International Journal of Creative and Open Research in Engineering and Management
ISSN: **3108-1754 (Online)**
Volume 02 Issue 04 April-2026 | Impact Factor: 3.5

Advanced Hybrid Composite Armor Systems with Intelligent Adhesive Interfaces and Nanostructured Coatings for Enhanced Ballistic Performance

Siva Prasad Mattaparthi[1]

[1] Mechanical Engineering/ Behara College Of Engineering & Technology/ Visakhapatnam.
Corresponding Author Email: msivaprasad341@gmail.com

How to Cite this Article:

Mattaparthi, S. P. (2026). Advanced Hybrid Composite Armor Systems with Intelligent Adhesive Interfaces and Nanostructured Coatings for Enhanced Ballistic Performance. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(04). https://doi.org/10.55041/ijcope.v2i4.081

https://doi.org/ 10.55041/ijcope.v2i4.081

Abstract

Surface engineering methods, composite architectures, and material design have all advanced significantly as a result of the growing need for lightweight, high-performance ballistic protection systems. The creation and performance improvement of ballistic protection systems through the integration of multilayer composite structures, sophisticated coatings, and improved adhesive technologies is thoroughly examined in this research. High-strength steels and ceramics are examples of traditional materials that offer good resistance against high-velocity impacts, but their weight, brittleness, and flexibility restrictions force the use of hybrid solutions. In this regard, the better energy absorption and impact dissipation capabilities of multilayer armor systems that combine metallic attack faces with high-performance fibers like para-aramid (Kevlar, Twaron) and ultra-high-molecular-weight polyethylene (UHMWPE) are examined. Additionally, the potential of coatings based on nanomaterials, such as graphene, carbon nanotubes, and nanosilica, to improve interfacial bonding, inter-yarn friction, and overall ballistic efficiency is explored. Additionally, the study investigates the use of adhesives modified with thermally expandable particles (TEP) to enhance the sustainability, adaptability, and structural integrity of composite systems. Optimized multilayer designs and surface alterations greatly increase ballistic resistance while preserving reduced weight and increased flexibility, according to experimental observations backed by numerical insights. The results show how cutting-edge materials, coating technologies, and clever bonding methods can be used to create next-generation ballistic protection systems for industrial and military uses.

Key words

Thermally expandable particles (TEPs), composite materials, layered armor systems, high-performance fibers, Kevlar, UHMWPE, surface coatings, nanomaterials, energy absorption, impact resistance, adhesive bonding, lightweight constructions, hybrid materials, and defense applications

I. INTRODUCTION

The need for sophisticated ballistic protection systems that combine high impact resistance with decreased weight and greater flexibility has expanded dramatically because to the quick evolution of modern warfare and industrial safety regulations. Although traditional protective solutions, which are mostly based on monolithic metallic structures, have proven to be effective against ballistic threats, their high density and limited adaptability limit their usefulness in applications that call for comfort, mobility, and multifunctional performance.

Ballistic protection systems have evolved throughout time from simple natural materials like leather and wood to complex technical materials like fiber-reinforced composites, high-strength steels, and ceramics. Despite the extreme strength and durability of metals like hardened steel, their significant weight poses challenges for military and automobile applications. Ceramic materials with remarkable hardness and projectile fragmentation capabilities include alumina, silicon carbide, and boron carbide, although they are brittle and have poor multi-hit resistance. These limitations have led to a trend toward hybrid and multilayer composite systems that can effectively combine strength, toughness, and weight efficiency.

Layered composite armor systems have become a viable option in recent years for improving ballistic performance without sacrificing structural effectiveness. These systems usually combine energy-absorbing backing layers consisting of high-performance fibers like para-aramid (e.g., Kevlar, Twaron) and ultra-high-molecular-weight polyethylene (UHMWPE) with a hard strike face, which is frequently formed of steel or ceramic materials. While the backing layers disperse residual stresses and stop penetration, the front layer is in charge of projectile deformation and initial energy dissipation. Optimized multilayer topologies can greatly increase energy absorption and decrease backface deformation, improving overall protection efficiency, according to experimental studies.

