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ORIGINAL ARTICLE

Layer Influence on Organosilica Composites Strength to Withstand the Impact of 9mm Caliber Bullets

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ABSTRACT – The use of steel panels in conventional bulletproof vests is no longer relevant to current needs. In addition to being heavy, troop flexibility is disrupted. It is necessary to develop lighter and more reliable composite panels. The purpose of this study was to determine the ability of organosilica resin composite panels that were given variations of 5, 7, and 9 layers of woven fiberglass to withstand 9 mm caliber bullets using the NIJ-0101.06 Standard. The firing test results showed that the bullets were held back in the 7th and 9th layers. This result shows that this composite is a worthy candidate for replacing conventional steel panels in bulletproof vests.

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INTRODUCTION

The ongoing war in Ukraine involves the military forces of Russia, Ukraine, and North Atlantic Treaty Organization (NATO) [1]. Sophisticated weapons and the latest combat vehicles have been deployed to showcase their capabilities on the battlefield [2]. This conflict has also served as an indirect warning to other countries, highlighting the potential for broader international escalation. As a result, there is growing concern that this war could trigger conflicts in other parts of the world. In an era characterized by the increase in the lethality of contemporary warfare, the need for enhanced soldier protection and operational effectiveness has become paramount to research.

The advancement of modern warfare technology has significantly increased the risks to soldiers' lives. In today's battlefield, soldiers often face highly mobile enemies, such as terrorists or guerrilla forces, who are difficult to identify and can strike quickly [3]. Consequently, soldiers must continuously adapt their tactics to stay ahead of these fast-moving threats. The ever-present risk of injury from enemy projectiles forces soldiers to take measures to protect themselves, as survival on the battlefield heavily depends on minimizing injuries. The ability to reach strategic positions and complete missions is essential, and any injuries sustained can compromise a unit's operational capacity [4].

One of the key responses to this evolving threat is the development of personal protective equipment, particularly bulletproof vests [5]. Bulletproof vests are designed to shield vital areas of the body to reduce the risk of life-threatening injuries caused by sharp objects or projectiles [6]. This vest comes in various types, each offering different levels of protection. These vests are engineered to absorb or deflect the impact of bullets or knives. Typically, bulletproof vests consist of an outer layer made from protective fibers like Kevlar, which help distribute the pressure from impacts [7]–[10]. Inside the vest, a steel plate is often included to block high-speed projectiles that manage to penetrate the Kevlar layer. This dual-layer system significantly reduces the likelihood of fatal injuries caused by bullet impacts [11]. However, the weight of the steel plates can hinder soldier mobility, making it challenging for them to maneuver quickly on the battlefield [12].

In response to these mobility challenges, researchers have been investigating alternative materials to replace steel plates, such as ceramics and composites [13], [14]. Composite materials, which combine various materials for enhanced protection and reduced weight, have emerged as a promising solution. These materials, particularly composites, are lighter and easier to fabricate compared to steel plates [15]–[17]. Despite this promise, experiments with composite panels made from carbon fiber and polyester resin have shown that they were ineffective at stopping bullets, as they were successfully penetrated in testing [18]. However, more recent studies have demonstrated that ballistic panels made from carbon fiber and 16% hollow glass microsphere (HGM)-Epoxy—at a thickness of 20 mm and a weight of 1,384 kg—can withstand projectile impacts, with penetration limited to just 3,28 mm [6]. Shear thickening fluid (STF)/Twaron has shown potential for effectively stopping bullets, especially when the layers are increased [4].

Among the promising innovations in this field is the development of fiberglass-based bulletproof composite panels. Fiberglass's unique mechanical and thermal properties present significant opportunities for enhancing the performance of ballistic protection systems [3], [19], [20]. For instance, a multi-panel composite made from woven roving fiberglass and polyester resin, with varying panel configurations, has been tested. In one of the configurations, the projectile was stopped by the second panel [21]. Another fascinating development involves the integration of silicon, particularly organo-silica sourced from rice husk, into composite materials. This combination significantly enhances the energy absorption capabilities of the material and reduces the likelihood of failure upon impact. Furthermore, silicon's resistance to extreme temperatures makes it ideal for use in various operational environments [22].

