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Design and Ballistic Performance Assessment of Pattern-Optimized Lightweight Composite Armor Using ANSYS Explicit Dynamic and AUTODYN

Shah Nusrat Jahan Shanta[1,*], Abdus Sattar Mollah[2]

Abstract

This study investigates the ballistic performance of lightweight composite armor panels designed to defeat 9 mm full-metal-jacket (FMJ) threats using high-fidelity numerical simulations. Four different composite materials were arranged into panels of identical overall dimensions; only the internal segment pattern was varied to explore geometric resistance effects while keeping mass and material type controlled. Ballistic impact simulations were performed using ANSYS Explicit Dynamics and AUTODYN to capture high-strain-rate behavior, local perforation, delamination, and energy dissipation mechanisms. A systematic pattern screening identified a resisting layout that maximizes projectile energy absorption and minimizes rear face deformation. Based on that layout, an additional design iteration produced a lowest mass sample targeted at the BR2 class threat conditions for 9 mm projectiles (GOST BR series). Simulation outputs evaluated included residual projectile velocity, back-face deformation, strain, and damage maps, and component-wise energy absorption. Results demonstrate that pattern optimization without changing base material or panel footprint can substantially improve ballistic performance and enable significant mass reduction while maintaining protection against the specified 9 mm FMJ threat. The combined use of ANSYS Explicit Dynamics and AUTODYN provided complementary insight into early perforation events and later-stage structural fragmentation, informing practical design recommendations for lightweight composite armor. Future work will validate the numerical findings with controlled ballistic testing and refine manufacturing approaches for the optimal pattern identified.

Keywords: ANSYS explicit dynamics, AUTODYN simulation, ballistic performance, failure analysis, lightweight composite, pattern-optimized armor

INTRODUCTION

Due to the continuous advancement of modern weaponry and the increasing frequency of armed conflicts and terrorist attacks, the demand for lightweight yet highly effective ballistic protection systems has grown significantly in recent decades. Traditional steel armor, though highly effective, suffers from limited mobility due to its heavy weight. To overcome this limitation, researchers have shifted their focus toward advanced materials such as composites and ceramics, which offer superior strength-to-weight performance [1, 2]. Among these, fiber-reinforced plastics (FRPs) are particularly attractive because of their excellent strength-to-weight ratio and superior energy absorption capacity. These materials are widely used in helmets, shields, and body armor systems [1, 3, 4].

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However, fabric-based composites alone are often inadequate against advanced armor-piercing projectiles. To address this limitation, composite armors are typically designed with a hard ceramic front layer that blunts and fractures the incoming projectile. This layer is supported by a ductile backing material, which prevents catastrophic failure by absorbing residual energy and mitigating tensile stresses [1, 5]. Ceramics such as alumina, silicon carbide, and boron carbide are widely utilized due to their low density and high hardness [1, 4]. This multilayered configuration effectively dissipates impact energy and is now considered a standard design in modern ballistic protection systems [1, 5].

The internal architecture of the fabric layers also has a significant effect on ballistic penetration resistance. Factors such as yarn weave, crimp, orientation, projectile geometry, and impact velocity all influence ballistic performance [6]. Thermoset-based laminates have been extensively studied, but they exhibit several drawbacks, including the need for cold storage and long curing times. In contrast, thermoplastic-based composites offer several advantages: longer shelf life, faster processing, recyclability, and improved toughness. In laminated armor systems, the ceramic front layer disrupts and blunts the projectile, while the composite backing layer absorbs residual kinetic energy and contains the resulting fragmented debris [6].

The back-face signature (BFS) is a key metric used to evaluate ballistic efficiency. BFS quantifies the deformation transmitted to the wearer during impact. Minimizing BFS is essential for reducing injuries caused by behind-armor blunt trauma (BABT) [7, 8]. Both numerical modeling and high-speed experimental investigations have demonstrated that even small variations in material properties can significantly affect BFS values. Therefore, accurate predictive modeling is crucial for effective armor design [7, 8].

Alongside experimental studies, numerical simulations play a vital role in armor development by significantly reducing cost and time. These simulations help in understanding the failure mechanisms and defeat modes of armor systems under ballistic impacts. They also allow for detailed analysis of projectile–target interactions, including penetration, fracture, delamination, and energy dissipation. Commonly used simulation tools such as ANSYS, LS-DYNA, and ABAQUS employ constitutive models including Johnson-Cook, Zerilli-Armstrong, and Mechanical Threshold Stress (MTS) models, which predict deformation and fracture behavior with high accuracy when validated against experimental results [9–12]. This numerical approach not only reduces material wastage but also enhances cost-effectiveness while enabling detailed analysis of different material configurations [4, 8, 9].

Hybrid composite armors – combinations of ceramics and multiple fiber-reinforced laminates – offer a balanced solution between strength, weight, and toughness. Commonly used fibers include Kevlar, glass, polyethylene, and carbon fibers. The stacking sequence and areal density of these laminates critically influence their ballistic performance, with optimized hybrid designs demonstrating superior energy absorption and reduced residual velocity [5, 6]. Both experimental and computational studies confirm that appropriate hybridization strategies can significantly enhance impact resistance while minimizing overall mass [2, 5, 13].

The main objectives of this study are to reduce the overall weight of the armor, identify the most energy-absorbing pattern to maximize energy absorption, and enhance cost-effectiveness while improving the overall efficiency of the protective system. By achieving these goals, the study aims to develop a lightweight, high-performance composite armor design suitable for practical applications. Overall, the development of lightweight ballistic protection has been greatly advanced by the integration of hybrid composite systems and numerical modeling techniques. The combined use of ceramics, advanced fibers, and polymer matrices enables optimization of material utilization, armor mass, and production cost. Numerical simulations make the design process faster, more accurate, and economically efficient [4, 9, 11–13]. Therefore, this study focuses on the numerical investigation of hybrid composite armors using ANSYS Explicit Dynamics and AUTODYN, with the primary objective of identifying cost-effective material combinations and stacking sequences that provide high ballistic resistance while minimizing weight and back-face deformation.

RESEARCH GAP

Although several studies have investigated the ballistic performance of composite materials, the influence of striking pattern configurations on energy dissipation has not yet been explored. This study seeks to address this gap by examining the variation in energy loss among composites of identical thickness but different pattern arrangements, with the aim of identifying the most effective configuration for subsequent experimental and simulation-based investigations. Furthermore, this research attempts to fill another gap by proposing a lightweight and flexible armor design through minimizing overall thickness and reducing the dependence on hard materials such as steel.