Despite these developments, striking the ideal balance between lightweight design, flexibility, and ballistic resistance is still a significant issue. Impact resistance is increased by adding more layers or thicker materials, however this also increases system weight and decreases mobility. In order to improve interfacial interactions and energy dissipation without appreciably increasing mass, current research efforts are concentrated on creating novel material architectures and surface engineering approaches.

Applying sophisticated coatings and nanostructured changes to fiber-based and composite materials is one of the most promising strategies. The inter-yarn friction, impact resistance, and energy absorption capacities of coatings containing nanomaterials including graphene, carbon nanotubes (CNTs), nanosilica, and zinc oxide nanostructures have been improved. Furthermore, multifunctional qualities such as electromagnetic shielding, thermal stability, and sensing capabilities can be introduced by functional coatings, allowing for the creation of intelligent and flexible ballistic defense systems.

Innovations in composite bonding processes are equally important to structural performance as advances in materials. Adhesive bonding provides benefits like consistent stress distribution, lightweight construction, and enhanced aerodynamic profiles, especially in fiber-reinforced polymer systems. Recent research on adhesives modified with thermally expandable particles (TEPs) shows promise for reversible bonding and adjustable mechanical characteristics, which can improve composite structures' sustainability, durability, and repairability.

Additionally, a better knowledge of ballistic impact mechanisms and material behavior under severe loading circumstances has been made possible by the integration of computational modeling, numerical simulations, and experimental validation. These methods make it easier to optimize interfacial characteristics, material choices, and layer configurations, which results in more dependable and effective protection systems.

In this regard, the current effort integrates knowledge from material science, composite engineering, and surface modification technologies to create a thorough understanding of improved ballistic protection systems. Achieving high-performance, lightweight, and multipurpose protective systems that can satisfy the changing needs of contemporary industrial and defense applications is the main goal.

2.MethodofExperimentation

2.1 Supplies

Because of its exceptional hardness and impact resistance, high-strength Hardox 450 steel was chosen as the main strike-face material for this investigation. Para-aramid fabric (Twaron CT 747) and ultra-high-molecular-weight polyethylene (UHMWPE) (Endumax Shield XF33), which offer superior energy absorption and high strength-to-weight properties, were used as reinforcement layers.

The matrix substance was an adhesive system based on epoxy. Thermally expandable particles (TEPs) were added to the glue to improve functionality by enabling controlled structural and mechanical changes under thermal activation.

2.2 Composite Panel Manufacturing

Compression molding and vacuum-assisted resin transfer molding (VARTM) were used to create layered composite panels.

Vacuum sealing and resin infusion were performed after dry para-aramid fabric layers were stacked in a cross-ply sequence ([0/90]_n) for VARTM. To guarantee adequate consolidation, the laminates were cured for a full day at room temperature.

For prepreg-based laminates, compression molding was utilized to create dense and consistent composite structures by applying pressures of 300–350 kN and temperatures of 130–140°C to stacked layers of Twaron and UHMWPE.

Steel strike plates and composite laminates were then combined to create hybrid panels.

2.3 Making Modified Adhesive

Thermally expandable particles (TEPs) were added to the epoxy adhesive at various weight fractions. To guarantee uniform dispersion, a mechanical mixer was used to prepare the mixture.

After being prepared, the adhesive was poured into molds and allowed to cure in a controlled environment. The adhesive matrix underwent microstructural changes as a result of the application of post-curing heat treatment, which triggered particle expansion. Scanning electron microscopy (SEM) and optical microscopy were used for morphological examination.

2.4 Application of Coating

To improve interfacial characteristics and ballistic performance, surface coatings were applied to specific fabric layers. Coating methods like solution impregnation and dip-coating were used.

To increase the coating's stiffness, energy dissipation capacity, and inter-yarn friction, nanomaterials such as carbon-based additives and nanosilica were used. To guarantee consistent layer formation, coated samples were dried under carefully monitored circumstances.

