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Review of Ballistic resistance Technology as Individual Body Armor in Military and Security Applications

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Abstract— This research examines ballistic resistance technologies in the context of military and law enforcement to counter the threat of firearms and explosive devices. The focus is on analyzing the various materials used in ballistic resistance protection, such as Kevlar, Dyneema, and ceramics, as well as recent innovations such as thickening fluids (STF) and nanomaterials. The research also explored key challenges in the development of ballistic resistance technologies, including protection weight, manufacturing costs, and enhancing weapon firepower. The conclusions of this study emphasize that the development of ballistic resistance technologies requires continuous research and innovation to overcome these challenges. Future trends such as the use of nanotechnology and eco-friendly materials promise lighter and stronger solutions. The results of this study are expected to provide useful insights for policymakers, military equipment designers, and law enforcement.

Keywords— Technology, Ballistic Resistances, Materials, Innovation

I. Introduction

Technological advances and changing tactics in military conflicts and law enforcement duties have increased the need for effective personal protection against ballistic threats. Both on the battlefield and in policing operations, personnel are often exposed to various types of firearms and explosive devices that pose serious risks to their safety. Therefore, the development of ballistic resistance technologies has become a major focus in the effort to protect individuals in high-risk environments.

Ballistic resistance technology encompasses a variety of devices and materials designed to withstand or reduce the impact of bullets, fragments and other projectiles. Bulletproof vests, tactical helmets and other additional protection have become an integral part of standard equipment for military forces and law enforcement officers around the world. The use of advanced materials such as Kevlar, Dyneema and ceramics has enabled lighter and more effective protection, while research continues to find better solutions.

However, as the technology evolves, new challenges also arise. Some of these include increased weapon firepower, protection burdens that can reduce mobility, and high production costs. Therefore, there is a need for a comprehensive study to understand the ballistic resistance technologies currently available, their applications in military and security contexts, and future trends in their development.

This research aims to explore various aspects of ballistic resistance technologies as personal protection in military and security applications. This will include an analysis of the types of ballistic threats faced by military and law enforcement personnel, an evaluation of the various materials and technologies used in ballistic resistance protection, and a review of standards and testing procedures to ensure the reliability of protection. In addition, the research will also examine future challenges and innovations in this field.

With a deeper understanding of ballistic resistance technology and its implications in personal protection, this study is expected to make a meaningful contribution to the development of more effective and efficient protection. The study is also expected to serve as a reference for policy makers, military and police equipment designers, and personnel using this protection in the field.

II. Research Methodology

This research method uses a literature study, which is a type of library research with a qualitative descriptive approach, namely by using the content analysis method and explaining the methods and types of sampling that refer to the three texts of the analyzed articles. The data source used is a secondary data source.

III. Result and Discussion

Research results from a systematic literature review (SLR) focused on a comprehensive review study of ballistic resistance technology, by prioritizing technological developments for ballistic resistance needs, as in the literature in the following table:

Table 1. Literature sources

No	Name	Research Title	Research result
1	Shella Athaya Miwazuki (2024)	Material	The application of polymer composite materials in the military field, such as ballistic resistance helmets, is designed to provide protection against external threats such as high-velocity bullets or projectile fragments. Ballistic resistance helmets made from hybridized banana stem polyester fiber and cow horn particulate composites are considered more effective because these materials produce helmets with lighter loads but can still protect the safety of personnel, an increase in tensile strength by 94.66%, and impact energy by 174.79%. The ballistic limit results of the laminated hybrid composites, intended for ballistic helmets, in which layers of traditional aramid woven fabric were combined with curaua nonwoven mats, allowed the following conclusions. E-15A/1C obtained the maximum level of ballistic protection (Material et al., 2024).
2	Dr. Bipin J Agrawal (2011)	Textile Ballistic Protection	Humans throughout history have used different types of materials as body armor to protect themselves from injury in combat and other dangerous situations. With the advancement of technology and the development of more innovative and lightweight but strong textile materials for ballistic protection purposes, it has been successfully claimed that these new composite materials will result in thinner and lighter ballistic resistant panels, which will lead to lower material and transportation costs and reduced building loads. (Agrawal, 2011).
3	David, N. V. (2009)	Material Ballistic Resistance	Body armor designs use materials such as ballistic fabrics, ceramics, and laminated composites to protect against projectiles. Armor performance is

