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Design Optimization of Multilayer Ballistic Plates Using Steel Bearings for Impact Energy Dispersion and Projectile Trajectory Deflection

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ABSTRACT

This research aims to optimize the design of anti-ballistic plates by combining high-strength materials and geometric structures capable of changing the projectile contact angle. The materials used include perforated 304 stainless steel plates, steel ball bearings of varying diameters (3 mm, 4 mm, and 5 mm), resin adhesive, Hardox 450 plates, and rubber coatings of different thicknesses (4 mm, 5 mm, and 6 mm). The plate structure was designed in layers using a laminating method to increase the absorption of impact energy and reduce projectile penetration. This study used physical experimental methods, including weight fraction testing, ballistic tests with 5.56 × 45 mm caliber bullets, and morphological analysis using a stereo zoom microscope. The purpose of these tests was to evaluate the penetration depth, back face deformation (Back Face Signature), and projectile trajectory changes due to the design structure. The results show that variations in material configuration and ball bearing size significantly affect the armor's ability to block penetration. The plate configuration with 3 mm ball bearings and 6 mm rubber showed the lowest deformation and effectively changed the projectile path. This research contributes both theoretically and practically to the development of lightweight and effective ballistic protection, with potential applications in the military and civilian sectors. The findings provide a basis for further advances in armor technology based on structural and composite materials.

1. INTRODUCTION

Anti-ballistic plates are now becoming essential equipment for military personnel and law enforcement officers amidst increasing armed conflicts around the world. Despite its crucial role, a comprehensive review of the latest material innovations, standardized test methods, and performance measurement techniques is still limited, given the sensitive nature of this field and the frequent need for cooperation with national defense agencies [1]. For more than five centuries, the development of anti-ballistic materials has continued to progress along with advances in the fields of impact dynamics, experimental ballistics, computational mechanics, and evaluation protocols, all of which reflect consistent annual developments [2]. Today, modern anti-ballistic plates widely use materials such as polycarbonate, acrylic, and other advanced polymers known for their high mechanical strength and outstanding energy-absorbing capabilities. These materials not only offer important insights into the behavior of hard materials but also open up opportunities for design optimization [3]. In the past, body armor was made of natural materials such as animal skins. However, technological advances, especially in the military field, are driving the need for more effective and lightweight protection systems [4].

A major development in the world of armor occurred in 1945 when Andrew Webster introduced ceramic armor, a component that is still at the core of anti-ballistic plate design today. Today, advanced ceramics such as alumina, silicon carbide (SiC), and boron are widely used in both military and civilian applications for their ability to provide high protection with minimal weight [5]. Combining a rigid ceramic coating with a high-tensile material such as Hardox 450 steel has proven to be very effective. This hybrid structure not only slows down the projectile but also absorbs the residual energy from the impact, thus reducing the risk of penetration. In addition, bilayer and multilayer systems capable of changing the projectile trajectory angle have also been validated through simulations to effectively divert the direction of impact [6]. Modern armor design not only focuses on stopping threats but also considers user comfort and mobility. Therefore, backface deformation (BFD) is a major concern in order to reduce blunt trauma due to impact. Standards from the National Institute of Justice (NIJ) set deformation limits and detailed test procedures to ensure reliable ballistic durability evaluation [7].

Materials such as Kevlar and high-density polyethylene (HDPE) are widely chosen because they offer an ideal combination of light weight and penetration resistance. This evolutionary timeline, from animal skin armour to ceramic-composite hybrid systems, reflects the technological milestones that underpin the current demand for lightweight, high-performance body armour. These milestones influence both the selection of materials and the design methodology in our study.