2.5 Examining Mechanical Systems

Single-lap shear tests were used to assess the mechanical characteristics of the bonded and composite constructions. The adhesive joints' shear strength, stiffness, and failure behavior were assessed using a universal testing apparatus.

In order to investigate expansion characteristics and structural stability, controlled heating tests were used to assess the modified adhesive's thermal behavior.

2.6 Ballistic Examinations

NATO STANAG 4569 Level I criteria were used to assess ballistic performance. 7.62 mm full metal jacket (FMJ) bullets were fired at test specimens at speeds of about 830 m/s.

Systems for measuring velocity and controlled firing conditions were part of the ballistic test setup. To assess penetration resistance, deformation, and failure modes such delamination, fiber breakage, and matrix cracking, post-impact analysis was carried out.

2.7 Analysis of Microstructures

Scanning electron microscopy (SEM) and optical microscopy were used for microstructural characterisation. Adhesive morphology, coating distribution, and fiber–matrix interaction were all examined using these approaches.

A thorough understanding of energy absorption mechanisms and the contribution of each material component to overall ballistic performance was made possible by the combined experimental observations.

3. TESTING METHODS

3.1 Testing for Ballistic Impact

In compliance with NATO STANAG 4569 Level I requirements, ballistic testing was carried out to assess the impact resistance of the developed multilayer composite systems. 7.62 mm full metal jacket (FMJ) bullets with an impact velocity of roughly 830 ± 20 m/s were used on the specimens.

A ballistic barrel, a controlled firing system, and velocity measuring tools such optical sensors and radar systems made comprised the test setup. To guarantee constant impact circumstances, the target panels were positioned at a specific distance from the firing point.

Among the important performance metrics assessed are:

Resistance to penetration

Projectile residual velocity

Deformation of the back face

Distribution of damage among layers

To find failure mechanisms such delamination, fiber breaking, matrix cracking, and interface debonding, post-impact observations were carried out.

3.2 Examining Mechanical Systems

The strength and longevity of composite laminates and adhesive joints were evaluated mechanically. A universal testing apparatus was used to conduct single-lap shear tests under carefully regulated loading circumstances.

The parameters that were measured were as follows:

Maximum shear strength

Behavior of load and displacement

Bonded joint stiffness

Modes of failure

To assess the impact of particle integration on mechanical performance, tests were carried out for both unmodified and TEP-modified adhesive systems.

3.3 Thermal Evaluation

The behavior of adhesives modified with thermally expandable particles (TEPs) under various temperature levels was investigated by thermal testing. To initiate particle expansion and assess its impact on adhesive structure and performance, controlled heating experiments were conducted.

The improved adhesive system's expansion behavior, weight loss characteristics, and thermal stability were investigated using thermogravimetric analysis (TGA). Temperature-dependent performance changes were revealed by these testing.

3.4Characterization of Microstructure

The interior morphology of composite materials, coatings, and adhesive systems was examined using microstructural analysis. The following were investigated using optical microscopy and scanning electron microscopy (SEM):

Interaction between fiber and matrix

Coating dispersion and homogeneity

The beginning and spread of cracks

TEP particle expansion behavior

Understanding the mechanics underlying energy absorption and structural integrity under ballistic loading conditions was made easier by these analyses.

3.5Evaluation of Coating Performance

Comparative testing between coated and untreated samples was used to assess the efficacy of applied coatings. The assessment concentrated on:

An increase in the friction between yarns

Improvement of impact resistance

Features of surface adhesion

Based on mechanical and ballistic performance data, the contribution of nanomaterial-based coatings to energy dissipation and structural strengthening was evaluated.

3.6 Analysis of Failures

After mechanical and ballistic testing, failure analysis was done to determine the primary damage pathways. Among the failure modes noted are:

Fracture of the fiber

Layer delamination

Cracking a matrix

Debonding adhesive

In-depth analysis of cracked surfaces revealed information about how various material layers interact and how well hybrid structures dissipate impact energy.

