Creative Research in Engineering
| ISSN (Print): 2774-8278 | ISSN (Online): 2774-8006

CERIE
Creative Research In Engineering

Research Article

Ballistic Performance Anti-Projectile of Alumina and Weldox 460 E with Finite Element Method

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ARTICLE INFO

Article History:
Received : 27 October 2022
Revised : 29 December 2022
Accepted : 30 January 2023
Available online : 3 February 2023

Keywords: *Ballistic Test, Alumina, Weldox 460 E, Finite Element Method*

ABSTRACT

This research aims to determine the effect of the panel configuration which has the strongest resistance and to analyze the ballistic toughness of the Al_2O_3 and Weldox 460 E Steel panel configurations. The criteria to be looked for are the Depth of Penetration, Deflection and Final Projectile Length. To determine the accuracy of this study, a verification of the simulation research previously conducted by Dey et al. The method used is based on simulation with the finite element method. The software used is ANSYS/Explicit Dynamic solver AUTODYN 18.1. The modeling used in this study is simplified into 2D Axisymmetric. Alumina and Weldox 460 E steel panel configuration variations that will be used in this study. There are 7 variations of the panel configuration used, namely B12, A5B5, A5B10, A10B5, A10B10, A12B12 and A15B15. Alumina material as the front panel, while Weldox 460 E as the back panel. In calculating the mechanical behavior of the material, while the Alumina material uses the Johnson Holmquist (JH2) Strength parameter. And then, the Weldox 460 E material uses Johnson and Cook parameters. The results obtained indicate that the A12B12 and A15B15 panel configurations are able to withstand projectiles. The A12B12 panel configuration has a depth of penetration value of 23 mm, a deflection value of 4.3 mm and a Vbl value of 954.69 m/s. while the best panel configuration is A15B15 with a depth of penetration value of 21 mm, a deflection value of 1.4 mm and a Vbl value of 1345.9 m/s. then the conclusion of this study shows that the A15B15 panel configuration is the best panel configuration that is able to withstand projectiles.

1. INTRODUCTION

Technological developments that are currently growing rapidly make researchers compete to produce new, more sophisticated technologies. Body protection is one industry with cutting-edge technological advancements [1]. One of the concepts of body protection is using lightweight but strong materials. Metals and non-metals, which are undoubtedly light but uneconomical because of their high cost, are the materials employed in ballistic tests. Researchers began to compete to find non-metallic materials that are lightweight but able to withstand the impact and penetration of bullets [2]. As a result, the use of durable and lightweight ceramic protective materials for body protection is expanding [3][4]. Alumina is one of the ceramic materials used in addition to SiC or boron. In addition to body protection or anti-projectile vests, alumina is also used for coating military vehicles because of its lightweight material. Ceramics like alumina cost less than SiC or Boron. Pure alumina with a hardness of 14 GPa must have a density of 3.9 g/cm^3 in order to withstand bullets of type NIJ 4. The density decreases to 3.4 g/cm^3 (hardness 9.5 GPa) when 85% pure alumina (Coors AD85) is used, and typically 85% pure alumina is used for projectile type NIJ 3. (Alumina for body armor) [3][4]. Meanwhile, several studies on body armor also use steel materials, one of which is Weldox. Weldox is a high-strength steel that has excellent weldability along with high strength and ductility. This combination is obtained through a controlled rolling process and heat treatment [5]. Weldox comes in a number of varieties, with Weldox 460 E being one of them. This number signifies yield strength. Weldox 460 E is a TM steel that is rolled at a specific temperature before being controlled-cooled to produce high strength [5][6].

Significant research has been conducted in recent years to combine anti-projectile vest materials using a bi-layer protective system [6]. This system consists of a hard ceramic for the front surface and a back support layer made of steel material, and it can result in a lighter design than single-layer metallic armour. The backing plate is utilized to hold the cracked ceramic in place and absorb the projectile's remaining energy, while the ceramic coating serves to blunt and reduce the velocity of the projectile [6][7]. According to Zhao et al. [7], experimental and simulation studies were used to create armour utilizing three different methods: bi-layer armor, mosaic armor, and honeycomb armor. The projectile was made out of Steel 4340 and was fired at speeds ranging from 242 m/s to 725 m/s. The materials utilized were Aluminium 6061-T6 as a backing plate and Alumina as a front plate. The panel is 112 mm by 112 mm in dimension and 10 mm thick. The projectile can pierce the two panels at a speed of 600 m/s according to the test results, although the penetration is only moderately deep. A stronger material, such as Weldox, is required to withstand bullets in addition to the bi-layer technique that must be employed to anticipate material cracks in the armor. Dey's research [5] compared the steel materials Weldox 460 E, Weldox 700 E, and Weldox 900 E through experimental and computational simulation tests using the LS-DYNA program. In this study, the size of the panel was 500 mm with a thickness of 12 mm. Then, three different projectile kinds, including blunt, conical, and ogival, are employed. Between 150 and 350 m/s are employed as the speed. According to the test results, the beginning velocity graph and residual velocity from the simulation and experiment both display the same trendline. The projectile's nose shape has a significant impact on the panel's ballistic limit speed. While blunt projectiles have ballistic velocities below 200 m/s, conical and oval projectiles have a ballistic limit speed of roughly 300 m/s. The three different projectile types' visualization findings show that the panel is being penetrated and has cracks in them [5].