Material strength greatly affects armor performance. Bullet-resistant designs typically combine hard materials such as steel or ceramics with high-performance fibers to distribute energy and prevent structural failure upon impact [8]. Metal-based materials such as ballistic steel, aluminum alloys, and titanium offer advantages in strength and corrosion resistance, despite their heavier weight. Meanwhile, non-metallic alternatives such as HDPE, epoxy resin, and fiber composites are being increasingly used due to their lightweight nature and ability to absorb high energy [9]. Optimization of armor design includes setting the projectile contact angle, internal layer configuration, and integration of energy-absorbing media such as liquid rubber, resin, and metal pads [1, 10]. Material reinforcement through chemical modification, such as alkali treatment of rubber, has also been shown to improve resistance to extreme conditions [11]. Simulation and full-scale performance testing are essential to ensure resistance to axial and radial loads [12, 13]. Hardox 450 is emerging as an excellent material thanks to its ability to absorb impact energy and alter projectile trajectory, thus offering an ideal balance between protection and mobility [14, 15]. This hybrid composition is consistent with the aim of the study, which is to redirect projectile paths while minimising residual energy and thus enhancing the overall efficiency of the plate.

Standards such as those published by NIJ remain an important reference for assessing armor effectiveness in various threat scenarios [16, 17]. Evaluation of elasticity, deformation behavior, and projectile dynamics is done with Nonlinear Response to Dynamic Collisions (NRDC) formulas and kinematic modeling, while internal ballistic models help understand environmental influences such as gravity and air resistance [5]. Evaluation methods based on NIJ standards are the global benchmark for validating ballistic resistance. NRDC modelling, Finite Element Method (FEM) simulations and internal ballistics are critical for quantifying back face deformation and projectile dynamics. In the manufacturing process, hot and cold lamination techniques are widely used to increase the strength of the structure without adding excess weight [1, 18]. Mechanical testing is important to see how the armor responds to pressure, absorbs impact forces, and maintains its structural strength [19]. Modern armor designs generally rely on layered structures. Hard outer layers, such as stainless steel or Hardox, resist direct penetration, while elastic rubber inner layers absorb residual energy and reduce back deformation [16, 20]. In addition, fiber composites, advanced ceramics, and small metal balls are often used to disperse kinetic energy and reduce the risk of direct penetration [21, 22].

The adhesive resin not only serves to bond the layers together, but also helps distribute the impact force evenly to reduce the risk of delamination [16, 23]. Armor performance evaluation is done by numerical simulations such as FEM and material models such as Johnson-Cook, as well as Dynamic Mechanical Analysis (DMA) testing that measures three main parameters: Storage Modulus (capacity to store energy), Loss Modulus (capacity to release energy), and Tan δ (damping efficiency) [22]. This approach provides a comprehensive picture of the material's resistance to ballistic threats. Recent innovations introduce multilayer systems that combine stainless steel, Hardox, recycled rubber, metal balls, and resin adhesives to produce lightweight yet high-performance armor, which is flexible for various situations [16, 24]. DMA testing helps evaluate how these systems manage energy under high-speed impact conditions, thereby improving protection against a growing range of threats [25, 26]. Anti-ballistic plates are truly a vital part of protecting military and law enforcement personnel. However, thorough studies on these materials are still limited due to the sensitivity of this field as well as the need for cooperation with defense institutions [1].

The evolutionary journey of ballistic protection materials has spanned more than 500 years, involving both direct impact analysis and computational simulation [2]. Modern materials such as polycarbonate and acrylic offer promising mechanical strength and energy absorption capabilities [3]. From the use of animal skins to advanced ceramic armor such as alumina, silicon carbide (SiC) and boron, major innovations have emerged since 1945 [5, 27]. The combination of ceramics with high-strength metals such as Hardox 450 has been shown to absorb impact energy and deflect projectiles effectively [6]. The effectiveness of armor is not only measured by its ability to protect, but also by its comfort in use. The back deformation test based on the NIJ standard is an important benchmark in evaluating armor performance. The development of more effective anti-ballistic plates is very important in the military and security context. Well-designed armor not only protects individuals from ballistic threats, but also improves mobility and comfort. This research is relevant for the development of modern armor that meets operational needs in the field, as well as providing a basis for further research in armor design optimization. In testing, effective armor should exhibit low back deformation to reduce the risk of blunt trauma injury to the user [11].