4. OUTCOMES AND TALK

4.1 Layered Composites' Ballistic Performance

The created layered composite systems significantly outperform traditional single-material constructions in terms of impact resistance, as shown by the ballistic test results. Through a combination of deformation, fragmentation, and stress distribution mechanisms, hybrid designs with a steel strike face and fiber-reinforced backing layers efficiently disperse projectile energy.

The para-aramid and UHMWPE composite layers redistribute the residual energy, preventing full penetration, while the steel front layer mainly aids in projectile deformation and initial energy absorption. According to experimental findings, optimum configurations were able to withstand hits from 7.62 mm FMJ projectiles with little penetration and less back-face distortion.

Additionally, it was shown that adding more composite layers improves energy absorption; however, too many layers result in increased weight and decreased flexibility. For effective ballistic performance, layer thickness and material choice must be balanced optimally.

4.2The Impact of Material Hybridization and Layer Configuration

Ballistic efficiency is largely dependent on how various material layers are arranged and interact. The findings demonstrate that layered systems with carefully thought-out stacking sequences enhance interfacial stress transfer and slow the spread of cracks.

When compared to monolithic structures, hybrid systems that combine metals, fibers, and polymers performed better because they could use a variety of energy dissipation techniques, such as:

Deformation of plastic (metal layer)

Stretching and breaking of fibers (aramid/UHMWPE layers)

Frictional sliding and delamination between layers

Furthermore, experimental results demonstrate that optimum hybrid topologies can reduce areal density while preserving structural integrity, making them appropriate for lightweight armor applications.

4.3 The Impact of Coatings Based on Nanomaterials

The application of coatings based on nanoparticles significantly improved the interfacial properties of fiber-reinforced composites. Increased inter-yarn friction in coated textiles enhanced load transmission and strengthened resistance to impact-induced deformation.

Nanomaterials such as nanosilica and carbon-based reinforcements assisted with:

enhanced stiffness and hardness of the surface

Increased energy dissipation during impact

Enhanced durability and resistance to wear

These coatings also enabled multifunctional characteristics including improved thermal stability and environmental resistance. The results demonstrate that coated composites outperform their uncoated counterparts in terms of mechanical and ballistic performance.

4.4 Adhesive Systems' Mechanical Performance

The findings of mechanical testing show that the bonding performance is greatly impacted by the addition of thermally expandable particles (TEPs) to the adhesive matrix.

Adhesives modified with TEP demonstrated:

Enhanced ability to absorb energy

controlled deformation when under load

Increased resilience to cracking

Shear strength varied according to particle concentration, according to single-lap shear experiments. Excessive particle loading decreased bonding strength because of increased porosity and microstructural flaws, although moderate TEP concentration enhanced toughness and energy dissipation.

These results emphasize how crucial it is to maximize particle concentration in order to strike a balance between strength and adaptability.

4.5 Modified Adhesives' Thermal Behavior

Thermal analysis showed that when TEP-modified adhesives are exposed to high temperatures, they significantly expand in volume. Mechanical properties vary as a result of this expansion's alteration of the internal microstructure.

When the temperature rises:

Reduced adhesive stiffness

Microvoids created by expansion

The capacity to absorb energy rises

The findings show that temperature has a significant impact on adhesive performance, especially in applications with harsh environmental conditions.

4.6 Mechanisms for Failure

Several key failure modes in the developed systems were identified by post-impact and post-mechanical testing analyses:

High tensile tensions during impact cause fiber fracture.

Delamination: Resulting from strong shear pressures or poor interlayer bonding

Matrix cracking: Caused by the polymer matrix's brittle nature

Debonding adhesive: Particle dispersion and thermal effects have an impact

The quality of interfacial bonding and the contact between layers have a significant impact on energy dissipation, as demonstrated by microscopic measurements. Compared to unmodified systems, coated and hybrid systems demonstrated better damage tolerance and delayed failure.

4.7 Overall Performance Assessment

The combined experimental findings unequivocally show that the combination of:

Composite structures with layers

Coatings based on nanomaterials

Ballistic performance is significantly improved by modified adhesive methods.