In order to evaluate the armor performance under ballistic impact of a bi-layer system made up of a hard ceramic front surface and a metal backing layer, Chi et al. [6] employed a semi-analytical technique. Projectile impact velocity, residual velocity, and armored ballistic limit velocity are all covered by the semi-analytical model (BLV). The simulation in this study uses a two-dimensional (2D) axisymmetric model using AUTODYN. The first layer uses the SPH domain, while the second layer uses the Lagrain domain. The ceramic material uses alumina, while the metal material uses aluminium with a thickness of 15 mm. The speeds with correspond to the limit velocity (BLV) are at speeds of 545 m/s and 550 m/s. The projectile used to test the impact of this ballistic is the APDS 20 mm in diameter, 61.5 mm in length, and 72 grams in weight, made of tungsten alloy. According to the numerical simulation, certain types of BLV armor, projectile residual velocity, and alumina/aluminium armor have a constant or fixed value. Iqbal et al. [8] used 3D finite element simulation in ABAQUS to study the effects of sub-normal perforations and slopes of sharp-nose bullets on single and layered ductile targets. The properties of steel targets Weldox 460 E and aluminium targets 1100-H12 that are impacted by conical and ogive projectiles have been determined using numerical simulations. For the simulations, Weldox 460 E plates with a single thickness of 12 mm, a layered combination (2x6), and an aluminium target 1100-H12 with a thickness of 1 mm, a layered combination (2x0.5) with a slope of 15º and 30º were used. Target results are monolithically layered and compared with each impact angle. Comparing layered contact targets of equal thickness, it was discovered that monolithic targets had stronger ballistic resistance. Weldox 460 E steel, which is 12 mm thick, has a ballistic limit that extends up to 30° obliquity before increasing by 10% at 45° obliquity. In comparison to normal impact, the ballistic limit increased by 6.3% at 15° obliquity and by 9.3% at 30° obliquity for a 1 mm thickness on the 1100-H12 aluminium target. For steel, Weldox 460 E double layer (2x6) mm is almost the same as 30º obliquity but increases 6% at 45º obliquity. For aluminium 1100-H12 with a layer of (2x0.5) mm, the ballistic limit increased by 4.8% at 15º obliquity and 11.4% at 30º obliquity compared to normal impact. There is no significant difference in the resistance of the laminated and monolithic plates of the two materials to normal and inclined impacts. Projectiles with a conical shape can penetrate both materials. Using the material Weldox 460 E steel, Xiao et al. [9] investigated monolithic and layered panels. Conical projectiles with SPH simulation and analytical techniques are used. The panel thickness can vary from 2 to 12 mm, and the impact speed can range from 80 to 405.7 m/s. The results obtained from the SPH simulation show that the target monolithic ballistic resistance increases with increasing panel thickness. The results of the layered targets SPH analysis and simulation approaches agreed quite well in terms of qualitative agreement. Because it ignores the interaction between panels, the analytical method predicts a lower ballistic boundary velocity than the SPH simulation.

Zhang et al. [10] investigated the effect of prestress on bi-layer ballistic performance experimentally and numerically. There are three different target plate types with various prestress levels. The front panel is made of alumina, the rear plate is made of aluminium alloy 2024-T3, and the arm plate is made of AISI 4340 steel. The speed varies between 300 and 600 m/s. FEM is used in numerical simulations with the LS-DYNA 3D program. According to the simulation results, prestress improves the ballistic performance of the bi-layer ceramic composite armour, and the effect is stronger at higher prestress levels. Borvik et al. [11] investigated projectiles with three different shapes (blunt, hemispherical, and conical) used in gas gun experiments to numerically penetrate Weldox 460 E steel plate 12 mm thick. The projectile's nose shape has a significant impact on how much energy it absorbs and can cause the plate structure to break during penetration. The mesh used is adaptive to get good results on conical projectiles. In terms of numerical, the ballistic limit velocity with adaptive mesh generates a value of 203.8 m/s for blunt projectiles, 297.8 m/s for hemispherical projectiles, and 278.3 m/s for conical projectiles. At the highest impact velocity, the plastic deformation of the projectile absorbs much of the initial kinetic energy.