Lightweight materials such as Kevlar and HDPE have proven effective in resisting bullet penetration [4]. Composite structures also increase resistance to impact energy, with absolute strength being the main determining factor. Ballistic plates themselves are generally divided into hard armor and soft armor. Hard armor made from ceramics or metals is designed to withstand high-velocity projectiles and meets the NIJ's Level III protection standard, while soft armor, made from aramid fibers or polyethylene, is more suitable for lower-energy threats [1, 3]. Metal-based materials such as steel and titanium offer high strength, albeit with the consequence of heavier weight [8]. In contrast, non-metallic materials such as HDPE, epoxy resins and phenolic resins offer better flexibility and thermal stability [9]. The main materials used in this study include:

- Stainless Steel 304: Known to be deformation resistant and effective in absorbing impact energy [10, 16].
- Ball Bearings: Used to reduce friction and distribute energy upon impact [6].
- Aqualuxe Glue: Provides high adhesion and elasticity to maintain the integrity of the composite layer [1].
- Hardox 450: High tensile strength abrasion resistant steel that has excellent ballistic resistance [14, 28].
- Rubber: Often combined with Kevlar/epoxy and nano-silica composites to improve energy absorption and flexibility [11, 29].

The projectile used in this study, specifically the 7.62 × 39 mm round, was analyzed to understand the kinetic behavior and energy dispersion. Studies from NRDC emphasize the importance of armor design in changing projectile trajectory and absorbing kinetic energy [1]. Material characteristic tables show important properties such as strength, density, and impact resistance in projectiles and materials such as lead and brass, helping to explain how they behave under dynamic conditions. The results show that composite materials are better able to maintain the structure after being hit by a bullet compared to multilayer laminated ceramics. This suggests that, with proper design, laminated ceramics could be a robust solution to withstand armor-piercing bullet attacks [30].

2. METHODOLOGY

2.1 Materials and construction

The study of projectiles in the context of anti-ballistic plates involves the calculation of NRDC, this formula $d = G.\frac{V}{d_p}.\sqrt{\rho}$ analyzes the non-linear response to impacts between projectiles and targets. The NRDC formula is used to quantify the deformation and elastic or plastic response of Body armor material when a projectile strikes it at high speed [1]. The NRDC equation quantifies the deformation behaviour of materials under impact, integrating strain rate effects and material strength properties. The NRDC equation correlates impact energy with deformation metrics such as Back Face Signature (BFS).

The Kinetics Plus framework combines the basic principles of kinetics with several additional factors that influence the motion of projectiles. These factors include projectile mass, initial velocity, launch angle and frictional forces. Unlike traditional kinematics, the framework also considers the effects of friction and momentum transfer between material layers. Consequently, it can simulate more realistic projectile deflection patterns, particularly in multilayer armour structures.

This experiment helps researchers to design body armour that can effectively change the direction of a projectile after impact [1]. DMA is used to evaluate how well a material absorbs energy. This method measures two key properties: storage modulus (elastic response) and loss modulus (viscous response).

In addition, the projectile's kinetic energy, calculated from its mass and velocity, is used to assess the material's resistance to impact. This analysis forms part of impact kinetics, the study of how a projectile's energy changes when it strikes anti-ballistic materials.

The kinetic energy of the projectile can be calculated using the formula $Ek =\frac{1}{2} mv^2$. When a projectile strikes an anti-ballistic plate, this energy must be absorbed by the armor material to prevent penetration. Impact analysis allows the selection of materials capable of absorbing as much energy as possible to reduce injury to the user [1].

The theory of drag on a projectile is concerned with the air resistance that the projectile experiences during trajectory. This drag affects the velocity, trajectory, and ultimately the impact energy of the projectile as it reaches the target. Drag force is calculated using the formula $F_d = \frac{1}{2} C_{d.}\rho. A. v^2$. Where A is the cross-sectional area and v is the velocity. Drag plays a key role in reducing projectile kinetic energy during flight. This reduction affects penetration power and the angle of incidence, particularly when interacting with angled or rough surfaces of the plate [1].

There is some plate-weld arrangement to get some better construction, as shown in Figure 1. Three configurations were developed using a combination of stainless steel, Hardox 450, resin adhesive, rubber layers, and spherical steel ball bearings.