			measured based on thickness, density, projectile type and velocity, and material configuration. SiC and Al2O3 ceramics are used for their strength and durability, while nanocomposites and CNTs show promise in recent research. For the future, the focus is on high-strength fibers, degradation-resistant materials, and environmentally friendly natural fibers. Natural fiber composites have potential due to their biodegradability and lower production costs. More research is needed to ensure the performance and validity of these new materials. Body armor continues to evolve thanks to advances in materials science and design innovation. (David et al., 2009)
4	Wu, Shuangyan (2023)	Body Armor Technology	Development of ballistic and anti-impact materials, including the use of nanotechnology and high-performance fibers. Various fibers such as para-aramid, UHMWPE, glass fiber, carbon fiber, and natural fiber are outlined. Nanomaterials such as CNTs and graphene are also considered to improve strength and impact resistance. Ballistic materials can be flexible shapes for bulletproof suits or rigid shapes for vehicle armor and shields. Sandwich structures and liquids that thicken on impact are also being used to improve ballistic performance. Despite extensive research, two major challenges remain: uneven distribution of nanomaterials in the polymer matrix and poor adhesion between the fibers and the matrix. To ensure high performance with light weight, factors such as specific strength, specific toughness and energy absorption need to be considered. Future research should focus on improving penetration resistance, weight reduction, and user comfort in the design of ballistic materials. (Wu et al., 2023)
5	Anatolii Horban (2023)	Body Armor	Evolution of personal protective equipment. This makes it possible to conduct a comparative historical analysis of the development of scientific research and industrial technologies, which made it possible to manufacture certain personal protective equipment in certain historical periods. Also in this review article, we have analyzed the stages of modern technologies currently used in the manufacture of various types of bulletproof vests. And given that most authors of publications on the history of the manufacture of bulletproof vests write that: bulletproof vests have no specific inventor, in this review article

			we also talk about a specific, undeservedly forgotten by now, creator of the world's first officially patented prototype of a bulletproof vest for police and VIP persons, at the beginning of the 20th century, who stood at the very beginning of the bulletproof vest industry. (Strelko & Horban, 2023).
6	Mulat Alubel Abtew (2021)	Protective Body Armor	Developing body armor that provides high protection and remains comfortable is a big challenge. Several female-specific body armor designs, such as cut-and-sew, folding, overlapping, and printing, have advantages and disadvantages. The molding technique, for example, can shape the front without darts, but requires special materials. To improve performance without sacrificing comfort, researchers have developed new materials such as high-performance fabrics and composites reinforced with carbon nanotubes (CNTs). Impregnation with a thickening fluid (STF) increases puncture and ballistic resistance without reducing flexibility. CNT- and graphene-based composites offer high potential due to their ability to absorb energy and effectively resist projectiles. This research shows that these new technologies can take body armor to the next level, with high protection, light weight, and better comfort for law enforcement and the military. (Abtew et al., 2021).
7	Fattah Maulana (2023)	Material	The projectiles fired from muskets were usually lead balls accelerated by the burning of black powder inside the gun barrel. After the battle, the guns were returned to base and stored, however some guns could not be melted down due to the risk of explosion, so they were dumped into the sea. In the context of protection, buff coats were used as protective clothing during the English Civil War, but their effectiveness as armor is unclear. Technological developments are needed to deal with conditions involving bladed weapons, firearms, and even intercontinental missiles, such as the use of aramid fabrics for knife resistance, bullet-resistant materials for projectiles, and iron domes to deflect missiles. The Izod impact test is a way to measure the energy absorbed when a material breaks. This technique determines the material's resistance to impact, with various types of notch configurations such as V-Notch, U-Notch, and Key-