As a result of the numerous investigations that have been conducted, scientists modified the creation of panels utilizing ANSYS/Explicit Dynamic software for this study. The front plate is made of alumina, the back plate is made of Weldox 460 E steel, and the projectile is an NIJ Type IV. The researchers modified the arrangement of panels and projectiles and also used the outcomes of experimental experiments to validate the simulations. You can also determine the final projectile length, deflection, and depth of penetration.

2. RESEARCH METHOD

The research method used in this study is the non-linear finite element method. The software used is ANSYS/Explicit Dynamic with Solve AUTODYN 18.1. This research depends on research from Dey et al. that has been supported by experimental experiments for its verification.

In a study conducted by Dey et al. [5], which is a verification study, the shape of a blunt cylindrical projectile (Blunt Projectile) with Arne Tool Steel material is 197 grams. The properties of the projectiles made with Arne tool steel are listed in **Table 1**. Meanwhile, in this test, projectiles using the National Institute of Justice (NIJ) Standard-0101.06 Type IV standard were used. This type IV projectile has two core parts and a skin part, which is more detailed in **Figure 1** in part b. The projectile core uses brass or brass material. while the projectile shell uses steel 4340 with material properties as shown in **Table 2**.

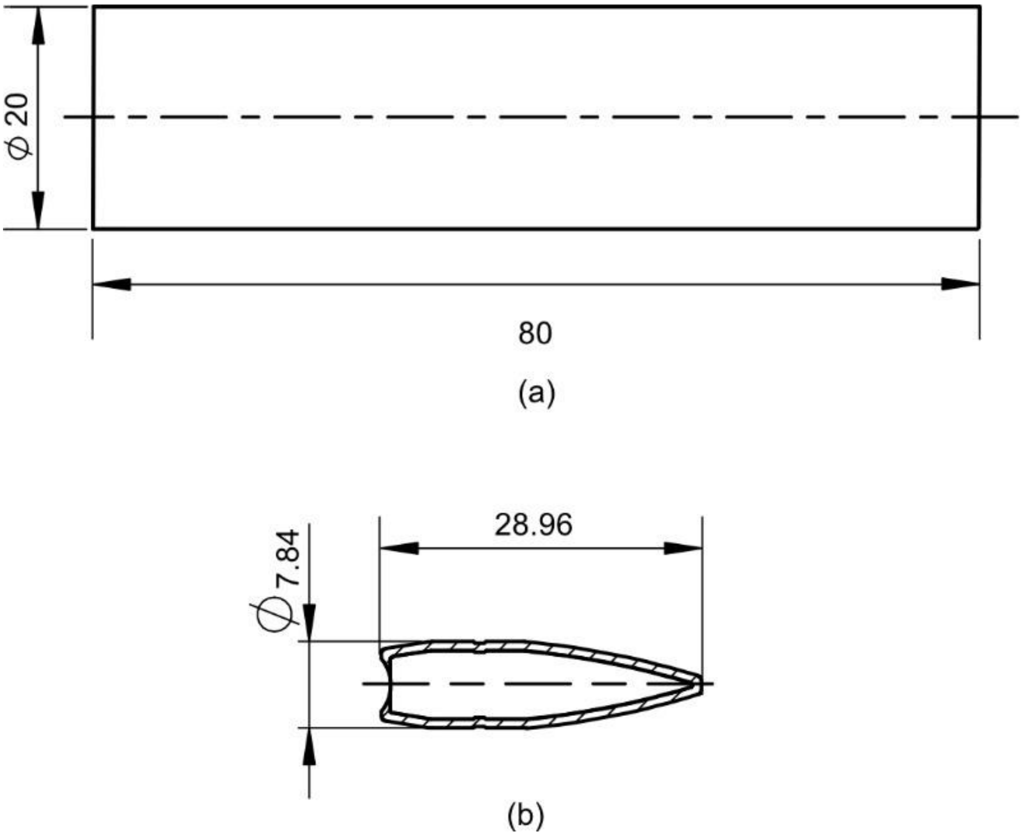

Figure 1. Blunt Projectile and Projectile of NIJ type IV

The panel material employed in the Dey et al. research as a model for verification research is Weldok 460 E, which has a circle form of 500 mm and a thickness of 12 mm. The modeling used is 2D axisymmetric, which is more detailed in **Figure 2**. Then it is changed by adding Alumina material for the front panel and Weldox 460 E for the back panel. The specifications for the properties of Alumina are in **Table 2**, while the properties of Weldox 460 E are in **Table 2**.