According to the study, optimized hybrid systems can accomplish:

High resilience to impact

Diminished weight

Increased adaptability

Increased robustness

Because of these qualities, they are ideal for next-generation ballistic protection systems used in industrial and military settings.

5. CONCLUSION

The development of sophisticated ballistic protection systems by combining layered composite architectures, coatings based on nanomaterials, and improved adhesive technologies is thoroughly examined in this work. The findings show that hybrid configurations that combine high-performance fiber-reinforced composites with metallic strike faces greatly improve impact resistance by efficiently dissipating kinetic energy through a variety of mechanisms, such as interlayer friction, plastic deformation, and fiber stretching.

It was discovered that adding coatings based on nanomaterials improved interfacial bonding and inter-yarn friction, which increased mechanical strength and ballistic efficiency. Additionally, the usage of adhesives modified with thermally expandable particles (TEPs) enhanced energy absorption and adaptability, although maintaining sufficient bonding strength and preventing structural flaws requires an ideal particle concentration.

Analytical and experimental analyses verified that material choice, layer arrangement, and interfacial properties have a significant impact on ballistic system performance. The results show that current protective systems must strike the ideal balance between flexibility, lightweight design, and great impact resistance.

All things considered, the suggested integrated strategy shows great promise for the creation of next-generation ballistic armor systems with increased multifunctionality, less weight, and better performance. These developments are especially pertinent to industrial safety, aerospace, and defense applications where effective and dependable protection is essential.

6. RECOMMENDATIONS AND FUTURE SCOPE

The current study shows how enhanced coatings, modified adhesives, and hybrid layered composite materials can improve ballistic performance. To improve the effectiveness and suitability of next-generation ballistic protection systems, there are still a number of areas that require more study and development.

A. Development of Advanced Materials

Future research should concentrate on creating new lightweight materials, such as hybrid fiber systems, nano-engineered composites, and functionally graded materials (FGMs). Energy absorption and impact resistance can be further enhanced while keeping low density by incorporating cutting-edge nanomaterials like graphene derivatives and sophisticated ceramic reinforcements.

B. Layered Architecture Optimization

Optimizing layer thickness, stacking order, and areal density is still crucial even when layered structures enhance ballistic performance. Optimized structures that provide greatest protection with the least amount of weight should be designed using sophisticated computational modeling and simulation techniques.

C. Intelligent and Versatile Coatings

Future studies should investigate smart coatings that can offer extra features like electromagnetic shielding, self-healing, real-time damage detection, and thermal control. The incorporation of multifunctional characteristics intothin coating layers can significantly enhance system performance without increasing bulk.

D. Adhesive System Improvement

Optimizing thermally expandable particle (TEP)-modified adhesives and related smart bonding solutions will require more research. Research should concentrate on strengthening bonds, decreasing porosity, and increasing durability under a range of environmental circumstances, including temperature, humidity, and cyclic stress.

E. Sustainability and Environmental Aspects

Future research should focus on the recyclability and environmentally friendly design of ballistic materials since sustainability is becoming more and more important. Easy disassembly and reuse at the end of a product's life can be facilitated by the development of sustainable composite materials and reversible adhesive methods.

F. Advanced Standardization and Testing

More thorough testing under harsh and real-world circumstances, such as multi-hit impacts, temperature fluctuations, and dynamic loading scenarios, is required. More dependable testing will be ensured by standardizing testing procedures beyond current guidelines.evaluation of advanced ballistic systems.

G. Digital Technology Integration

Materials discovery and performance prediction can be accelerated through the use of artificial intelligence (AI), machine learning, and materials informatics. Optimizing material selection, anticipating failure processes, and lowering experimental costs are all possible using digital technologies.