- Variation A: 5 mm ball bearings (216 pcs)
- Variation B: 4 mm ball bearings (262 pcs)
- Variation C: 3 mm ball bearings (430 pcs)

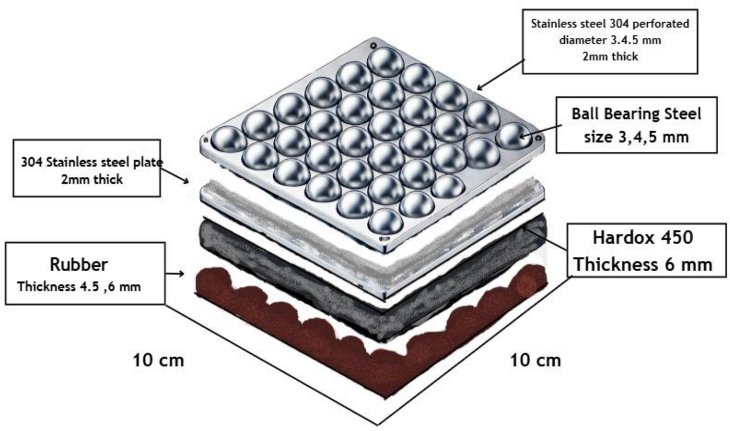

Figure 1. The arrangement of plates to be made

Each configuration employed perforated stainless steel for ball insertion, layered over solid stainless steel and Hardox 450 with rubber on the exterior.

The physical and mechanical properties of tin and brass show significant differences, which affect their behavior upon impact, as shown in Table 1. In terms of density (ρ), tin has a higher value of 10.660 kg/m³ compared to brass, which is only 8.520 kg/m³. This indicates that tin is heavier per unit volume than brass. In terms of stiffness, brass has a much higher elastic modulus (E) of 115,000 MPa, while tin is only 1,000 MPa. This indicates that brass is much more resistant to elastic deformation under load. When viewed from Poisson's ratio (v), tin has a value of 0.42, while brass is slightly lower at 0.31, which means that tin tends to experience greater lateral expansion when longitudinally stressed. In addition, the specific heat capacity (C_p) of tin is 124 J/kg-K, much lower than that of brass which reaches 385 J/kg-K, indicating that brass is able to absorb more heat energy before a temperature rise occurs.

Table 1. Properties of anti-ballistic plate

Parameter	Symbol	Unit	Tin	Brass
Density	ρ	Kg/m^3	10660	8520
Elastic Modulus	E	MPa	1000	115000
Poisson's Ratio	v	-	0.42	0.31
Specific Heat	C_p	J/kg	124	385

The following table presents data on several materials, alongside important parameters related to their mechanical and physical properties. The displayed information includes the strength-to-weight ratio, ultimate strength and density of materials such as stainless steel, Hardox plates, rubber, waterproof adhesive and bullet material. The table also includes supplementary parameter data for tin and brass materials, such as density, elastic modulus, Poisson's ratio, and specific heat. This data can be used as a reference for material design analysis, strength calculations and material selection for specific engineering applications.

These parameters are crucial in the material selection process, particularly for applications requiring specific mechanical and thermal properties. Material specifications for the plates are shown in Table 2, detailing the layer composition, dimensions, and strength of each material.

Table 2. Anti-ballistic plate properties

Material	Strength to Weight (Kn m)/kg	Ultimate Strength (Mpa)	Density (g/cm^3)
Stainless Steel 304	5.31×10^6 N/kg	505-850 MPa	7,930 kg/m^3 or 7.93 g/cm^3
Stainless Steel Ball Bearing	-	600-1000 MPa	7.85 g/cm^3
Aqualuxe Special Waterproof Glue	-	40 hingga 90 MPa	1.55-1.75 g/cm^3 (depending on the mixing ratio between resin and hardener)
Hardox 450 Plate	2960 kN·m/kg	1400-1700 MPa	7.85 g/cm^3
Rubber 4-6 mm	-	80-120 MPa	1.2 g/cm^3-1.4 g/cm^3

2.2 Weight fraction analysis

The design of the ballistic plate began with a simple but crucial step: weighing each component individually. Using high-precision digital scales, the research team aims to determine how much each material contributes to the total weight of the plate. This step is crucial to ensure that each layer performs its function effectively by providing strength without unnecessary weight. The main materials used in the protective structure include perforated stainless steel plates, metal balls (ball bearings), and adhesive compounds. Measurement results show that the metal balls contribute the most to the total mass, followed by the stainless steel plate. These two materials are then combined to form the first layer of the forward-most defense that directly faces the incoming projectile.