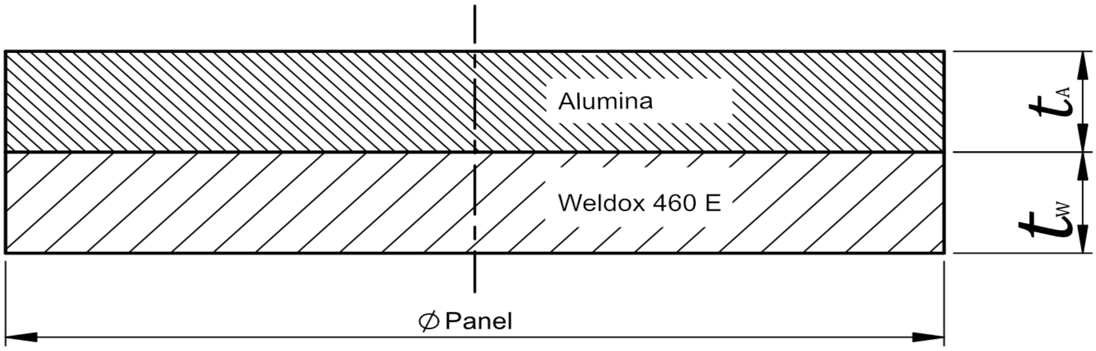

Figure 2. Panel Configuration Alumina (Al_2O_3) and Weldox 460 E

Two different sorts of materials are used in the study's materials. While the panels are made of ceramic (Alumina) and metallic materials, the projectiles are made of metallic materials (steel 4340 and brass) (Weldok 460 E). The requirements for strength and fracture failure are necessary for simulating material properties under high impact loads. In metallic materials, strength and mechanism parameters follow Johnson and Cook's model with parameter constants, as shown in table 2. According to the Johnson and Cook material model, deformation occurs when a material experiences stress that is greater than its yield stress, which is what happens when extreme conditions are present. plastic. The material's strength behavior is subjected to significant strains, high temperatures, and rapid strain rates. In this Johnson-Cook model, the value of the stress depends on the strain. The metal materials used in this study are Weldox 460, Steel 4340, and brass. The Johnson-Cook model's equation is as follows [12]:

$$\sigma_y = \left(A + B\left(\varepsilon_p\right)^n\right)(1 + C \ln \dot{\varepsilon}^*)(1 - (T^*)^m)$$

Where ε_p is effective plastic strain, $\dot{\varepsilon}^*$ is normalized plastic strain, T^*

As for the model with ceramic materials, the Johnson-Holmquist Strength Continuous (JH-2) constitutive equation is used. Johnson-Holmquist Strength Continuous (JH-2) is commonly used for brittle materials, especially ceramics. In JH-2, the hydrostatic response of the material is described by a polynomial equation in which the effect of energy density on pressure is neglected. In **Table 3**, the parameters of Johnson-Holmquist Strength Continuous can be seen. As for the definition of the relationship between pressure and the degree of compression with damage-free materials [13]:

$$P = K_1\mu + K_2\mu^2 + K_3\mu^3, \mu > 0 (\text{Hidrostatic Compression})$$

and

$$P = K_1\mu, \mu < 0 \qquad (\text{Hydrostatic tension})$$

Where the degree of compressor is $\mu = (\frac{\rho}{\rho_0} = 1)$ and ρ is the current density, while 0 is the reference density, K1 (bulk modulus), K2, and K3 are material-specific constants.

Table 1. Physical and mechanical of arne tool steel [5]

Parameter	Unit	Value
Mechanical Properties		
Density	tonne/m^3	7.85x10^9
Poisson's Ratio		0.33
Young's Modulus	MPa	2.04x10^5
Shear Modulus	MPa	7.70x10^4
Bulk Modulus	MPa	2.06x10^5

Table 2. Physical and mechanical Properties of Weldox 460 E, Brass and Steel 4340