OBJECTIBES

Objectives of this study are,

1. To reduce the weight of the armor.
2. To find most energy absorbing pattern for increasing the energy absorption rate.

LITERATURE REVIEW

Extensive research has been conducted on the development of lightweight ballistic armor systems to overcome the mobility limitations associated with conventional steel-based protection. Fiber-reinforced composite materials such as Kevlar, Dyneema, glass fiber, and polyethylene have been widely investigated due to their high strength-to-weight ratio and superior energy absorption capabilities. Previous studies have demonstrated that multilayered hybrid armor systems, often incorporating a hard ceramic or metallic front layer supported by composite backings, are effective in dissipating projectile kinetic energy through mechanisms such as projectile blunting, fracture, delamination, and fiber stretching. Numerical and experimental investigations have confirmed that stacking sequence, areal density, and material hybridization significantly influence ballistic performance, back-face deformation, and residual velocity of projectiles [14–17].

Several researchers have employed numerical simulation tools such as ANSYS Explicit Dynamics, AUTODYN, LS-DYNA, and ABAQUS to analyze high-velocity impact behavior of composite armors, as these methods reduce experimental cost and provide detailed insight into failure mechanisms under extreme strain rates [18]. Constitutive models including Johnson–Cook, Grüneisen equation of state, and damage evolution criteria have been successfully applied to predict penetration, cracking, and energy dissipation in armor materials. Studies have also reported that optimized hybridization of Kevlar and Dyneema layers can enhance ballistic resistance while reducing overall weight; however, many of these designs still require relatively large thicknesses or high mass to achieve adequate protection against handgun threats [17, 20–24].

Despite these advancements, most existing works primarily focus on material selection, thickness variation, or hybrid combinations, while the influence of internal striking pattern or layer arrangement optimization on ballistic energy absorption remains largely unexplored. Additionally, previously reported armor systems often exhibit excessive thickness and weight, which restrict their applicability in wearable protection systems. Therefore, a clear research gap exists in systematically investigating pattern-optimized composite armor configurations that can achieve effective ballistic resistance with minimal thickness and mass. Addressing this gap through high-fidelity numerical simulations forms the central motivation of the present study [19, 23, 25].

GEOMETRY MODELING AND BOUNDARY CONDITIONS SETTING

The working flow chart of dynamic load is shown in Figure 1.

The composite armor sample is designed using ANSYS Design Modeler, as shown in Figure 2. The armor consists of multiple layers made of 2.4 mm Kevlar, 6 mm Dyneema, 0.5 mm steel, and 2.5 mm cement fiber.

To analyze the effect of layer arrangement, five different stacking patterns with identical overall dimensions are modeled, as presented in Table 1. Among these configurations, the pattern that exhibits the highest energy absorption is selected through simulation and is considered for future experimental validation

For the ballistic impact analysis, suitable boundary conditions are applied. A projectile velocity of 800 m/s represents the 9 mm FMJ impact, and the rear surface of the armor is assigned a fixed support condition to simulate realistic backing constraints during impact. Material property is defined in table 3 [14].

The energy deposition equation is [15],

$$E = \frac{(\rho \triangle V)U^2}{2} + (\rho \triangle V)gz + P \triangle V. \quad (1)$$

Where,
E = Energy loss;
ρ = Density;
$\triangle V$ = Volume;
U = Kinetic Energy;
g = Gravity;
P = Pressure;

After identifying the best energy-absorption combination, three optimized designs with that pattern were selected for a projectile velocity of 400 m/s, which is appropriate for a 9 mm FMJ round [14]. The sample configurations are:

1. *Sample 1:* Cenent fiber 1.1 mm, Kevlar 1.2 mm, Dyneema 3.2 mm, and steel 1.0 mm.
2. *Sample 2:* (same fiber/laminate stack) with steel 0.8 mm.
3. *Sample 3:* (same fiber/laminate stack) with steel 0.7 mm.

A pictorial representation of Sample 1 is shown in Figure 2. These three samples will be validated experimentally later to determine the most successful design.

MESH QUALITY ANALYSIS

Mesh statistics for all the samples are given in table 2. The range of skewness >0–0.25 excellent according to [16] and the range of aspect ratio 1.5–3.0 is acceptable according to [17]. So skewness and aspect ratio for all of the samples are in acceptable range for further investigations.

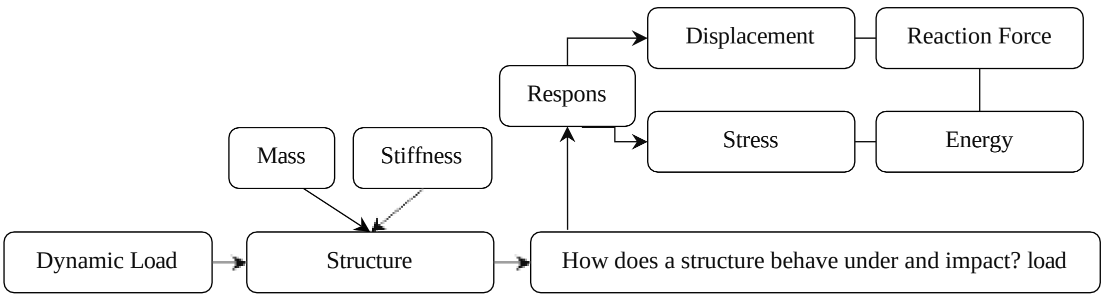


Figure 1. Working flow of dynamic load.

Table 1. Different stacking combination for finding most energy absorbing pattern. (Start form the striking face).

Serial No	Combination
Pattern 1	Cenent fiber→Kevlar→Dyneema→steel
Pattern 2	steel→Dyneema→Kevlar→Cenent fiber
Pattern 3	Dyneema→Cenent fiber→Kevlar→steel
Pattern 4	Cenent fiber→Kevlar→steel→Dyneema
Pattern 5	Dyneema→steel→Cenent fiber→Kevlar

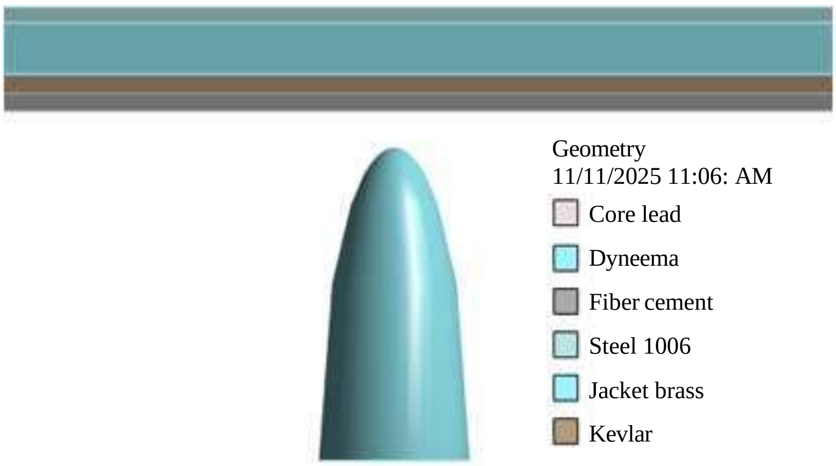


Figure 2. Armor design which is created using ANSYS design modeler.