This initial layer is designed not only to absorb impact but also to deflect the projectile's trajectory, minimizing the energy passed on to the underlying layers. When assembled, the integration of the metal balls and perforated plate creates a solid yet efficient structure: one that is strong while still distributing impact forces evenly across the surface. Though it may seem simple, this early step lays the foundation for more complex design stages that follow. By understanding the mass contribution of each layer, researchers can develop a protective system that is not only durable but also ergonomic suited for real-world applications where both protection and comfort are critical.

2.3 Ballistic testing

To understand how well the armor plate can withstand real-world threats, ballistic tests were conducted using 5.56 × 45 mm and 7.62 × 51 mm NATO rounds, fired from a distance of 15 meters. A chronograph was used to track the velocity of each projectile, ensuring that each shot delivered consistent impact energy. Beyond just stopping the bullet, a good armor plate also needs to manage the force it receives. To measure this, the researchers examined the BFS, which is the deformation on the back side of the plate, using plasticine molds and calipers. This helps reveal how much energy is absorbed or transmitted.

Several plate configurations were put to the test, each with different combinations of materials and structural layouts. The goal was to see how design choices like the size and placement of holes, how ball bearings were arranged, and the strength of the materials contributed to the plate's overall performance. In essence, this method was all about finding the right balance between strength, structure, and smart engineering.

2.4 Morphology observation

After the impact, the researchers carefully observed the deformation patterns and cracks using a 10x zoom stereo microscope. The goal was to analyze how the projectile deviated and how the energy from the impact was propagated across the plate. Part of the research focused on understanding the role of specific design features, such as the placement of the metal balls and the geometry of the holes, in influencing the path of the projectile and how the force is dispersed across the structure. In this design, the metal balls not only serve as structural parts, but also have an active role in absorbing shock and deflecting the bullet trajectory. Their shape and placement are believed to play a key role in redirecting the bullet after impact, a hypothesis confirmed by the damage patterns seen on the plates. To examine this effect more closely, the researchers used a stereo zoom microscope to view the small-scale cracks and deformations formed after impact.

The team paid attention to details like the extent and direction of the damage and whether fragments of the bullet had become embedded in the plate. This close inspection provided insight into how the layered design combining various materials and geometric features could improve the plate's effectiveness. It wasn't just about stopping the bullet; it was about redirecting its energy in a way that minimized the overall damage. Through this hands-on visual analysis, researchers gathered valuable information on how to create protective systems that are not only stronger but smarter. The findings will contribute to refining designs for even more effective ballistic protection in the future.

3. RESULTS AND DISCUSSION

3.1 Weight distribution

The ballistic plate design process begins with weighing each component to better understand the individual contribution to the overall weight. The main components used in this design, including the perforated stainless steel plate, metal balls, and adhesive, are shown in Tables 3-5. Measurements showed that the metal spheres layer had the highest mass, averaging 34.62 grams, followed by the stainless steel plate with an average of 28.47 grams. The first layer, which combines the metal balls with the perforated stainless steel, plays an important role in absorbing the bullet's energy and changing its trajectory. After assembly, the combined mass of this layer was recorded at 63.09 grams. As shown in Figure 2, the graphic image illustrates the weight fraction of the material components. These results show that the integration of the two materials is efficient and that this combination is structurally capable of distributing the impact force more evenly across the plate.

After all the components were assembled, final measurements were taken to determine the total mass of the ballistic plate, which stood at 71.23 grams. This increase in weight is due to the addition of adhesives and other manufacturing materials. Despite the added mass, the ratio between weight and protective performance remains efficient and acceptable, especially when considering the plate's ability to prevent projectile penetration and effectively dissipate impact energy.