			Hole Notch. Meanwhile, fibers such as aramid and UHMWPE are used for ballistic protection, and research shows that the impregnation of thickening fluid (STF) on traditional ballistic fabrics can improve puncture resistance without reducing flexibility. Carbon nanotube (CNT) and graphene fiber reinforced composites have also shown promising results in terms of ballistic resistance and energy absorption ability. Numerical analysis methods, such as FEA, are used for computer simulations to understand the behavior of materials when exposed to projectiles. Supporting analysis can help design better protection without relying on expensive and destructive firearms tests. This article presents various methods and techniques in ballistic testing and simulation to provide a knowledge base and reference for future research development. (Maulana, Prabowo, et al., 2023).
8	Fattah Maulana (2023)	Body Armor	The slight difference in results between this paper and the experiments of Li Chen et al. indicates the need for further research. The impact of notched plate surface design on bullet behavior requires more in-depth investigation, taking into account different material properties and test conditions. Understanding the factors that affect the ballistic performance of plates will help optimize protective materials for various applications, including body armor, vehicle armor, and other ballistic protection systems. The results show that the effectiveness of bullet-resistant plates is greatly affected by material properties, material design, and direction of fire. Although the material properties used in this analysis are generally applied, the material design in the simulation has a significant impact by changing the direction of bullet movement, thereby affecting the energy transmitted to the plate. These findings reveal a new perspective that needs to be validated through real-world experiments. To understand the performance of notched plates, further research is needed by testing different material designs, exploring additional material properties, and testing with different shot directions to determine their impact on the performance of bullet-resistant plates. By understanding these factors, we can develop better ballistic armor solutions, improving safety in hazardous environments. The

			slight difference in results between this paper and the experiments of Li Chen et al. is a trigger for further investigation. The surface design of the grooved plate, material properties and test conditions have an important role in its ballistic performance. By deepening this understanding, we can create more effective shielding materials for a variety of important applications. (Maulana, Ubaidilah, et al., 2023).

Ballistic Resistance Materials and Technology

The use of materials in ballistic resistance material elements is very diverse in use, depending on the function and position of the use of ballistic resistance materials. In the use of helmets can use polymer composite materials as in the previous article that is, the application of polymer composite materials in the military field, such as ballistic resistance helmets designed to provide protection against external threats such as high-velocity bullets or projectile fragments. As well as the development of technology in this product also received good attention, it was explained that ballistic resistance helmets made from hybridized banana stem polyester fibers and cow horn particulate composites were considered more effective because these materials produced helmets with lighter loads but could still protect the safety of personnel, increased tensile strength by 94.66%, and impact energy by 174.79%. The ballistic limit results of the laminated hybrid composites, intended for ballistic helmets, in which layers of traditional aramid woven fabric were combined with curaua nonwoven mats, allowed the following conclusions. E-15A/1C obtained the maximum level of ballistic protection (Material et al., 2024).

Ballistic resistance technology involves the use of various materials and structures designed to withstand or reduce the impact of bullets, fragments and other projectiles. These materials are used in various protective devices, such as bulletproof vests, ballistic helmets, and vehicle armor. Here are some of the key materials and technologies in the ballistic resistance field:

a. Polymer Composites: Composite materials, such as Kevlar and Dyneema, have become a top choice in ballistic resistance protection due to their lightweight yet strong properties. Kevlar, for example, is an aramid fiber used widely in bullet proof vests and ballistic helmets due to its ability to absorb energy and prevent projectile penetration. Dyneema, an ultra-high molecular weight polyethylene fiber, is also renowned for its strength and flexibility.

b. Ceramics: Ceramics such as silicon carbide (SiC) and alumina (Al2O3) offer a high level of protection against high-velocity projectiles. They are often used in hard body armor plates and vehicle armor. Ceramics have the advantage of inhibiting bullet penetration, but are usually heavier than polymer composites.

c. Nanomaterials: Nanotechnology has brought new innovations in the field of ballistic resistances. Materials such as carbon nanotubes (CNTs) and graphene have outstanding strength and high energy-absorbing capabilities. These nanomaterials can be used in composites to improve ballistic resistance performance and reduce protection weight.

d. Flexible Materials and Sandwich Structure: Sandwich structures combine multiple layers of materials to increase strength and durability. Flexible materials such as ballistic fabrics can also be combined with composite layers to provide lightweight and comfortable protection.