The use of fiberglass composites as panels in bulletproof vests is expected to reduce the weight of bulletproof vests, replacing conventional panels that use quite heavy steel metal. The use of dual-panel fiberglass composites has been known to withstand bullet speeds in the second panel section. However, the use of dual panels in bulletproof vests is still too thick. So, it can potentially hinder the movement of combat personnel on the battlefield. For this reason, it is necessary to study further the ability of fiberglass composites to withstand bullets when made as a single panel. This research aims to further explore the use of fiberglass-based composites, reinforced with organo-silica and polyester resin, for creating effective single-panel ballistic protection systems. The specimens will be tested according to the NIJ-0101.06 standard for type-IIA vests, where is the body armor will provide minimal protection against smaller caliber handgun threats [23], [24]. These composite panels offer several advantages: they are more affordable, lighter, and easier to manufacture, making them a viable alternative to traditional steel-based vests in personal protective equipment.

EXPERIMENTAL METHOD

Materials and Methods

The composite panel specimens were fabricated using the hand lay-up method, each measuring 25 × 25 cm. The matrix material used was fiberglass woven roving mat (WRM)-800 type S-Class. For the filler, YUKALAC BQTN-EX polyester resin was employed, along with organo-silica derived from reinforced rice husk. The composite panels were created with three variations of WRM layers: 5, 7, and 9 layers.

The panel manufacturing process begins with the manufacture of resin that is given 10 wt% organo-silica powder as a filler. Then, the filler is applied to the matrix layer by layer using the hand lay-up method in the mold. Furthermore, compaction is carried out to remove trapped bubbles. After the panel has hardened, it is baked at a temperature of 70 °C for 60 minutes, before the panel is ready to be tested. Each panel that has been made (5 layers, 7 layers, 9 layers) has a thickness of 13 mm, 14 mm, and 15 mm.

Testing and Characterization

The ballistic testing was carried out at the PERBAKIN Cilegon GSCC Balemkambang shooting range. The shooting was conducted using a CZ Shadow-2 9mm caliber pistol, fired at a distance of 10 meters, according to the NIJ-0101.06 standard for type-IIA vests. MU1-TJ ammunition, manufactured by PT. PINDAD was used. This ammunition has a mass (m) of 8 grams and an average velocity (v) of 380 m/s.

Impact testing was performed in accordance with ASTM E23-18 standards for metallic materials. For morphological analysis, an optical microscope with 800× magnification was used to observe the specimen's surface and structure after the test. Measurement of the depth of bullet penetration was carried out using a caliper with an accuracy of 0.05 mm.

RESULT AND DISCUSSION

Shooting Test Results

The results of the shooting test on the three composite panel samples are visually represented in Figure 1. In the composite panel with 5 layers of woven roving mat (WRM) fiberglass (Figure 1 (a)), the bullet successfully penetrated the panel. The area of damage is visible on the back side of the panel. This damage indicates that, although the projectile managed to penetrate the back, the last layer of fiberglass attempted to disperse the projectile's impact energy radially [21]. As a result, the kinetic energy of the projectile after penetrating the panel is lower.

In the sample specimen with 7 layers of WRM fiberglass (Figure 1 (b)), the bullet was effectively stopped by the panel, and the resulting impact caused the panel to undergo structural deformation. The damaged area on the back side, where the projectile was blocked, appears oval-shaped. This deformation suggests that, in addition to absorbing kinetic energy, the panel's layers also absorbed energy to deform the projectile structure itself [25].