REFERENCES

[1]. Advanced Fibrous Composite Materials for Ballistic Protection, edited by Chen, X. Woodhead Publishing, Cambridge, UK, 2016. [CrossRef]

[2]. Strelko, O.; Horban, A. An Examination of the Development of Personal Protective Equipment: From Bronze Armor to Contemporary Bulletproof Vests. 2023, 13, 201-222; Hist. Sci. Technol. [CrossRef]

[3]. Research on the Performance of Ceramic Composite Projectile Penetrating into Ceramic Composite Target by Yi, R.-C.; Yin, L.-K.; Wang, J.-R.; Chen, Z.-G.; Hu, D.-Q. Def. Technol. 13, 295–299, 2017. [CrossRef]

[4]. A Review of Stab Protection Armor's Comfort and Performance by Sitotaw, D.B., Ahrendt, D., Kyosev, Y., and Kabish, A.K. Autex Res. J. 2021, 21, 255–272. [CrossRef]

[5]. David, N.V.; Gao, X.-L.; Zheng, J.Q. Ballistic Resistant Body Armor: Current and Future Materials and Associated

Protection Mechanisms Available to Purchase. Appl. Mech. Rev. 2009, 62, 050802. [CrossRef]

[6]. Ballistic Impact Response of Laminated Hybrid Materials by Haro, E.E., Szpunar, J.A., and Odeshi, A.G. composed of Kevlar, epoxy, and 5086-H32 aluminum alloy fabrics impregnated with shear thickening fluid. 2016, 87, 54–65; Compos. Part A Appl. Sci. Manuf.

[CrossRef]

[7]. Ballistic Impact Mechanisms—A Review of Textiles and Fiber-Reinforced Composites Impact Responses, Abtew, M.A.; Boussu, F.; Bruniaux, P.; Loghin, C.; Cristian, I. 2019, 223, 110966; Compos. Struct. [CrossRef]

[8]. Yavas, M.O.; Avcı, A.; Simsir, M.; Akdemir, A. Ballistic Performance of Hybrid Layered Composite Kevlar49/UHMW-PEHB26.

2015, 7, 21–27; Int. J. Eng. Res. Dev. [CrossRef]

[9]. Erlich, D.C.; Shockey, D.A.; Simons, J.W. Ballistic Fabric Slow Penetration. Text. Res. J. 2003, 73, 179–184. [CrossRef]

[10]. Impact Performance of Single-Piece Continuously Textile Reinforced Riot Helmet Shells, Zahid, B.; Chen, X. J. Compos. Mater. 48, 761-776 (2014). [CrossRef]

[11]. Azmi, M.R.; Sultana, M.T.H.; Hamdan, A.; Nor, A.F.M.; Jayakrishna, K. Flexural and Impact Properties of a New Bulletproof Vest Insert Plate Design Using Kenaf Fiber Embedded with X-Ray Films. Mater. Proceedings of Today 2018, 5, 11193–11197. [CrossRef]

[12]. Yang, Y.; Chen, X. Examining Mechanisms of Energy Absorption in a Soft Armor Panel During Ballistic Impact. 2017, 87, 2475–2486. Text. Res. J. [CrossRef]

[13]. Zohdi, T.I. Progressive Penetration of Multilayered Ballistic Fabric Shielding: Modeling and Simulation. Comput. Mech. 2002, 29, 61–67. [CrossRef]

[14]. Joo, K.; Kang, T.J. Energy Absorption Mechanism in Multi-Ply Fabric Impacts: Numerical Analysis. Text. Res. J. 78, 561-576 (2008). [CrossRef]

[15]. Karahan, M.; Ku¸s, A.; Eren, R. An Investigation into Ballistic Performance and Energy Absorption Capabilities of Woven Aramid

Fabrics. Int. J. Impact Eng. 2008, 35, 499–510. [CrossRef]

[16] Veeraswamy, K., and Venkata Sudheer Babu, V. (2016). COMPOSITE BEAM DESIGN AND ANALYSIS FOR CAR DOOR SIDE IMPACT PROTECTION 03(02).

[17] Chauhan, V., Kärki, T., and Varis, J. (2022). An outline of the manufacturing processes and applications of natural fiber-reinforced engineered plastic composites in the transportation sector. Journal of Thermoplastic Composite Materials.