Parameter	Unit	Value		
		Weldox 460 E [5]	**Brass [14]**	**Steel 4340 [15]**
Mechanical Properties				
Density	tonne/m^3	7.85x10^9	8.59x10^{-9}	7.80x10^9
Specific Heat	J/Kg.C	452	0.38	477
Poisson's Ratio		0.33	0.34	0.3
Young's Modulus	MPa	2.10x10^5	97000	2.10x10^5
Shear Modulus	MPa	7.89x10^4	36194	8.08x10^4
Bulk Modulus	MPa	2.06x10^5	1.01x10^5	1.75x10^5
Johnson Cook Strength				
Initial Yield Stress	MPa	499	90	792
Hardening Constant	MPa	382	292	510
Hardening Exponent		0.458	0.31	0.26
Strain Rate Constant		0.0079	0.025	0.014
Thermal Softening Exponent		0.893	1.09	1.03
Melting Temperature	C	1526.9	1356	1793.1
Reference Strain Rate	1/s	0.0005	1	1
Johnson Cook Failure				
Damage Constant D1		0.636	0.54	0.05
Damage Constant D2		1.936	4.89	3.44
Damage Constant D3		-2.969	-3.03	-2.12
Damage Constant D4		-0.014	0.014	0.002
Damage Constant D5		1.104	1.12	0.61
Melting Temperature	C	1526.9	1356	1793.1
Reference Strain Rate	1/s	1	1	1

Table 3. Properties of Alumina JH-2 konatitutif model [13]

Parameter	**Simbol**	**Unit**	**Value**
Mechanical Properties			
Density	ρ	$tonne/m^3$	$3.89x10^9$
Johnson-Holmquist Strength Continuous			
Hydrodynamic Tensile Limit	T	MPa	-262
+Shear Modulus		MPa	$1.52x10^5$
Hugoniot Elastic Limit	HEL		6570
Intact Strength constant	A		0.88
Intact Strength Exponent	N		0.64
Strain Rate Constant	C		0.007
Fracture Strength Constant	B		0.28
Fracture Strength Exponent	m		0.6
Maximum Fracture Strength Ratio	S^f_{max}		1
Damage Constant	D1		0.01
Damage Constant	D2		0.7
Bulking Constant	β		1
Polynomial EOS			
Parameter A1		MPa	$2.31x10^5$
Parameter A2		MPa	$-1.60x10^5$
Parameter A3		MPa	$2.77x10^6$
Parameter B0			0
Parameter B1			0
Parameter T1		MPa	$2.31x10^5$

Each panel is mentioned using a code to make it easier to name its configuration. Alumina has the code A, while Weldox 460 E has the code B. The thickness of the panel is then indicated by the numbers behind the letters, as illustrated in **Table 4**.

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e-ISSN: 2774-8006 | p-ISSN: 2774-8278

Table 4. Panel configuration code

Code Panel	Thickness (mm)		Total Thickness (mm)
	Alumina	Weldox 460 E	
B12	-	12	12
A5B5	5	5	10
A5B10	5	10	15
A10B5	10	5	15
A10B10	10	10	20
A12B12	12	12	24
A15B15	15	15	30

Barrett's study [4] is applied to mesh convergence to confirm the convergence of the numerical technique. A cylindrical projectile with dimensions of 15 mm in length and 10 mm in diameter was used in the convergence research at a speed of 300 m/s. The goal of the mesh convergence study is to calculate the amount of projectile deformation and the projectile's final length. The convergence study was performed using mesh sizes of 0.5 mm, 0.25 mm, 0.125 mm, and 0.0625 mm. Because the size is quite accurate, the research's findings indicate that the mesh size that converges is 0.25 mm with a linear layout. The mesh size chosen in this work is 0.25 mm since the modeling is the same as that of Barrett [4].