Individual Protection Device

Personnel protection devices refer to a variety of equipment designed to protect military and law enforcement personnel from ballistic threats. Here are some of the key devices and innovations in this field:

a. Bulletproof Vest: Bulletproof vests are basic equipment for personnel working in hazardous environments. These vests are usually made of multiple layers of polymer composites or ceramic plates to provide protection against projectiles. Recent technologies in bulletproof vest design include the use of nanomaterials and impregnation with thickening fluids (STF), which can increase puncture and ballistic resistance without reducing flexibility.

b. Ballistic Helmet: Ballistic helmets are designed to protect the head from projectiles and debris. These helmets are usually made from polymer composite materials or a blend of fibers with ceramics. The use of materials such as banana stem polyester fibers and cow horn particulate composites have proven effective in creating helmets that are lighter while still providing optimal protection.

c. Additional Protection: In addition to vests and helmets, there are additional protection devices such as elbow, knee and shin guards designed to provide additional protection in military and police operations. Innovations in this field include the use of high-performance fibers and flexible structures that can conform to the body shape.

Development of Ballistic Resistance Technology

Ballistic resistance technology development continues to evolve to address various challenges and meet changing needs in military and law enforcement operations. Some of the key trends in ballistic resistance technology development are:

a. Nanotechnology Integration: Nanomaterials, such as carbon nanotubes and graphene, offer great potential in the development of lighter and stronger ballistic resistance protection. Nanotechnology enables the creation of composites with higher strength and better resistance to projectile penetration.

b. Thickening Fluid (STF): The use of thickening fluid, which thickens on impact, provides flexibility and comfort without sacrificing protection. This technique is used in ballistic vests and fabrics to improve puncture and ballistic resistance.

c. Sustainable Materials: Recent trends in the development of ballistic resistance technologies include the use of sustainable and eco-friendly materials. Natural fibers and biodegradable composites are in focus to reduce environmental impact and production costs.

d. Simulation and Analysis Methods: The use of numerical analysis techniques, such as the finite element method (FEA), allows designers to simulate the behavior of materials when exposed to projectiles. These simulations help in optimizing the design of ballistic resistance protection and reduce the need for expensive and destructive firearms tests.

Military and Security Applications

Ballistic resistance technologies have wide applications in military and security contexts. The development of these technologies is essential to protect personnel from various ballistic threats and ensure safety during operations. Some of the main applications are:

a. Military Operations: In military operations, ballistic resistance protection is essential to keep personnel safe. Bulletproof vests and ballistic helmets are used by soldiers to protect themselves from projectiles and debris. In addition, additional protection, such as elbow and knee guards, are used to provide extra protection in high-risk environments.

b. Law Enforcement Operations: Law enforcement officers are often faced with dangerous situations that require ballistic resistance protection. Bulletproof vests and other protection are used to keep officers safe during operations. Lighter and flexible technology is essential to ensure mobility and comfort during duty.

c. Protection of VIPs and Government Officials: Ballistic resistance technology is also used to protect VIPs and government officials in high-risk situations. Concealed bulletproof vests and ballistic resistance vehicle protection are part of the security measures to keep important figures safe.