Table 3. Variation A ball bearing 5 mm 216 pcs, hole 5 mm

No.	Weight (g)								
	SS L	BB	SS	PBB	H	R	LR	TB	JML
1	103.75	0.51	143.2	176.9	454.4	53.6	10	110.16	838.1
2	103.75	0.51	143	176.8	454.2	53.7	10.4	110.16	838.1
3	103.75	0.51	143	176.7	452.3	55.6	11.9	110.16	839.5
4	103.75	0.51	143.3	176.8	452.3	54.3	10.6	110.16	837.3
5	103.75	0.51	143.2	176.9	453.5	54.4	9.3	110.16	837.3

Table 4. Variation B ball bearing 4 mm 262 pcs, hole 4 mm

No.	Weight (g)								
	SS L	BB	SS	PBB	H	R	LR	TB	JML
1	103.75	0.13	156.5	143.2	459	82.9	2	56	843.6
2	103.75	0.13	156.5	143.4	457.1	84.2	4.5	56	845.7
3	103.75	0.13	156.5	143.5	449.7	81.9	13	56	844.6
4	103.75	0.13	156.5	143.3	450.8	81.9	12.6	56	845.1
5	103.75	0.13	156.7	143.3	449.3	86.6	8.5	56	844.4

Table 5. Variation C ball bearing 3 mm 430 pcs, hole 3 mm

No.	Weight (g)								
	SS L	BB	SS	PBB	H	R	LR	TB	JML
1	103.75	0.27	164.1	143.2	460	67.7	7.2	70.74	842.2
2	103.75	0.27	164	142.6	462	67.64	7.16	70.74	843.4
3	103.75	0.27	164	142.8	461	65.2	10.6	70.74	843.6
4	103.75	0.27	163.8	143.1	465	63.4	8.1	70.74	843.4
5	103.75	0.27	163.8	142.9	464.6	67.6	3.1	70.74	842

Note: SS L = Perforated Stainless Steel Plate, BB = Ball Bearing, SS = Stainless Steel, PBB = Ball Bearing Plate, H = Hardox, R = Rubber, LR = Resin Adhesive, JML = Quantity, TB = Total Balls

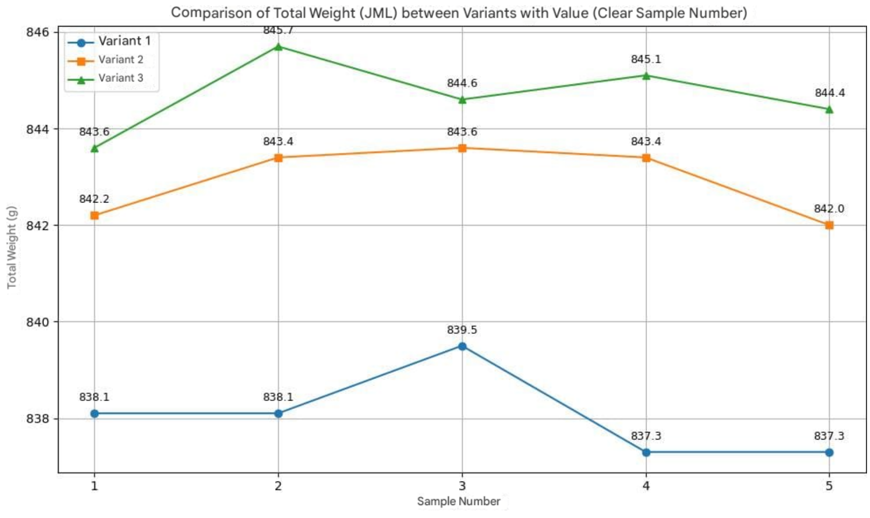

Figure 2. Graphic image of the weight fraction

Data analysis showed that the sample standard deviations for variants A, B, and C were 0.89, 0.75, and 0.70, respectively. The calculated population standard deviation is 2.89. As lower standard deviation values reflect higher data consistency, and given that the threshold for acceptable deviation is below 4, both the sample and population standard deviations are within the acceptable range, indicating a reliable level of data accuracy.

Overall, this analysis confirms that the ballistic plate design is not only structurally robust but also optimized in balancing weight and protective effectiveness, reinforcing the validity of the selected material and its configuration.

