Proceedings*, vol. 33, pp. 3093–3096, 2020.

[15] J. U. Prakash, P. Sivaprakasam, I. Garip et al., "Wire electrical discharge machining (WEDM) of hybrid composites (Al-Si12/B4C/fly Ash)," *Journal of Nanomaterials*, vol. 2021, Article ID 2503673, 10 pages, 2021.

[16] T. Yashas Gowda, G. Vinod, and P. Madhu, ""A new study on flax-basalt-carbon fiber reinforced epoxy/bioepoxy hybrid composites"," *Polymer Composites*, vol. 42, no. 4, pp. 1891–1900, 2021.

[17] F. Sarasini, J. Tirillò, L. Ferrante et al., "Drop-weight impact behaviour of woven hybrid basalt–carbon/epoxy composites," *Composites Part B: Engineering*, vol. 59, pp. 204–220, 2014.

[18] J. Gustin, A. Joneson, M. Mahinfalah, and J. Stone, "Low velocity impact of combination Kevlar/carbon fiber sandwich composites," *Composite Structures*, vol. 69, no. 4, pp. 396–406, 2005.

[19] R. Yahaya, S. M. Sapuan, M. Jawaid, Z. Leman, and E. S. Zainudin, "Measurement of ballistic impact properties of woven kenaf–aramid hybrid composites," *Measurement*, vol. 77, pp. 335–343, 2016.

[20] T. Sathishkumar, S. Satheeshkumar, and J. Naveen, "Glass fiber-reinforced polymer composites – a review," *Journal of Reinforced Plastics and Composites*, vol. 33, no. 13, pp. 1258–1275, 2014.

[21] E. Kessler, R. Gadow, and J. Straub, "Basalt, glass and carbon fibers and their fiber reinforced polymer composites under thermal and mechanical load," *AIMS Materials Science*, vol. 3, no. 4, pp. 1561–1576, 2016.

[22] V. J. John and B. Dharmar, "Influence of basalt fibers on the mechanical behavior of concrete—a review," *Structural Concrete*, vol. 22, no. 1, pp. 491–502, 2020.

[23] Z. Li, J. Ma, H. Ma, and X. Xu, "Properties and applications of basalt fiber and its composites," *IOP Conference Series: Earth and Environmental Science*, vol. 186, Article ID 012052, 2018.

[24] H. Fu, X. Feng, J. Liu, Z. Yang, C. He, and S. Li, "An investigation on anti-impact and penetration performance of basalt fiber composites with different weave and lay-up modes," *Defence Technology*, vol. 16, no. 4, pp. 787–801, 2020.

[25] D. P. C. Aiman, M. F. Yahya, and J. Salleh, "Impact properties of 2D and 3D woven composites: a review," *AIP Conference Proceedings. Author(s)*, vol. 1774, 2016.

[26] R. F Eslami, H. Aghamohammadi, S. Mohammad Reza Khalili, and J. Hamid, "Recent trend in developing advanced fiber metal laminates reinforced with nanoparticles: a review study," *Journal of Industrial Textiles*, vol. 51, no. 5_supp, pp. 7374S–7408S, 2022.

[27] T. Hasiotis, E. Badogiannis, and N. G. Tsouvalis, "Application of ultrasonic C-scan techniques for tracing defects in laminated composite materials," *Strojniškivestnik – Journal of Mechanical Engineering*, vol. 3, pp. 192–203, 2011.

[28] E. Kazemi-Khasragh, F. Bahari-Sambran, M. HosseinSiadati, and R. EslamiFarsani, "High velocity impact response of basalt fibers/epoxy composites containing GrapheneNanoplatelets," *Fibers and Polymers*, vol. 19, no. 11, pp. 2388–2393, 2018.

[29] 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.

[30] M. Moyo, K. Kanny, and R. Velmurugan, "Performance of kenaf non-woven mat/PLA biocomposites under medium velocity impact," *Fibers and Polymers*, vol. 21, pp. 2642–2651, 2020.

[31] T. A. Lenda and S. Mridha, "Impact strength of carbon reinforced epoxy composite at different temperatures," *Advanced Materials Research*, vol. 264, pp. 451–456, 2011.

[32] S. Chocron, A. J. Carpenter, N. L. Scott, R. P. Bigger, and K. Warren, "Impact on carbon fiber composite: ballistic tests, material tests, and computer simulations," *International Journal of Impact Engineering*, vol. 131, no. 143, pp. 39–56, 2019.