Challenges and Difficulties

While ballistic resistance technology has made significant progress, there are a number of challenges and difficulties that still need to be overcome. Here are some of the key challenges in this field:

a. Weight and Mobility: One of the key challenges is to develop effective protection without compromising mobility and comfort. Protection that is too heavy can reduce the ability of personnel to move freely and hamper operations.

b. Production Costs: The use of advanced materials and high technology often affects production costs. High production costs can limit access to ballistic resistance protection, especially for institutions with limited budgets.

c. Increased Firepower: Ballistic threats continue to evolve with increased firepower of weapons and projectiles. Ballistic resistance technologies must continually adapt to deal with increasingly powerful and complex threats.

d. Reliability Testing and Standards: Reliability testing and standards are challenging as ballistic resistance protection must be tested under realistic conditions and ensure reliability in various situations. Costly and destructive testing can hinder development and innovation in this field.

The development of ballistic resistance technologies continues to address these challenges and deliver more effective and efficient protection. By continuing to push the boundaries of innovation, the field can provide better solutions to maintain safety and security in a variety of military and law enforcement contexts.

Table 2. Ballistic Resistance Technology Matrix with Critical Parameters

No	Ballistic Resistance Technology	Parameters			
		Weight and Mobility	**Production Cost**	**Increased Firepower**	**Reliability Testing and Standards**
1	Polymer Composites	**Plus**: Lightweight and flexible, enhancing mobility.	**Plus**: Mass production can reduce costs.	**Plus**: Good strength against projectiles.	**Plus**: It has been tested and widely used in various situations.
		Minus: May require multiple layers for maximum protection.	**Minus**: Use of premium materials (Kevlar, Dyneema) can be expensive.	**Minus**: May be less effective against very high-velocity projectiles.	**Minus**: Requires regular testing for new batches.
2	Ceramics	**Plus**: High-level protection.	**Plus**: Basic ceramic materials are relatively cheap.	**Plus**: Highly effective against high-velocity projectiles.	**Plus**: It has undergone extensive testing.
		Minus: Heavy, reduced mobility.	**Minus**: Complex production and integration can increase costs.	**Minus**: It can rupture and require replacement after being hit by a projectile.	**Minus**: Testing broken ceramics requires expensive and destructive methods.
3	Nanomaterials	**Plus**: Very light and strong.	**Plus**: Potential for long-term low-cost production.	**Plus**: Strength and durability are very high.	**Plus**: The simulation showed positive results.
		Minus: The distribution of nanomaterials can be challenging.	**Minus**: New technology and high initial research costs.	**Minus**: Technology is still at the research stage, lacking practical evidence.	**Minus**: Real-world testing is still limited and expensive.
4	Sandwich Structure	**Plus**: Combination of flexibility and strength, comfortable to wear.	**Plus**: Can use relatively cheap materials.	**Plus**: Effective protection against various threats.	**Plus**: Using a combination of tested ingredients.
		Minus: It may not be as effective as hard materials for certain projectiles.	**Minus**: Complex manufacturing processes can increase costs.	**Minus**: May be less effective against very high-velocity projectiles.	**Minus**: Tests should include all combinations of materials used.
5	Thickener Liquid (STF)	**Plus**: Provides protection without sacrificing flexibility.	**Plus**: Production costs can be affordable.	**Plus**: Improves puncture resistance and ballistics.	**Plus**: It has been tested in various applications.
		Minus: It may be unstable under extreme conditions.	**Minus**: Certain chemical components can be expensive.	**Minus**: Effectiveness may be reduced in extreme temperature conditions.	**Minus**: Requires repeated testing to ensure stability.
6	Sustainable Materials	**Plus**: They are often lightweight and easy to use.	**Plus**: Lower production costs and environmentally friendly.	**Plus**: Has great potential for future applications.	**Plus**: Implement standardized testing for new materials.

		Minus: It may be less robust than synthetic materials.	**Minus**: Initial research and development can be expensive.	**Minus**: Protection may be less than conventional materials.	**Minus**: Requires additional testing to ensure consistency and reliability.
7	Simulation and Analysis Method	**Plus**: Indirectly affects weight and mobility.	**Plus**: Reduces the need for expensive physical testing.	**Plus**: Assist in material design and optimization for higher firepower.	**Plus**: Assists in ensuring reliability standards through simulation.
		Minus: Relies on accurate data for relevant results.	**Minus**: Requires initial investment in software and training.	**Minus**: Simulation results may not always be accurate.	**Minus**: Simulation results need to be validated with real-world testing to ensure reliability.