3.2 Ballistic performance

Ballistic tests were conducted using 5.56 mm projectiles fired from a distance of 15 m. The results indicate that most plate configurations experienced varying degrees of deformation; however, only one configuration consistently prevented projectile penetration under all test conditions. The observed deformation, primarily in the form of circular indentations with varying depths, suggests effective absorption of the projectile's kinetic energy by the structural configuration.

As shown in Tables 6 and 7, the plate designs incorporating perforations of 5 mm and 4 mm, respectively, failed to completely stop the projectile. Partial penetration was observed, particularly in regions lacking direct reinforcement from the metal balls.

Table 6. Variation A ball bearing 5 mm 216 pcs, hole 5 mm, Rubber 4 mm

No Plate	Velocity (m/s)	BFD (mm)	Penetrating / Not	Caliber (mm)
1	710	4.7	Not	5.56 × 45
2	710	4.6	Not	5.56 × 45
3	850-900	14.3	Not	7.62 × 51
4	710	7.4	Penetrating	5.56 × 45
5	710	3.8	Not	5.56 × 45

BFD denotes backface deformation.

Table 7. Variation B ball bearing 4 mm 262 pcs, hole 4 mm, Rubber 5 mm

No Plate	Velocity (m/s)	BFD (mm)	Penetrating / Not	Caliber (mm)
1	850-900	12.7	Not	7.62 × 51
2	710	4.2	Not	5.56 × 45
3	710	4.2	Not	5.56 × 45
4	710	7.2	Penetrating	5.56 × 45
5	710	4.4	Not	5.56 × 45

BFD denotes backface deformation.

In contrast, the configuration presented in Table 8 (Variation C), featuring 3 mm perforations combined with an optimized metal ball arrangement, demonstrated complete resistance to penetration for both projectile types. This variation also exhibited the lowest BFS value, indicating superior energy absorption and projectile deflection capability. Although surface deformation was still present, it remained within acceptable limits and no perforation was detected.

These results confirm that perforation size and metal ball distribution play a critical role in enhancing ballistic resistance. Inadequate perforation dimensions or suboptimal ball placement significantly reduce the protective effectiveness of the plate.

Table 8. Variation C ball bearing 3 mm 430 pcs, hole 3 mm, Rubber 6 mm

No Plate	Velocity (m/s)	BFD (mm)	Penetrating / Not	Caliber (mm)
1	710	4.2	Not	5.56 × 45
2	850-900	11.5	Not	7.62 × 51
3	710	5.7	Not	5.56 × 45
4	710	7.4	Not	5.56 × 45
5	710	5.4	Not	5.56 × 45

BFD denotes backface deformation.

Furthermore, the type of projectile also influenced the test outcomes. The use of hardened steel projectiles with high penetration capability contributed to the failures observed in Variations A and B. Meanwhile, the success of Variation C highlights how smaller perforation size and well distributed ball bearings enhance the plate's ability to distribute impact forces and redirect the projectile's path, ultimately preventing penetration. This analysis underscores the importance of precise material arrangement and design geometry in maximizing ballistic protection. The data clearly demonstrate that optimized configurations, like that of Variation C, offer significant improvements in energy dispersion and impact resistance compared to less refined designs.

3.3 Morphology observation

Observations from ballistic tests revealed that the inclusion of metal balls in the plate design significantly affected the trajectory of the incoming projectile. Bullets hitting the metal balls showed clear signs of deflection, as seen in the deformation patterns in the plate. The downward elongation of the damage indicates that the metal balls not only serve as energy absorbers, but also actively redirect the trajectory of the bullet after impact. The ballistic test results show that the samples from Variation A (Table 9), Variation B (Table 10), and Variation C (Table 11) exhibit less deformation.

Table 9. Morphological observation of side view Variation A

No.	Figure of Variation A Plate	Keterangan
1		The image shows how the structure is deformed due to bullet penetration, but the bullet cannot penetrate the structure of the Hardox plate.

Table 10. Morphological observation of side view Variation B

No.	Figure of Variation B Plate	Keterangan
4		In the picture, it can be seen that the projectile is able to penetrate the plate, but only a small part because the projectile does not hit the steel ball on the top plate layer.