Table 2. Mesh properties.

Samples	No of Elements	No of Nodes	Skewness	Aspect Ratio
Pattern 1	10397	15359	5.7217e-002	1.6277
Pattern 2	13503	18845	3.9233e-002	2.1512
Pattern 3	15434	23953	4.0056e-002	1.5445
Pattern 4	16576	28459	0.11296	2.1541
Pattern 5	17532	31242	6.9321e-002	1.9342
Sample 1	11397	22256	4.7668e-002	1.5179
Sample 2	11382	22251	4.6996e-002	1.5795
Sample 3	11413	22261	4.7716e-002	1.6169

Table 3. Material properties. [14, 18].

Brush						
Density (kg·m−3)	Shear modulus (Pa)	Gruneisen coefficient	Parameter S1	Parameter quadratic S2 (s·m−1)	Parameter C1 (m·ts−1)	
8450	4.6e + 010	2.04	1.434	0	3726	
Lead						
Density (kg·m−3)	Shear modulus (Pa)	Gruneisen coefficient	Parameter S1	Parameter quadratic S2 (s·m−1)	Parameter C1 (m·ts−1)	Specifific heat (kg−1·C−1)
11340	8.6e + 009	2.74	1.429	0	2006	124
Initial yield stress Y (Pa)	Maximum yield stress, Ymax (Pa)	Derivative (dG/dP, G’P)	Derivative dG/dT, G’T Pa·C−1	Hardening constant, B	Hardening exponent, n	
8e + 006	1e + 008	1	−9.976e + 006	110	0.52	

Fiber cement layer						
Density (kg·m−3)	Temperature (°C)	Young's modulus (Pa)		Poisson's ratio	Bulk modulus (Pa)	
1390	25	7.62e + 009		0.1	3.175e + 009	
Shear modulus (Pa)		Yield strength (Pa)	Tensile ultimate strength (Pa)		Tangent modulus (Pa)	
3.4636e + 009		6e + 006	2.9e + 009		1.2e + 007	
Kevlar 29						
Temperature (°C)	Young's modulus X direction (Pa)	Young's modulus Y direction (Pa)	Young's modulus Z direction (Pa)	Poisson's ratio XY	Poiss's ratio YZ	Poisson's ratio XZ
25	1.85e + 010	1.85e + 010	6e + 009	0.25	0.33	0.33
Shear modulus XY (Pa)	Shear modulus YZ (Pa)	Shear modulus XZ (Pa)	Density (kg·m−3)	Specific heat J·kg−1·C−1	Compressive yield strength (Pa)	Tensile yield strength (Pa)
7.7e + 008	5.43e + 009	5.43e + 009	1440	1420	1.85e + 008	1.85e + 009
Steel						
Density (kg·m−3)	Specific heat constant pressure (J·kg−1·C−1)	Gruneisen coefficient	Paramete r S1	Parameter quadratic S2 (s·m−1)	Parameter C1 (m·ts−1)	
7896	452	2.17	1.49	0	4569	
Initial yield stress Pa	Hardening constant Pa	Hardening exponent	Strain rate constant	Thermal softening exponent	Melting temperature 0C	Reference strain rate (sec)
3.5e + 008	2.75e + 008	0.36	2.2e - 002	1	1537.8	1
Dyneema						
Density (kg m−3)	Tensile failure strength (s−1)	Failure strain (GPa)	Strain rate (%)		Cunniff velocity (ms−1)	
970	700	2.55	6.26		698	

WEIGHT CALCULATION OF THE ARMOR PLATE

In this work used 100 cm×100 cm. The armor consists of multiple layers made of 1.2 mm Kevlar, 3.2 mm Dyneema, 1 mm steel, and 1.1 mm cement fiber for sample 1. Now,

Volume,

$V_{Cement} = 0.1 \times 0.1 \times 0.0011 = 1.1 \times 10^{-5}\ \text{m}^3$;

$V_{Kevlar} = 0.1 \times 0.1 \times 0.0012 = 1.2 \times 10^{-5}\ \text{m}^3$;

$V_{Dyneema} = 0.1 \times 0.1 \times 0.006 = 3.2 \times 10^{-5}\ \text{m}^3$;

$V_{Steel} = 0.1 \times 0.1 \times 0.001 = 1 \times 10^{-5}\ \text{m}^3$;

And,

$Weight_{Total} = (Volume \times Density)_{Total}$;

$\text{W}_\text{T} = (Volume \times Density)_{Cement} + (Volume \times Density)_{Kevlar} + (Volume \times Density)_{Steel} + (Volume \times Density)_{Dyneema}$;

$\text{W}_\text{T} = (1.1 \times 10^{-5} \times 1390 + 1.2 \times 10^{-5} \times 1440 + 1 \times 10^{-5} \times 7890 + 3.2 \times 10^{-5} \times 970)$ Kg ;

$\text{W}_\text{T} = 0.1425$ Kg $= 142.5$ g ;

Which is also GSM for sample 1. Similarly 126.7 GSM for sample 2 and 118.8 GSM for sample 3. The weight of the research sample 1 is found to be GSM, while in previous work, it was 224.66 GSM for the same thickness. This shows that the designed sample is lighter, and one of the research objectives has been achieved. Therefore, further study can be continued with all of these samples.