Polymer Composites

a. Weight and Mobility: The material is lightweight and flexible, which increases user mobility. However, to achieve maximum protection, multiple layers may be required, which can add weight.

b. Production Costs: Mass production can keep costs down, but the use of premium materials such as Kevlar or Dyneema can be expensive.

c. Increased Firepower: This material has good power against projectiles, but may be less effective against very high-velocity projectiles.

d. Testing and Reliability Standards: These materials have been tested and are in wide use, but each new batch requires regular testing.

Ceramics

a. Weight and Mobility: They offer a high level of protection but are heavy, reducing user mobility.

b. Production Costs: Ceramic base materials are relatively inexpensive, but production and integration are complex and can increase costs.

c. Increased Firepower: They are highly effective against high-velocity projectiles, but can break and require replacement after being hit by a projectile.

d. Reliability Testing and Standards: The material has undergone extensive testing, but testing for broken ceramics requires expensive and destructive methods.

Nanomaterials

a. Weight and Mobility: These materials are very light and strong, but distribution of nanomaterials can be challenging.

b. Production Costs: They have the potential for low-cost production in the long term, but the technology is new and the initial cost of research is high.

c. Increased Firepower: These materials have very high strength and durability, but the technology is still in the research stage and lacks practical evidence.

d. Reliability Testing and Standards: Simulations show positive results, but real-world testing is limited and expensive.

Flexible Materials and Sandwich Structures

a. Weight and Mobility: They combine flexibility and strength, which is comfortable to wear, but may not be as effective as hard materials for certain projectiles.

b. Production Costs: They can use relatively cheap materials, but complex manufacturing processes can increase costs.

c. Increased Firepower: They provide effective protection against a wide range of threats, but may be less effective against very high-velocity projectiles.

d. Testing and Reliability Standards: This material uses tested combinations of materials, but testing should include all combinations of materials used.

IV. CONCLUSION

This research has explored various aspects of ballistic resistance technology as personal protection in military and security applications. From an analysis of the existing literature, it is apparent that ballistic resistance protection is a constantly evolving field, with a variety of materials and technologies being used to meet protection needs. Materials such as Kevlar and Dyneema remain the top choices for bulletproof vests and ballistic helmets, while ceramics and nanomaterials offer alternatives that are robust and resistant to more severe ballistic threats. Technological developments such as the use of thickening fluids (STF) and laminated structures provide additional protection without sacrificing flexibility.

The application of ballistic resistance technology is not only limited to personal protection, but is also used in vehicle protection and VIP protection. The main challenges faced in the development of this technology are the weight of protection, production costs, ever-increasing firepower, as well as the need for valid testing and high reliability standards. Therefore, continuous innovation and in-depth research are required to overcome these challenges and create better and more efficient protection.

This research also demonstrates the importance of understanding future trends in the development of ballistic resistance technologies. The use of nanotechnology and environmentally friendly materials is expected to reduce environmental impact and improve protection efficiency. Future research also needs to focus on testing and standards that ensure the reliability of protection in various situations. With a deeper understanding of ballistic resistance technologies and their implications in personal protection, the results of this study are expected to make a meaningful contribution to the development of more effective and efficient protection. The study can also serve as a reference for policy makers, military and police equipment designers, and personnel using this protection in the field.

Based on the comparison matrix of ballistic resistance technologies that has been created, the conclusion is that each technology has advantages and disadvantages that should be considered according to the needs of the application. Technologies that stand out in superior ballistic performance require additional considerations related to weight, stiffness, cost and environmental impact. Proper technology selection should consider these factors holistically to meet application priorities and long-term goals.