For the sample with 9 layers of WRM fiberglass (Figure 1 (c)), the bullet was again stopped by the panel. However, this time, the impact did not cause any visible damage to the back side of the panel. This outcome shows an improvement in the panel's ability to withstand impact loads and effectively distribute the shock of the projectile strike. The front of the composite panel, where the projectile impacted, exhibited damage similar to the other variations.

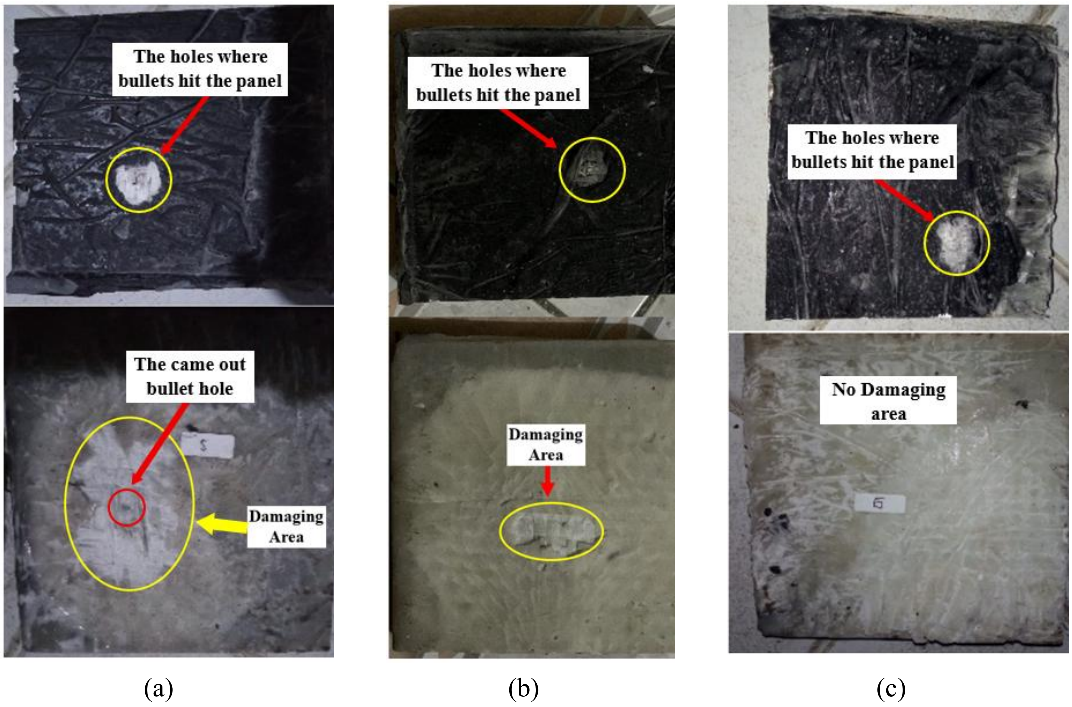

Figure 1. Shooting result for specimen panel with (a) 5, (b) 7, and (c) 9 layers of WRM fiberglass

Optical Identification

The optical identification of the composite panel samples using a microscope is shown in Figure 2. In the 5-layer sample (Figure 2 (a)), fibers that failed to absorb the shock load were pulled out. The filler material had separated from the fiberglass, and the fiberglass itself broke due to its inability to withstand the impact from the projectile. It appears that the 5th layer of fiberglass experienced a long tensile break, indicating the projectile was quite strongly held in that layer. The 7-layer specimen (Figure 2 (b)) shows that the projectile embedded deeply in the composite panel passed through 5 layers of WRM fiberglass before being retained on the 6th layer of fiberglass, where it absorbed the incoming energy. This also led to deformation of the projectile structure. The 9-layer sample (Figure 2 (c)) shows that the penetration depth of the projectile is much shallower when compared to the 7-layer sample. The projectile successfully passed through 5 layers of WRM fiberglass but was retained at the 6th layer. Furthermore, upon impact, the projectile was deformed to flatter [5]. Additionally, the back side of the panel appeared unaffected by the projectile impact.