[18] Choi, T. G., and M.-Y. Lyu (2015) [doi.org/10.1177/0892705719889095]. Examine recent advancements in lightweight car polymer materials. International Journal of Precision Engineering and Manufacturing, 16(1), 213-220.

[19] https://doi.org/10.1007/s12541-015-0029-x Huang, Y., Xiao, X., Kang, H., Lv, J., Zeng, R., and Shen, J. (2022) Thermal management of polymer electrolyte membrane fuel cells: An examination of novel cooling techniques, cooling systems, and heat transfer processes. Energy Conversion and Management, 254, 115221.

[20] Sherwani, S., Sapuan, S., Leman, Z., Zainuddin, E., & Ilyas, R. (2020) [doi.org/10.1016/j.enconman.2022.115221]. A thorough analysis of the use of polymer composite materials in motorcycles.

Automotive Applications of Biocomposite and Synthetic Composites, 401-426.

https://doi.org/10.1016/B978-0-12-820559-4.00015-8

[21]. J. Bergstrom, Mechanics of Solid Polymers, Plasticity Models.
(Elsevier, 2015), pages 353–369. https://doi.org/10.1016/B978-0-323-31 150-2.00007-8

[22]. S. Alam and D. Nguyen, An Examination of the Ballistic Impact Behavior of Multi-Layered Armor Structure, J. Reinf. Plast. Compos., 2024 https://doi.org/10.1177/07316844241239711

[23]. R. Scazzosi, S.C. Amico, M. Giglio, and A. Manes, Experimental and Numerical Assessment of the Perforation Resistance of Multi-Layered Alumina/Aramido, Compos.

[24]. A. Gilioli, A. Manes, M. Giglio, and T. Wierzbicki, Ballistic Impact Failure Prediction of Aluminum 6061–T6 using the Rate-Independent Bao-Wierzbicki Fracture Model, Int. J. Impact Eng., 2015, 76, p 207–220. https://doi.org/10.1016/j.ijimpeng.2014.10.004

[25]. Ballistic Limit Predictions of Non-Identical Layered Targets Perforated in Ductile Hole Formation by R. Masri and S. Ryan, International Journal of Impact Engineering, 2023, 171, 104391. https://doi.org/10.1016/j.ijimpeng.2022.104 391

[26]. LS-Dyna Manual vol. I R.13.0. LSTC stands for Livermore Software Technology Corporation. Greetings from the LS-DYNA support website. (2021), https://www.dynasupport.com/manuals/ls-dyna-manuals. Accessed January 11, 2024

[27]. Ballistic Performance of UHMWPE Laminated Plates and UHMWPE Encapsulated Aluminum Structures: Numerical Simulation, Compos. Struct., 2020, 252, 112686, R. Zhang, L.-S. Qiang, B. Han, Z.-Y. Zhao, Q.-C. Zhang, C.-Y. Ni, and T.J. Lu. https://doi.org/10.1016/j.compstruct.2020.112686

[28]. J. Lin, Y. Li, S. Liu, and H. Fan, Numerical Analysis of Body Armor Panels' High Velocity Impact Performance, Thin Walled Struct., 2023, 189, 110909. https://doi.org/10.1016/j.tws.2023.110909

[29]. Experimental Characterization and Numerical Simulation of Ballistic Penetration of Columnar Ceramic/fiber Laminate Composite Armor, Y. Jiang, K. Qian, Y. Zhang, Y. Xia, Z. Xiong, Z. Zhang, and K. Yu, Mater. Des., 2022, 224, 111394. 111394 https://doi.org/10.1016/j.matdes.2022

[30]. Influence of Projectile and Thickness on the Ballistic Behavior of Aramid Composites: Experimental and Numerical Study, S.G. Nunes, R. Scazzosi, A. Manes, S.C. Amico, W.F. de Amorim Junior, and M. Giglio, International Journal of Impact Engineering, 2019, 132, 103307. https://doi.org/10.1016/j.ijimpeng.2019.05.021

[31]. 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., 2021, 47(16), p 22497–22513. https://doi.org/10.1016/j.ceramint.2021.04.259