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REFERENCES

[1]. Abtew, M. A., Boussu, F., & Bruniaux, P. (2021). Dynamic impact protective body armour: A comprehensive appraisal on panel engineering design and its prospective materials. Defence Technology, 17(6), 2027–2049. https://doi.org/10.1016/j.dt.2021.03.016

[2]. Agrawal, B. J. (2011). High performance textiles for ballistic protection. 2011 Defense Science Research Conference and Expo, DSR 2011, 001, 1–4. https://doi.org/10.1109/DSR.2011.6026857

[3]. David, N. V., Gao, X. L., & Zheng, J. Q. (2009). Ballistic resistant body armor: Contemporary and prospective materials and related protection mechanisms. Applied Mechanics Reviews, 62(5), 1–20. https://doi.org/10.1115/1.3124644

[4]. Material, J. R., Energi, M., Miwazuki, S. A., Anisa, P., & Rustama, R. Z. (2024). FT-UMSU FT-UMSU. 7(1), 120–126.

[5]. Maulana, F., Prabowo, A. R., Ridwan, R., Ubaidillah, U., Ariawan, D., Sohn, J. M., Muhayat, N., Tjahjana, D. D. D. P., & Do, Q. T. (2023). Antiballistic material, testing, and procedures of curved-layered objects: A systematic review and current milestone. Curved and Layered Structures, 10(1). https://doi.org/10.1515/cls-2022-0200

[6]. Maulana, F., Ubaidilah, Lenggana, B. W., & Ariawan, D. (2023). Enchanching Body Armor: Evaluating UHMWPE with Contoured Surfaces for Improved Ballistic Resistance Performance using Finite Element Methods. E3S Web of Conferences, 465. https://doi.org/10.1051/e3sconf/202346501005

[7]. Strelko, O., & Horban, A. (2023). Analysis of the history of creation and improvement of personal protective equipment: from bronze armor to modern bulletproof vests. History of Science and Technology, 13(1), 201–222. https://doi.org/10.32703/2415-7422-2023-13-1-201-222

[8]. Wu, S., Sikdar, P., & Bhat, G. S. (2023). Recent progress in developing ballistic and anti-impact materials: Nanotechnology and main approaches. Defence Technology, 21, 33–61. https://doi.org/10.1016/j.dt.2022.06.007

[9]. Sen, F., et al. (2018). "Review on Hybrid Fiber-Reinforced Polymer Composites." Polymers, 10(6), 622. doi:10.3390/polym10060622

[10]. Zhang, X., et al. (2020). "Improved ballistic performance of hybrid polymer composites." Journal of Composite Materials, 54(3), 349-361. doi:10.1177/0021998319877576

[11]. Fink, B.K. (2014). "Ballistic Performance of Composite Structures." Composite Structures, 108, 151-163. doi:10.1016/j.compstruct.2013.06.020

[12]. Medvedovski, E. (2010). "Ballistic performance of armor ceramics: Influence of design and structure. Part 1." Ceramics International, 36(7), 2103-2115. doi:10.1016/j.ceramint.2010.05.015

[13]. Zenkert, D. (2017). "The Mechanical Performance of Composite Sandwich Structures." Journal of Sandwich Structures & Materials, 19(1), 3-12. doi:10.1177/1099636216686047

[14]. Smith, E.C., et al. (2016). "Design and Manufacturing of Composite Sandwich Structures." Composite Structures, 139, 1-16. doi:10.1016/j.compstruct.2015.12.038

[15]. Lee, Y.S., & Wetzel, E.D. (2003). "Enhanced ballistic performance using shear thickening fluids." Journal of Materials Science, 38(13), 2825-2833. doi:10.1023/A:1024424200221

[16]. Majumdar, A., et al. (2008). "Application of shear thickening fluid in ballistic and stab protection." Journal of Composite Materials, 42(24), 2731-2746. doi:10.1177/0021998308094824

[17]. Faruk, O., et al. (2012). "Biocomposites reinforced with natural fibers: 2000–2010." Progress in Polymer Science, 37(11), 1552-1596. doi:10.1016/j.progpolymsci.2012.04.003