From the measurement results using a vernier caliper, it is also known that the penetration distance of the bullet on samples with 7 and 9 layers of fiberglass is 6 mm and 5 mm from the panel surface. In both specimens, we also found that the projectile was stopped in front of the 6th layer. This indicates that in the 5th layer, the projectile has exhausted its destructive energy.

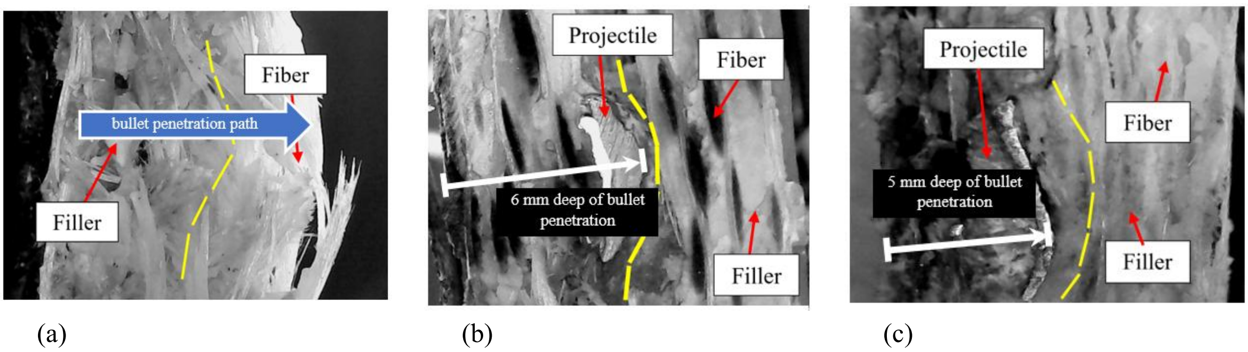

Figure 2. Microstructure of (a) 5-layer, (b) 7-layer, and (c) 9-layer WRM after the shooting test

Impact Test

The impact testing aimed to evaluate the effect of adding layers of WRM fiberglass to the bulletproof composite panels, specifically their ability to withstand low-speed impact shock loads [7], [8]. To find the impact value (I) based on the energy absorbed (E_{abs}) for each notch cross-sectional area (A_o), the calculation is carried out using Equation (1), where the impact test results are shown in Figure 3.

$$I = \frac{E_{Abs}}{A_o} \tag{1}$$

The impact test results for the three variations are shown in Figure 3. The impact value of the composite panels increased with the addition of more layers of WRM fiberglass. The composite panel with 5 layers had an impact value of 0.2258 J/mm², while the panel with 7 layers had a value of 0.3801 J/mm². The panel with 9 layers showed the highest impact value of 0.4375 J/mm².

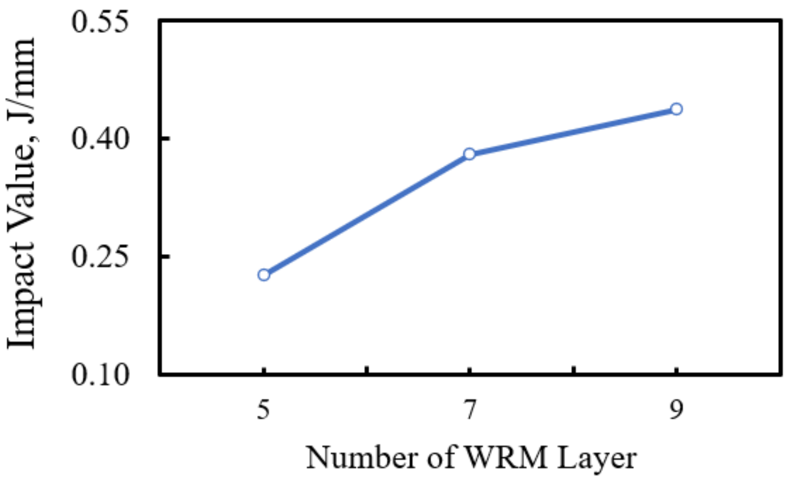

Figure 3. Graph of impact values for composite test results of 5-layer, 7-layer, and 9-layer WRM