RESULT AND DISCUSSION

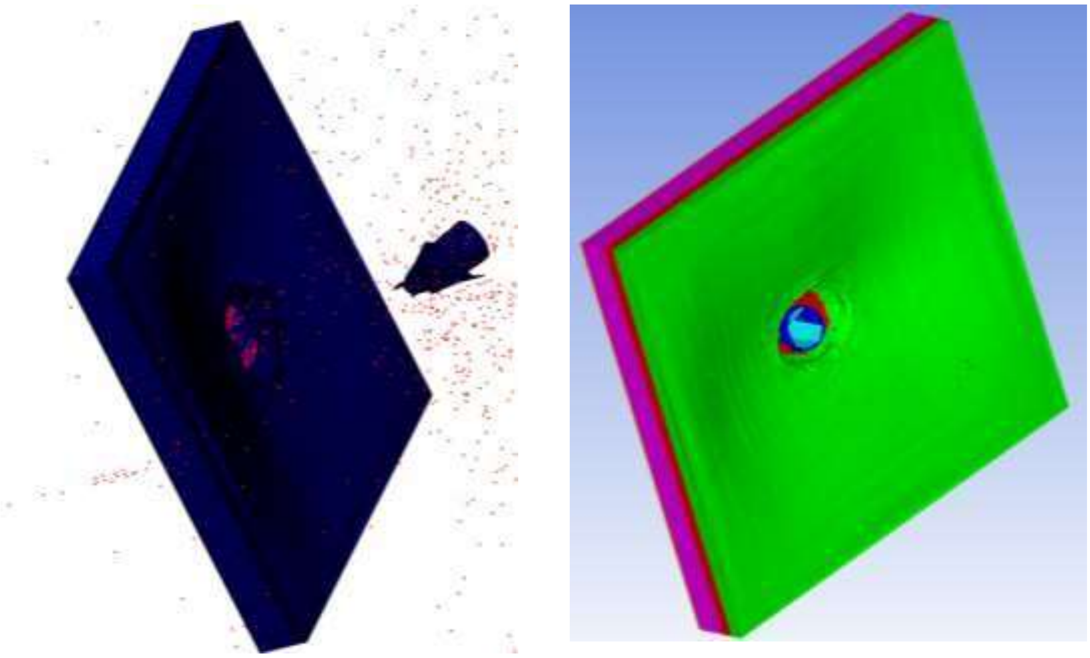
Based on the conducted simulations using ANSYS Explicit Dynamics and Autodyn, five different armor material combinations (Pattern 1 to Pattern 5) were tested under the same bullet velocity to evaluate their ballistic performance. The goal was to determine which material sequence provides the most effective resistance against bullet penetration while minimizing structural damage.

Among all the patterns, Pattern 1 which is showing in Figure 3 demonstrated the best performance. It successfully resisted bullet penetration without showing any visible cracks or structural failure. This makes it the most promising configuration for further study and development.

The results indicate that the specific sequence of high-energy absorption materials like Dyneema and Kevlar followed by high-strength steel effectively dissipates and distributes the impact energy. The energy deposition curve for Pattern 1 supports this, showing a relatively smooth energy drop over time show in Figure 8(a), indicating efficient energy absorption and low backface deformation.

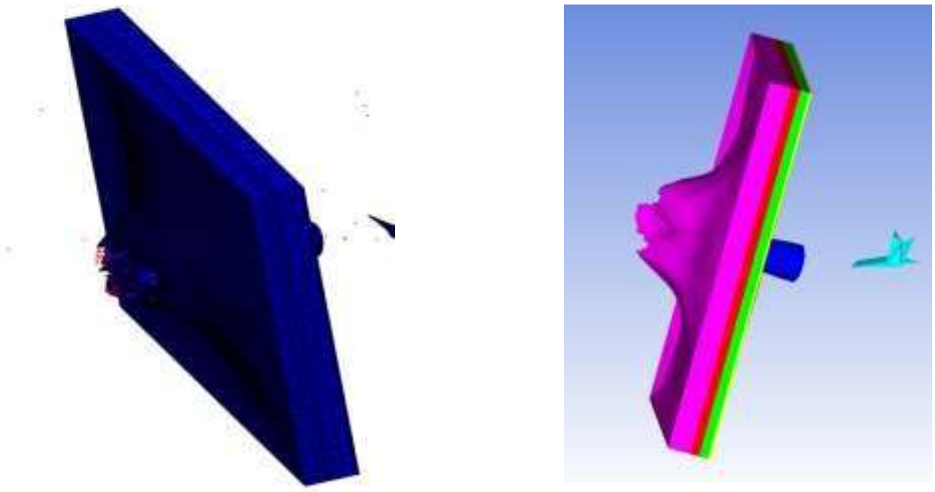
Patterns 2, 3, and 4 according to Figure 4, Figure 5 and Figure 6 are able to stop the bullet without complete penetration, but all of them exhibited cracking in the armor structure, indicating partial failure. Among these, Pattern 2 had a deformation of 32 cm, Pattern 3 showed 75 cm, and Pattern 4 exhibited the lowest deformation of 25 cm.

Despite Pattern 4 having the least deformation, it still showed structural cracking, suggesting that while the material resisted impact well, the energy was not distributed effectively enough to prevent localized failure. Pattern 3, with the highest deformation, indicated weaker structural integrity and poor energy dissipation.



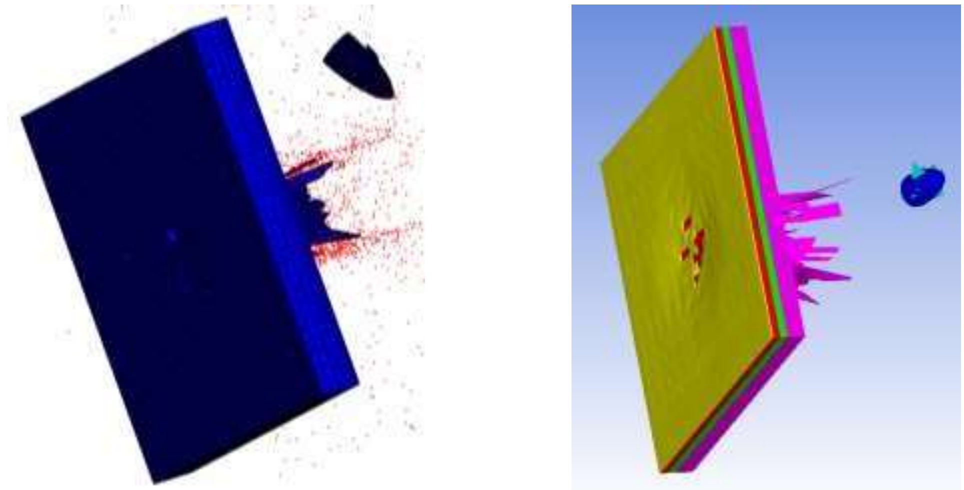
(a) Explicit dynamic. (b) Autodune

Figure 3. Pictorial representation of strike for pattern 1.