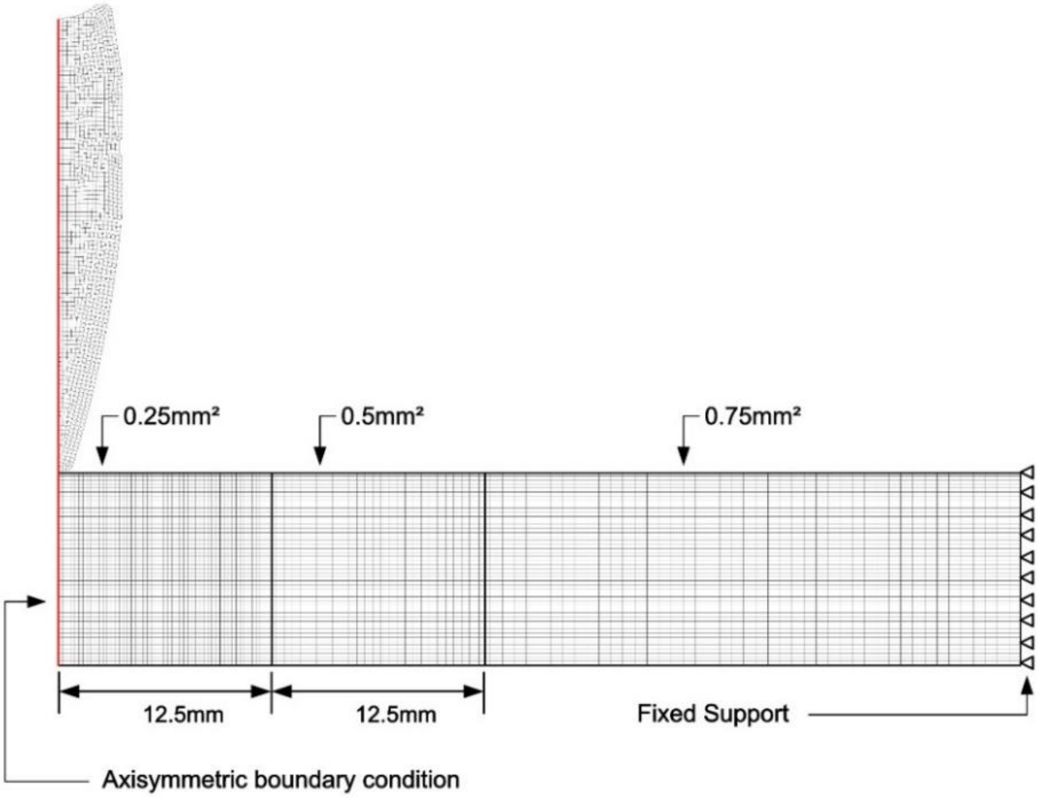

Figure 3. Boundary condition and mesh configuration

According to the research of Dey et al. [5], which is relevant to all variants employed in this investigation, the value of the friction coefficient between the panel and the projectile is disregarded. The right side of the panel is locked in Figure 3 and established as a fixed support to stop it from moving during a collision.

Convergent outcomes from computation take a long time to obtain. The size and quantity of the elements have an impact on this. Make a mesh setting as a result. The projectile shot area has fine mesh, while the areas farther away from the shot area have rough mesh. A panel partition separated into three pieces is depicted in Figure 3.4. A 0.25 mm mesh is used for the partition in the first part, a 0.5 mm mesh for the partition in the second part, and a 0.75 mm mesh for the partition in the third part.

3. RESULTS AND DISCUSSION

3.1 Projectile Residual Velocity Comparison

It is required to compare the research findings from the simulation with the results from the experimental tests conducted by Dey et al. [5] in order to assess their accuracy. The blunt projectile in this instance has a diameter of 20 mm and a length of 80 mm, and it is made of Arne tool steel to verify the projectile data. The panel is made of the steel alloy Weldox 460 E, has a diameter of 500 mm, and a panel thickness of 12 mm. The accuracy and strength of the model under various weights were evaluated, utilizing a variety of speeds to validate this research.

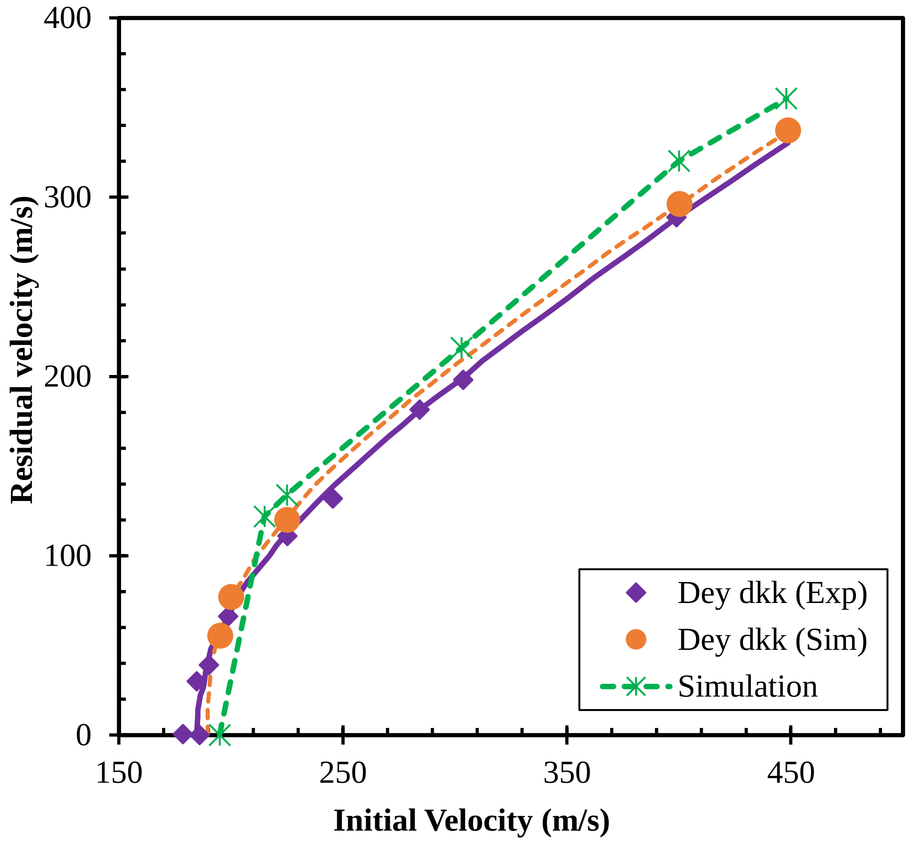

Figure 1. Verification of residual projectile velocity from numerical simulation Dey dkk