Absorption Force Value

When a projectile strikes a composite panel, it transfers energy to the material. The composite panel then distributes the shock load throughout its structure, particularly through the arrangement of the fiberglass layers [26]. The energy value carried by the projectile was calculated to be 577.60 Joules using the kinetic energy (E_k) equation, shown in Equation (2). The deceleration produced by the panel, relative to the bullet's speed (v), and penetration distance (x) was determined using the energy equation, shown in Equation (3).

$$E_k = \frac{1}{2} m v^2 \tag{2}$$

$$E = F \cdot x \tag{3}$$

Figure 4 shows the graph of absorption force values as the number of WRM fiberglass layers increases. The graph demonstrates that the absorption force values increase directly with the number of fiberglass layers. This indicates that the bulletproof composite panel's ability to absorb and distribute shock loads is enhanced as more layers of fiberglass are added. The magnitude of the absorbed force value on the 7th and 9th panels is 9.62×10^4 N and 11.55×10^4 N. Meanwhile, the 5th layer is zero, assuming that the bullet is not held by the composite panel. When the magnitude of the force absorption is calculated based on the panel thickness, a value of 4.44×10^4 N is obtained. Then, between the 9th and 7th layers, an interpolation line is made connecting the 5th layer linearly, then the value of the force absorption is $7{,}75 \times 10^4$ N. The deviation value of $3{,}31 \times 10^4$ N between the two values indicates the remaining projectile force to leave the composite panel.

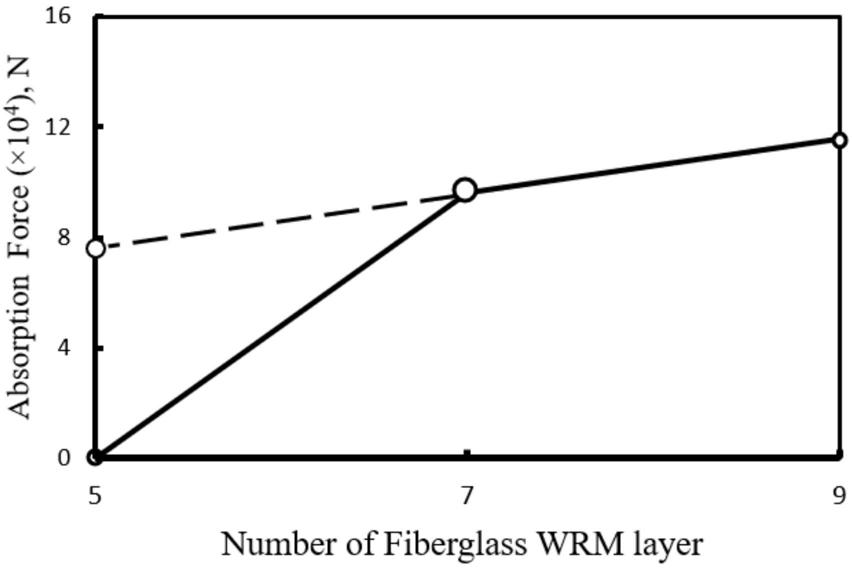

Figure 4. Graph of absorption force values versus layer variation in composite panels

CONCLUSION

The manufacture of woven roving mat (WRM) fiberglass resin composite panels reinforced with organo-silica to withstand bullets with variations of 5, 7, and 9 layers has been carried out. The panels with 7 and 9 layers of WRM fiberglass were able to withstand impacts from 9 mm caliber bullets at a distance of 10 meters. Meanwhile, on the 5th layer, the panel failed to function to withstand bullets. This indicates that the ability to absorb projectile forces is still not sufficient to withstand the forces received by the panel. The 9-layer composite panel shows the highest performance and is suitable for use as a 9 mm caliber bulletproof panel. It is also found that both the impact and force absorption values increased as more layers of fiberglass were added to the composite panels. This result has shown that this composite is a worthy candidate to replace conventional steel panels in bulletproof vests according to the NIJ-0101.06 standard for type-IIA vests, where is the body armor will provide minimal protection against smaller caliber handgun threats.