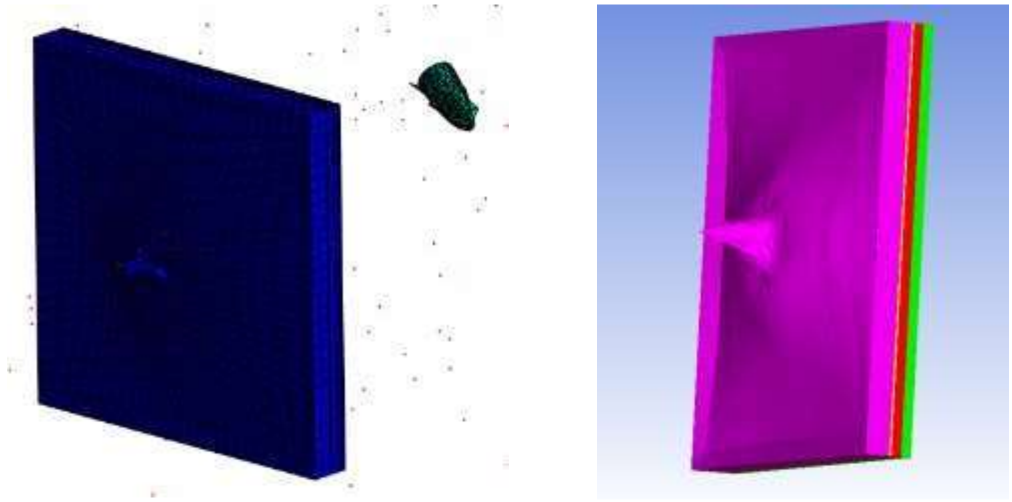
(a) Explicit Dynamic (b) Autodyne

Figure 4. Pictorial representation of strike for pattern 2.



(a)Explicit Dynamic (b) Autodyne

Figure 5. Pictorial representation of strike for pattern 3.



(a) Explicit Dynamic (b) Autodyne

Figure 6. Pictorial representation of strike for pattern 4.

Pattern 5 in Figure 7 performed the worst among all. The bullet fully penetrated the armor, rendering the configuration ineffective for ballistic protection. The energy deposition curve for Pattern 5 in Figure 8(e) shows a steep and continuous drop, suggesting a failure to absorb and dissipate the bullet's kinetic energy efficiently. This may be attributed to the sub-optimal placement of materials, where Dyneema at the front failed to provide sufficient initial resistance, and the following layers could not compensate adequately.

The energy absorption curves in Figure 8 show that the composite material pattern strongly affects ballistic performance because each material layer responds differently to impact. When high energy absorbing materials like Kevlar and Dyneema are arranged in an optimal sequence, the impact energy is distributed more evenly, leading to smoother energy decay and less deformation.

In contrast, poorly arranged patterns cause uneven stress transfer and faster energy loss, resulting in cracks or failure. Thus, the layer sequence directly controls how efficiently impact energy is absorbed and dissipated.

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Comparing the simulation outputs from ANSYS Explicit Dynamics and Autodyn, both platforms consistently reflected similar trends in performance evaluation across all five patterns. The energy deposition behavior, crack formation, and deformation values matched closely between the two tools, reinforcing the reliability of the simulation results.

Figure 9 presents pictorial views of all samples after ballistic testing. The results show that Sample 1 remained intact and successfully absorbed the projectile’s energy, so it is classified as within the safe zone. Sample 2 arrested the projectile but exhibited cracking of the outermost layer, indicating partial structural failure and reduced durability. Sample 3 was fully penetrated and is therefore considered a failure. Based on these outcomes, Sample 1 has been selected for further experimental validation to confirm its ballistic performance and to investigate its repeatability and failure limits.

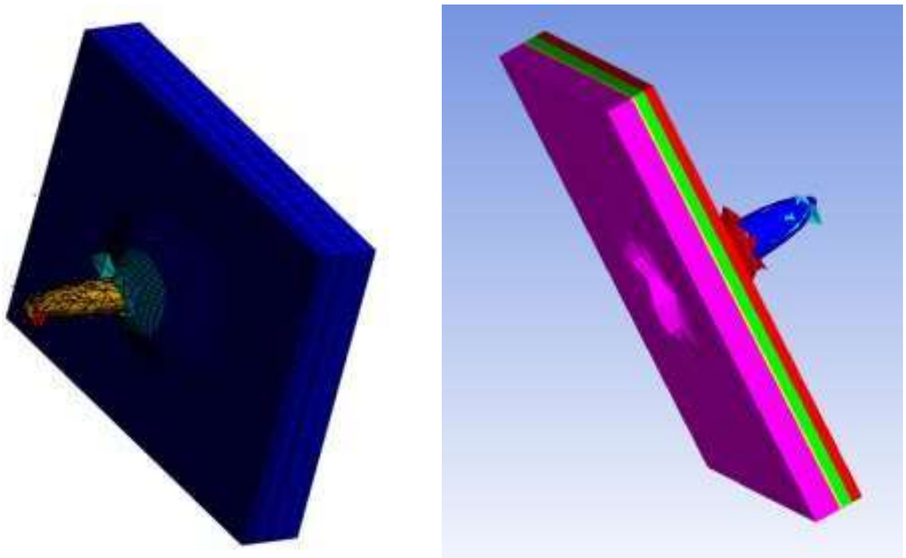
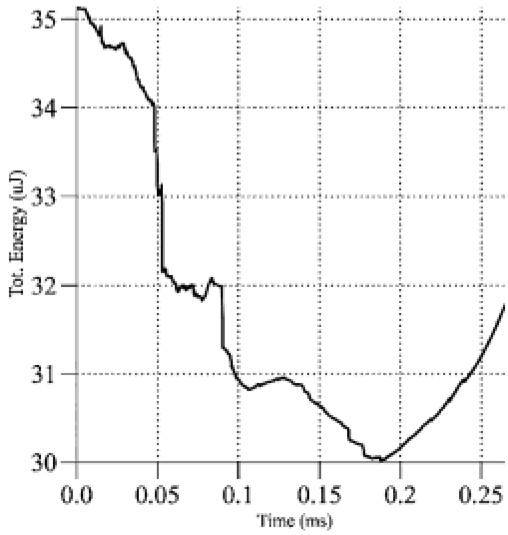
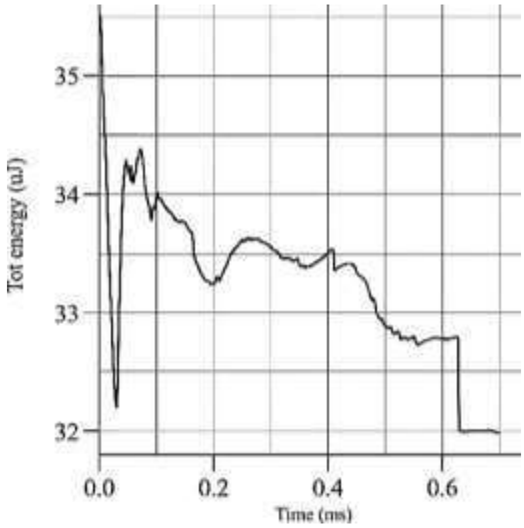