The comparison between the simulation and the experiment from the Dey et al. [5] test is shown in **Figure 1** as a graph, which compares the initial velocity of the projectile to the projectile's final velocity in the firing test using Weldox 460 E steel panel material. The projectile's velocity after passing through the panel's thickness is known as the residual velocity (Vr). The projectile speed limit can still be maintained by the panel if Vr = 0 m/s. Meanwhile, the velocity ballistic limits (Vbl) are the ballistic resistance of the panel material when the residual velocity is zero.

Table 1. Validation of residual velocity from numerical simulation Dey dkk

Validation panel Weldox 460 E Steel					
Vinitial (m/s)	Vresidu (m/s)			Error (Exp)	Error (Sim)
	Simulation	Dey (Exp)	Dey (Sim)	%	%
215	121.92	100.02	108.03	21.89	12.85
225	133.94	111.03	120.01	20.64	11.61
300	216.02	199.33	207.35	8.37	0.05
400	320.20	298.95	296.19	7.11	8.10
450	354.96	330.41	337.22	7.43	5.26
			Average	**13.09**	**7.58**

The comparison of the projectile's initial velocity and residual velocity is shown in Table 1 as the result. The bullet has clearly departed from its slow initial velocity. However, as the projectile's initial velocity increases, the divergence becomes smaller. According to the research of Dey et al. [5], the variation is 7.58% to 13.09% at speeds between 215 and 450 m/s. The least deviation occurs at the projectile's beginning velocity of 300 m/s.

It can be seen in the trendline in **Figure 1**. A trend with a speed of 300 m/s is expected to be present in the middle of the curve and is increasing in accuracy. In line with the findings of Dey et al. [5], the simulation results used in this study can be accepted. The simulation results in this study are acceptable compared to the results of the experimental and simulation research conducted by Dey et al. [5].

3.2 Profile Residual Velocity and Depth Penetration

The panel model used for the validation of this study was taken from the results of Dey's research [5] using Weldox 460 E material with a thickness of 12 mm. However, the research conducted by Dey et al [5] has not used the projectile standard set by the National Institute of Justice (NIJ) Standart-0101.06 Type IV. Therefore, a typical NIJ 7.62 mm Type IV projectile was used in this particular research study. However, despite having a thickness of 12 mm, the panel made of Weldox 460 E material cannot sustain the projectile rate. With this in mind, the Weldox 460 E panel was modified by adding ceramic material to the alumina front panel to make it a two- or bi-layer panel. In order to determine the optimal panel thickness that can withstand projectiles, it is necessary to have various thickness variations and panel configurations. The configuration was obtained from the firing test with the standard NIJ 7.62 mm Type IV projectile by measuring the profile of its residual velocity. The results of the projectile velocity profile against the penetration time with various panel configuration adjustments are shown in **Figure 2**. The results of the projectile velocity profile against the penetration time with various panel configuration adjustments are shown in **Figure 2**. The time from when the projectile first touches the panel until it exits the panel or becomes attached to the panel is known as the penetration time. The remaining velocity of the projectile-resistant panel is zero. While the panel's ability to penetrate indicates that the projectile's residual velocity is zero. indicates that the panel can withstand bullets, whereas a residual velocity that is greater than zero indicates that the projectile has passed through the panel. **Figure 2** shows that the projectile's velocity begins to fall off at time = 0, which is when the projectile strikes the panel.