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REFERENCES

[1] T. F. Arbar, “Timeline! Begini Rusia-Ukraina Berubah Jadi Ancaman Perang,” *CNBCIndonesia.com*, 2022. [Online]. Available: https://www.cnbcindonesia.com/news/20220214133441-4-315212/timeline-begini-rusia-ukraina-berubah-jadi-ancaman-perang. [Accessed: Sep. 19, 2023].

[2] Al Jazeera, “Russia-Ukraine war: List of key events, day 404,” *Al Jazeera*, 2023. [Online]. Available: https://www.aljazeera.com/news/2023/4/3/russia-ukraine-war-list-of-key-events-day-404. [Accessed: Sep. 19, 2023].

[3] T. M. Zelelew, A. N. Ali, G. Ayele, G. Kidamemariam, and E. G. Koricho. “Numerical Simulation of Composite Materials with Sisal and Glass Fibers for Ballistic Impact Resistance.” *Mater. Eng. Res.*, vol. 6, no. 1, pp. 323–331, 2024.

[4] Y. J. Xu, H. Zhang, and G. Y. Huang. “Ballistic Performance of B4C/STF/Twaron Composite Fabric,” *Compos. Struct.*, vol. 279, 2022.

[5] P. Hu, Y. Cheng, P. Zhang, J. Liu, H. Yang, and J. Chen. “A Metal/UHMWPE/SiC Multi-Layered Composite Armor Against Ballistic Impact of Flat-Nosed Projectile.” *Ceram. Int.*, vol. 47, no. 16, pp. 22497–22513, 2021.

[6] M. A. Pulungan. "Analisis Kemampuan Rompi Anti Peluru yang Terbuat Ari Komposit Hgm-Epoxy dan Serat Karbon dalam Menyerap Energi Akibat Impact Peluru." Master thesis, Institut Teknologi Sepuluh Nopember, Surabaya, 2008.

[7] G. G. Ojoc, L. Chiper Titire, C. Munteniță, C. Pîrvu, S. Sandu, and L. Deleanu. "Ballistic Response of a Glass Fiber Composite for Two Levels of Threat." *Polymers (Basel).*, vol. 15, no. 4, pp. 0–21, 2023.

[8] I. Saleem, M. Abed, and P. Ahmed. "Numerical and Experimental Study of Hybrid Composite Body Armor." *Eng. Technol. J.*, vol. 39, no. 11, pp. 1681–1687, 2021.

[9] R. Stopforth and S. Adali. "Experimental Study of Bullet-Proofing Capabilities of Kevlar, of Different Weights and Number of Layers, with 9 mm Projectiles." *Def. Technol.*, vol. 15, no. 2, pp. 186–192, 2019.

[10] L. Sorrentino, C. Bellini, A. Corrado, W. Polini, and R. Aricò. "Ballistic Performance Evaluation Of Composite Laminates In Kevlar 29." *Procedia Eng.*, vol. 88, pp. 255–262, 2014.

[11] J. R. Davis. *ASM Specialt Handbook: Aluminum and Aluminum Alloys*. ASM International, 2001, pp. 351–416.

[12] P. V. Cavallaro, "Soft Body Armor: An Overview of Materials, Manufacturing, Testing, and Ballistic Impact Dynamics," Naval Undersea Warfare Center Division, Newport, RI, NUWC-NPT Technical Report 12,057, 2011. [Online]. Available: https://apps.dtic.mil/sti/tr/pdf/ADA549097.pdf.