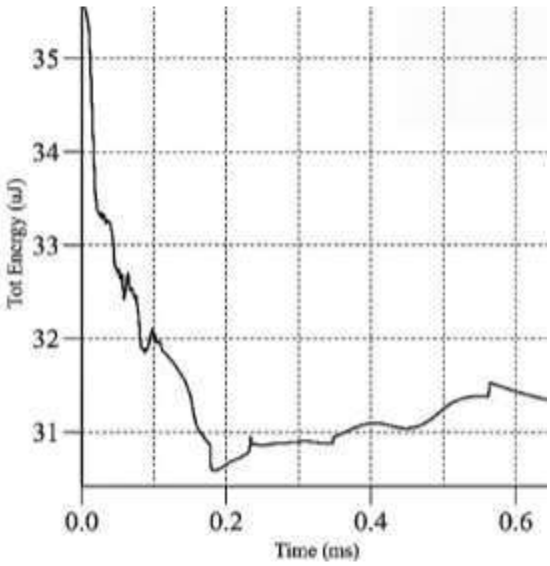
Figure 7. Pictorial representation of strike for pattern 5.



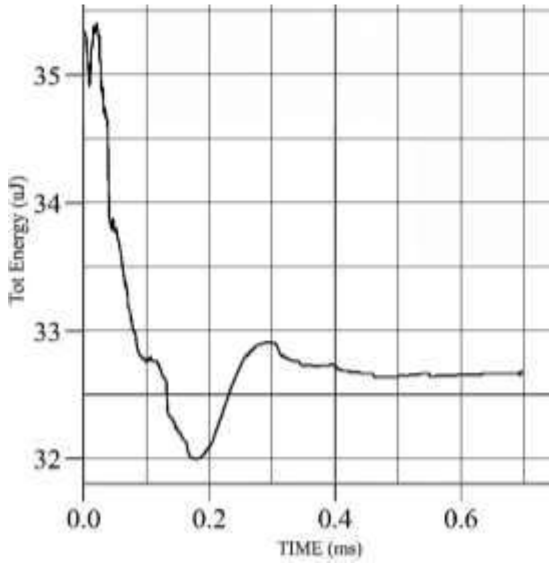
Pattern 1



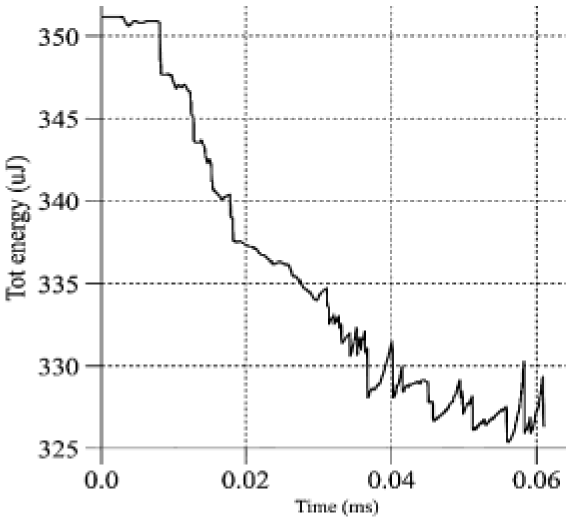
Pattern 2



Pattern 3

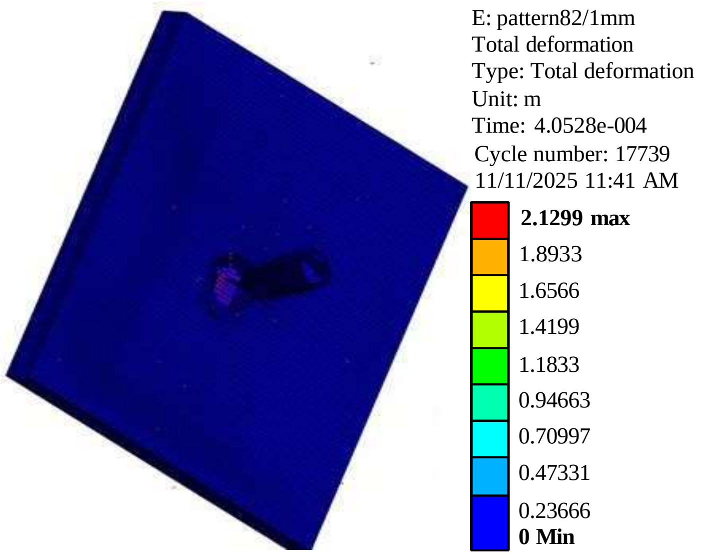


Pattern 4

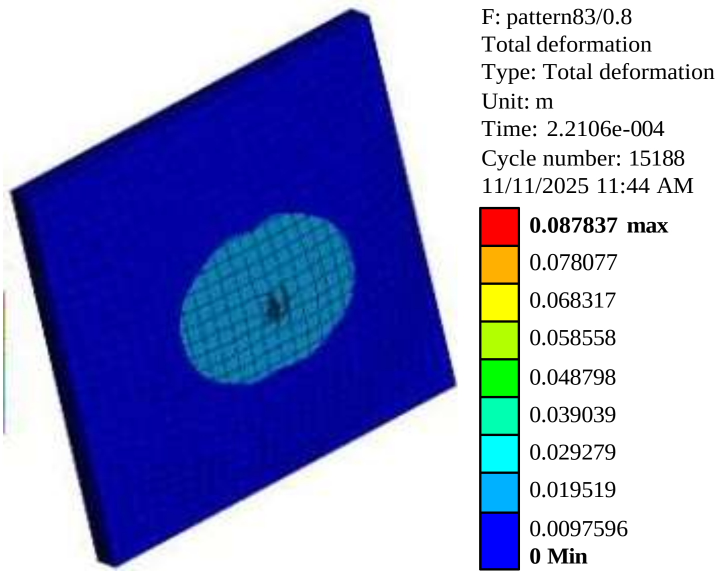


Pattern 5

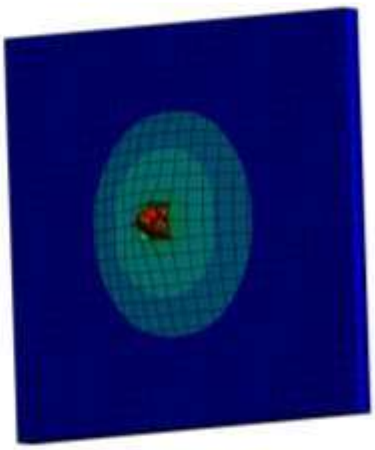
Figure 8. (a–e) Energy deposition curve with time.