Table 11. Morphological observation of side view Variation C

No.	Figure of Variation C Plate	Keterangan
3		In the picture, it can be seen that the bullet did not penetrate the plate because during the first impact, the bullet hit an angle on the steel ball layer.

4. FUTURE HIGHLIGHTS

In the future, the development of ballistic plate systems is expected to place greater emphasis on the redistribution of mechanical energy, particularly through the strategic use of metal balls. Experimental results show that when the bullet hits the plate, the force does not stop at the point of impact. Instead, the forward momentum of the bullet continues to spread through the surrounding metal balls, triggering an interesting secondary dynamic response. The directly hit metal ball absorbs most of the projectile's energy, yet nearby balls still receive enough residual energy to move or even be pushed out. This reveals that the system does not simply function as a passive shield; instead, it functions as an active structure that disperses the force to various points, reducing the intensity of the impact in certain areas [31-33].

This discovery opens up new opportunities for designing next-generation ballistic plates that are more effective at distributing impact forces. Such designs can significantly reduce damage while providing better protection against high-energy threats. Further research using advanced simulation and high-speed motion analysis is expected to deepen our understanding of this behavior, ultimately supporting the development of smarter and more efficient ballistic protection systems with superior energy management.

Based on the findings of this study, several steps can be taken to further develop the ballistic plate design with an internal bearing system. Future research should focus on optimizing the placement and size of the ball bearings. By adjusting the spacing and selecting the right materials, we can ensure that the energy from the impact is more evenly distributed. Additionally, testing other materials for the bearings and the plate, such as lightweight composites or ceramics, could help reduce the plate's weight without compromising its bullet resistance. One interesting approach is the installation of sensors to monitor the plate's performance in real-time. This could provide deeper insights into how forces and deformations behave when the plate is hit by a projectile, which would certainly aid in the design improvement process. Further research should also test the plate under repeated impacts, considering that, in real-life scenarios, the plate may face consecutive threats. Testing with higher-energy projectiles is also crucial, as it will help determine the extent to which this plate design can be relied upon. Collaboration with the protection or defense industry is also essential to bring the research findings into prototype development and real-world testing. With these steps, we can create more advanced, efficient, and reliable ballistic protection systems, providing better protection against higher-energy threats.

5. CONCLUSIONS

This research shows that the use of a layered ballistic plate design, especially one that includes 3 mm steel bearing balls, offers clear advantages in dealing with bullet impact forces. The presence of these small steel balls not only makes the plate physically stronger, but also helps to disperse the energy from the impact, rather than allowing it to concentrate at one point. A design like this doesn't just absorb the shot; it reacts to it, actively working to reduce damage. What makes this internal bearing system so interesting is how it manages the impact. When the bullet hits, the energy doesn't just stop, it moves. The force spreads through the surrounding spherical bearings, distributing itself in a way that relieves pressure at any given point. In some cases, the energy is even redirected, showing signs that the system can push against the impact, almost like fighting back. Behavior like this shows that these plates are not only resilient but also intelligent in dealing with threats.

The research also points to how important design choices are. Plates with specific angles and layering techniques showed they could actually change a bullet's path, reducing how deeply it could go. These small structural tweaks, like tilting surfaces or stacking materials, can make a big difference in stopping a projectile. All of this underlines how powerful good design can be in modern protection systems. By combining clever geometry, layered materials, and built-in energy management, we're looking at a new generation of ballistic gear that isn't just stronger, but also lighter and more comfortable to wear something that's crucial in the field.

In the bigger picture, this research lays the groundwork for more advanced armor in the future. By using smart engineering to not only resist but respond to threats, we can build protective systems that truly go beyond just standing still. They become part of a smarter, more responsive solution for both personal safety and military defense in a rapidly changing world.

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NOMENCLATURE

d	depth of penetration
G	geometry constant
V	projectile velocity
d_p	projectile diameter
ρ	target material density
F	Force which works on the projectile
m	Mass projectile
a	Acceleration
Ek	Kinetic energy
v	Velocity
Fd	Drag force
Cd	Drag coefficient
ρ	Density
A	Cross-sectional area