[13] M. J. Oliveira, A. V. Gomes, A. R. Pimenta, and A. B. H. da S. Figueiredo. "Alumina and Low Density Polyethylene Composite for Ballistics Applications." *J. Mater. Res. Technol.*, vol. 14, pp. 1791–1799, 2021.

[14] W. Yu, W. Li, Y. Shangguan, X. Ji, T. Ma, and G. Wu. "Relationships between Distribution Characteristics of Ceramic Fragments and Anti-Penetration Performance of Ceramic Composite Bulletproof Insert Plates." *Def. Technol.*, vol. 19, pp. 103–110, 2023.

[15] B. Q. I. Hanifi, "Pengaruh Variasi Susunan Serat Eceng Gondok (*Eichhornia Crassipes*) dengan Resin Polyester sebagai Bahan Komposit Alternatif Rompi Anti Peluru." Undergraduate thesis, Universitas Wahid Hasyim, Semarang, 2017.

[16] M. U. Obot, D. S. Yawas, and S. Y. Aku. "Development of An Abrasive Material using Periwinkle Shells," *J. King Saud Univ. - Eng. Sci.*, vol. 29, no. 3, pp. 284–288, 2017.

[17] J. J. Mathavan and A. Patnaik. "Analysis of Wear Properties of Granite Dust Filled Polymer Composite for Wind Turbine Blade." *Results Mater.*, vol. 5, no. December 2019, p. 100073, 2020.

[18] D. S. Anakottapary, T. Gde, and T. Nindhia. "Interaksi antara Proyektil dan Komposit Polimer Diperkuat Butiran Silikon Karbid (SiCp) dan Serat Karbon pada Pengujian Balistik." *J. Ilm. Tek. Mesin Cakram*, vol. 4, no. 2, pp. 99–105, 2010.

[19] J. C. Farias-Aguilar, M. J. Ramírez-Moreno, D. M. Gonzalez-García, L. Téllez-Jurado, and H. Balmori-Ramírez. "Evaluation of the Ballistic Protection Level of (Glass-Fiber Reinforced Polyamide 6)-Aramid Fabric Sandwich Composite Panels." *J. Mater. Res. Technol.*, vol. 12, pp. 1606–1614, 2021.

[20] S. Alam and P. Aboagye. "Numerical Modeling on Ballistic Impact Analysis of the Segmented Sandwich Composite Armor System." *Appl. Mech.*, vol. 5, no. 2, pp. 340–361, 2024.

[21] B. Soegijono, "The Characterization of the Impact Resistance of the Multi- Panel Fiber Composite Structure through A Ballistic Test," 2018, pp. 25–29.

[22] A. Lamy-Mendes, A. D. R. Pontinha, P. Alves, P. Santos, and L. Durães. "Progress in Silica Aerogel-Containing Materials for Buildings' Thermal Insulation." *Constr. Build. Mater.*, vol. 286, p. 122815, 2021.

[23] M. B. Mukasey, J. L. Sedgwick, and D. Hagy, "Ballistic Resistance of Body Armor, NIJ Standard-0101.06," Law Enforcement and Corrections Standards Testing Program, U.S. Dept. Justice, Washington, DC, USA, 2000, pp. 1–67.

[24] B. Standards, "Ballistic Standards," *BodyArmorNews.com*, 2011. [Online]. Available: http://www.bodyarmornews.com/ballistic-standards/.

[25] Y. Zhang, H. Dong, K. Liang, and Y. Huang. "Impact simulation and ballistic analysis of B4C composite armour based on target plate tests." *Ceram. Int.*, vol. 47, no. 7, pp. 10035–10049, 2021.

[26] Y. Guo, J. H. Wang, X. Y. Xu, T. T. Duan, S. Q. Yan, D. G. Wang, P. X. Xin, L. Wang, Y. S. Huang, and N . Li. "Ballistic Performance of Protection Structures Using Fiber Composites as Matrix Armor." *J. Phys. Conf. Ser.*, vol. 2460, no. 1, 2023.