Sample 1



Sample 2



Sample 3

Figure 9. Pictorial representation of strike for Sample 1**,** Sample 2 and Sample 3.

The composite armor model developed in this study has a total weight of for sample 1. In contrast, a sample of the same overall thickness reported in a previous study [14] weighs 224.66 g, yet fails to resist a 9 mm FMJ projectile traveling at 400 m/s. In comparison, the present model successfully withstands the impact of a 9 mm FMJ bullet at 400 m/s while maintaining thickness 6.5. Where thickness of the previous benchmark work was 11.5 mm. In this study, our developed sample has almost half the thickness and is about 1.58 times lighter than the sample from the previous work used for comparison. This means our design is much thinner and lighter, which makes it easier to wear and more comfortable, while still giving good protection against bullets. This result clearly demonstrates the superior energy absorption efficiency and structural effectiveness of the current composite configuration, highlighting its potential for lightweight ballistic protection applications shown in Figure 10.

A comparative evaluation with recent studies clearly highlights the superiority of the proposed armor configuration in terms of weight and thickness reduction while maintaining ballistic resistance (Table 4). In Paper [19], despite the use of aerogel exhibiting a lower density per unit volume compared to the present work, effective bullet resistance was achieved only by employing a substantially larger thickness and overall mass. The reported armor required a thickness of 50 mm and a total weight of approximately 4.059 kg, which significantly compromises mobility and practical usability. In Paper [20], although Kevlar was utilized in a manner similar to the present study, the developed armor sample demonstrated an excessive thickness of 107 mm along with a total weight of 1.55 kg. Furthermore, Paper [21] investigated several alternative configurations, where the lightest effective sample still possessed a thickness of 10 mm and a mass of approximately 750 g. In contrast, the armor design developed in the present study successfully resisted ballistic impact with a remarkably reduced thickness of only 6.5 mm and an ultra-lightweight sample mass of 142.5 g. This substantial reduction in both thickness and weight, when compared with existing studies, clearly indicates that the proposed design provides a more sustainable, efficient, and practical solution for lightweight ballistic protection applications.

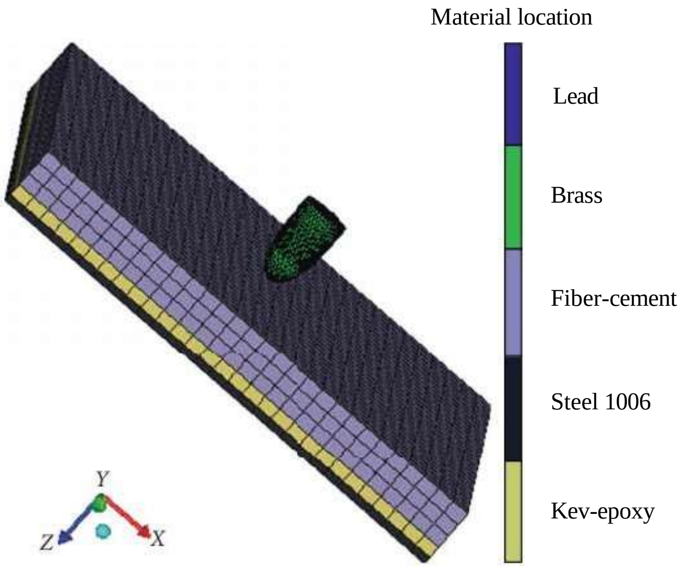


Figure 10. Pictorial representation of benchmark work.

Table 4. Data comparison table.

Parameters	Original Work	Reserence Paper 1	Reserence Paper 19	Reserence Paper 20	Reserence Paper 21
Thickness	6.5 mm	12 mm	50 mm	107 mm	10 mm
Weight	142 g	224 g	4 Kg	1.55 Kg	750 g

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Mesh Convergence Test

For Sample 1, six different mesh densities with node numbers of 21, 054; 21, 745; 22, 003; 22, 256; 22, 846; and 23, 231 were analyzed to evaluate the effect of mesh refinement on skewness, deformation, stress, and strain energy, as illustrated in Figure 11. From the plotted results, it was observed that the mesh quality parameters and response values converged at 22, 256 nodes, indicating that this mesh density provides sufficient accuracy. Therefore, the results obtained in this study can be considered mesh-independent and reliable. A similar convergence approach was also applied for the remaining samples to ensure consistency and validation of the simulation outcomes.

Mesh Sensitivity Analysis

A sensitivity study was conducted to evaluate the effect of minor variations in boundary conditions on the ballistic performance of the composite armor which is shown in Figure 12. The original simulation employed a projectile velocity of 400 m/s, at which the bullet did not penetrate the armor. When the boundary conditions were decreased by 5% in Figure 12(a), corresponding to a slight reduction in effective impact parameters, the armor continued to prevent penetration, and the total deformation was slightly reduced, indicating that the system remains robust under minor adverse variations.

In contrast, a 5% increase in boundary conditions in Figure 12(c), effectively raising the projectile velocity to approximately 420 m/s, resulted in complete penetration of the armor. This outcome highlights that the armor’s protective performance is highly sensitive to increases in impact velocity near the critical penetration threshold. The results demonstrate that the developed model can reliably capture the mechanical response of the armor and accurately predict critical conditions leading to failure. Moreover, the observed behavior underscores the importance of considering operational tolerances and boundary condition uncertainties when assessing armor performance.

Comparison With Previous work and Result Summary

The current study produced a significantly lighter armor design (142.5 g) compared to previous work (224.66 g), while also using a thinner material (6.5 mm vs. 11.5 mm). Additionally, the current work focused on investigating and identifying the best energy-absorbing pattern, which was not explored in the previous studies. Overall, the results indicate a lighter, thinner, and potentially more efficient design in terms of energy absorption. And the comparison is shown in Table 5.

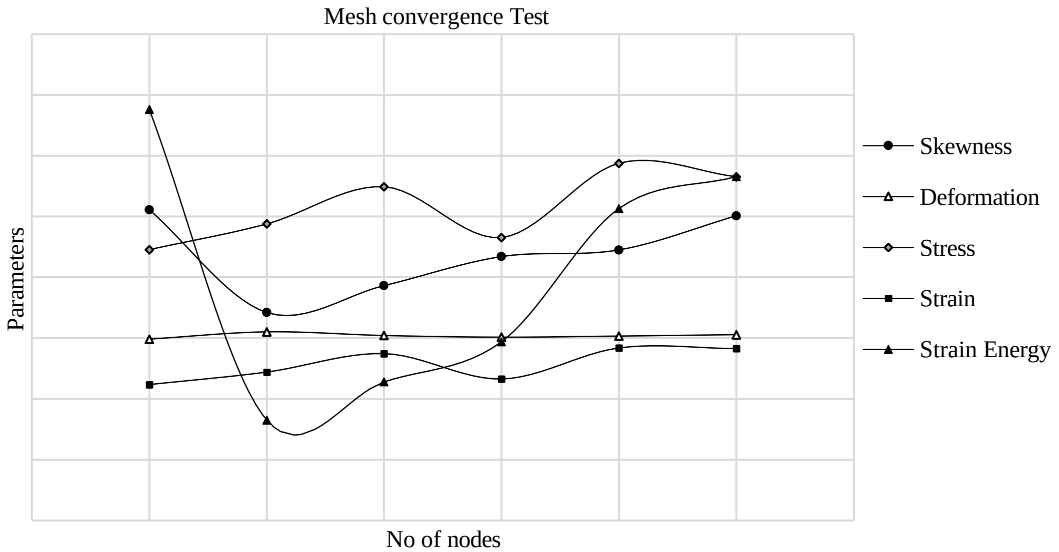
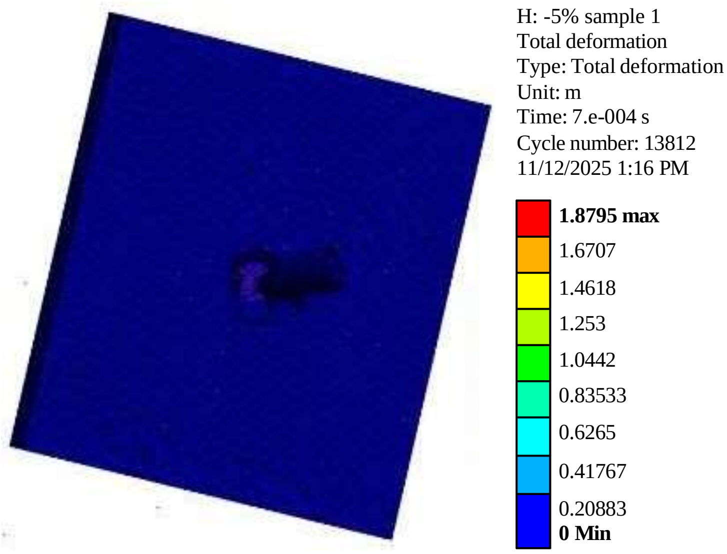
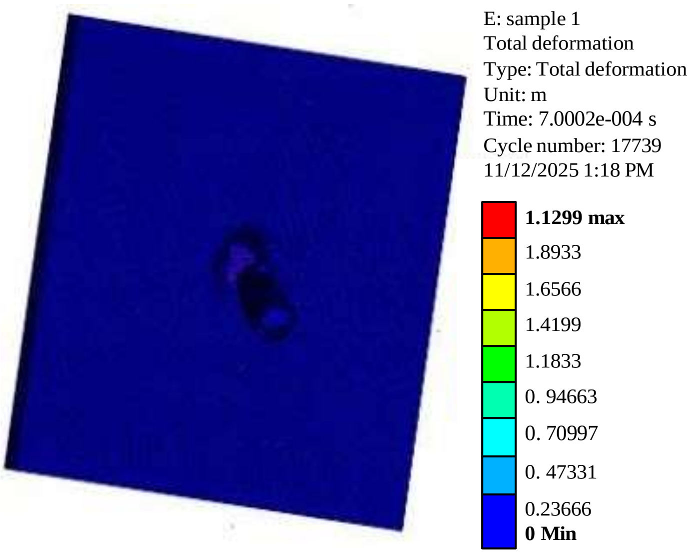


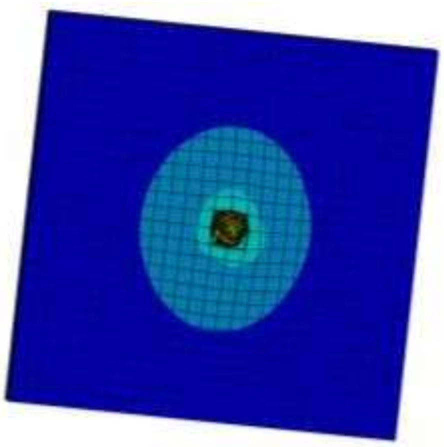
Figure 11. Graphical representation of mesh convergence test.



5% of decreasing boundary conditions



Original boundary condition.



5% of increasing boundary conditions.

Figure 12. (a–c) Comparison of simulation for sensitive analysis.

Table 5. Comparison of this study with previous work.

Parameters	Current Work	Previous Work [14]
Weight	142.5 g	224.66 g
Thickness	6.5 mm	11.5 mm
Pattern	Investigate to find best energy absorbing pattern	No other group has undertaken this kind of investigation into the best energy-absorbing pattern.

CONCLUSION

This study successfully demonstrated the effectiveness of pattern-optimized lightweight composite armor for resisting 9 mm FMJ projectile impacts through detailed numerical simulations using ANSYS Explicit Dynamics and AUTODYN. By systematically analyzing five different material stacking configurations, the research identified the most efficient combination of Kevlar, Dyneema, cement fiber, and steel layers for maximum energy absorption and minimum back-face deformation. The optimized configuration, referred to as Pattern 1, showed superior ballistic resistance by fully stopping the projectile without significant structural damage. Further optimization led to the development of three lightweight samples, among which Sample 1 provided the best performance under a velocity of 400 m/s. The newly designed armor panel achieved nearly half the thickness and 1.58 times lower weight compared to previous designs, while maintaining excellent protective capability. These findings confirm that proper layer sequencing and pattern optimization can greatly enhance ballistic efficiency without increasing material cost or thickness. Overall, the developed composite design demonstrates strong potential for future use in lightweight body armor applications, where mobility, comfort, and protection must be effectively balanced.

LIMITATIONS

The study is limited to numerical simulations and validation against a single reference data set. Also absence of experimental analysis. Besides only three materials were consider.

FUTURE WORK

In future work, experimental validation of the simulation results will be carried out to confirm the ballistic performance of the proposed designs. Additionally, natural materials such as jute and bamboo will be utilized as reinforcement in the composite structure to develop a more sustainable and cost-effective armor system. Further investigations will focus on the development of a thinner and softer armor configuration that maintains effective protection while enhancing comfort and flexibility for practical applications.

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