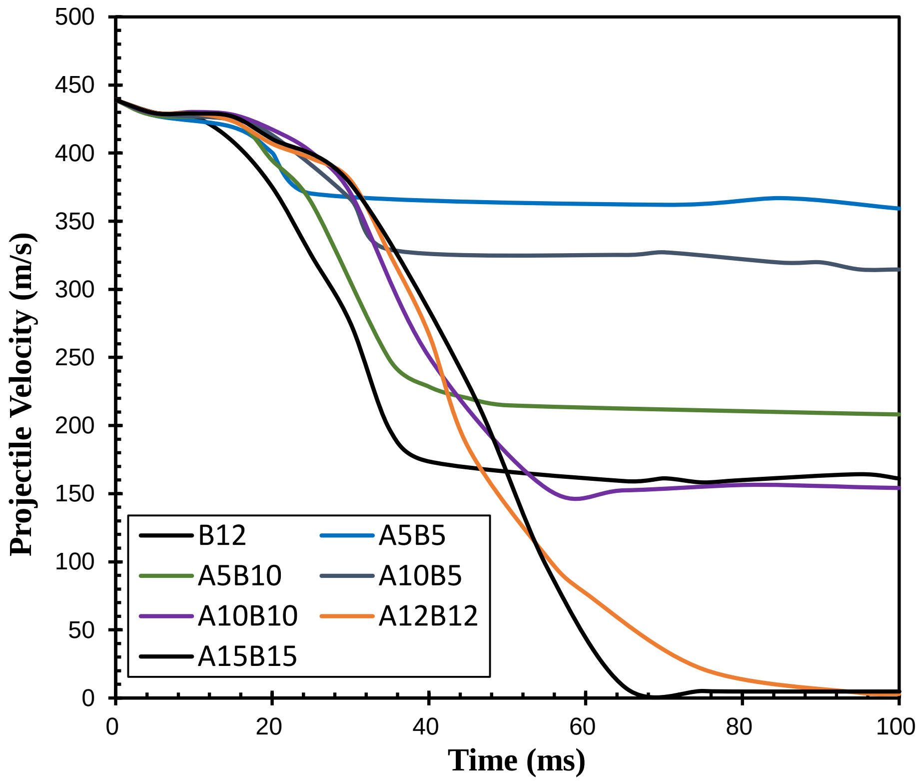

Figure 2. Projectile velocity profile against penetration time with various panel configurations

In this work, a comparison of projectile velocity profiles during a firing test simulation was done to assess ballistic resistance with different panel layouts. In contrast, it was discovered that panel B12 from the study by Dey et al. [5] still had a significant residual velocity of 738 m/s, indicating that the panel could not sustain the projectile rate, as shown in **Table 2**. Remaining velocity is included in A5B5, A5B10, A10B5, and A10B10. This shows that the panel cannot survive the projectile rate because it still has a residual velocity, as illustrated in **Figure 3**. The velocity profile drops to zero for panels with the A12B12 and A15B15 combinations. The panel configuration that belongs to A12B12 and A15B15 can then withstand the projectile rate. The A5B10 and A10B5 panel configurations are another factor to take note of, with the residual speed in the A5B10 configuration being lower than in the A10B5. This demonstrates that Weldox 460 E material outperforms Alumina material in terms of projectile rate resistance. However, the body armor becomes heavy, uncomfortable, and stiff when Weldox 460 E is added, as seen by the mass of this material, which is heavier than alumina. The balanced addition of the two materials will produce a lighter, more comfortable, and less rigid mass if the panel configuration is eventually applied to the body armor.

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e-ISSN: 2774-8006 | p-ISSN: 2774-8278

Table 2. Final result ballistic performance from several panel configurations

Panel Code	Thickness (mm)		Total Thickness (mm)	Vinitial (m/s)	Vresidual (m/s)
	Alumina	Weldox 460 E			
B12	-	12	12	878	738
A5B5	5	5	10	878	737
A5B10	5	10	15	878	419
A10B5	10	5	15	878	640
A10B10	10	10	20	878	314
A12B12	12	12	24	878	0
A15B15	15	15	30	878	0

Table 3. Final results from several panel configurations

Panel Code	Depth of Penetration (mm)	tr (mm)	td (mm)	Final Length Projectile (mm)
B12	perforated			13.35
A5B5	perforated			20.83
A5B10	perforated			15.16
A10B5	perforated			17.74
A10B10	perforated			14.81
A12B12	23.39	4.74	4.3	12.23
A15B15	21.06	10.25	1.4	11.05

Table 3 shows the results, which demonstrate that panel B12 was unable to survive the 7.62 mm NIJ projectile's speed of 878 m/s. The A12B12 panel's residual velocity decreases to zero so that projectiles can limit the panel’s configuration, but the panel's total thickness of 24 mm results in a penetration depth of 23 mm and a deflection of 4.3 mm. The A15B15 panel is the ideal panel configuration for projectile resistance because projectiles with zero residual velocity will hit the panel. With a penetration depth of 21 mm and a total thickness of 30 mm, the A15B15 panel design results in a 1.4 mm deflection. Accordingly, the findings in Figure 8 demonstrate that the panel of A15B15 is the best configuration among multiple Alumina and Weldox 460 E coating panel combinations that can successfully stop a 7.62 mm NIJ bullet moving at 878 m/s.

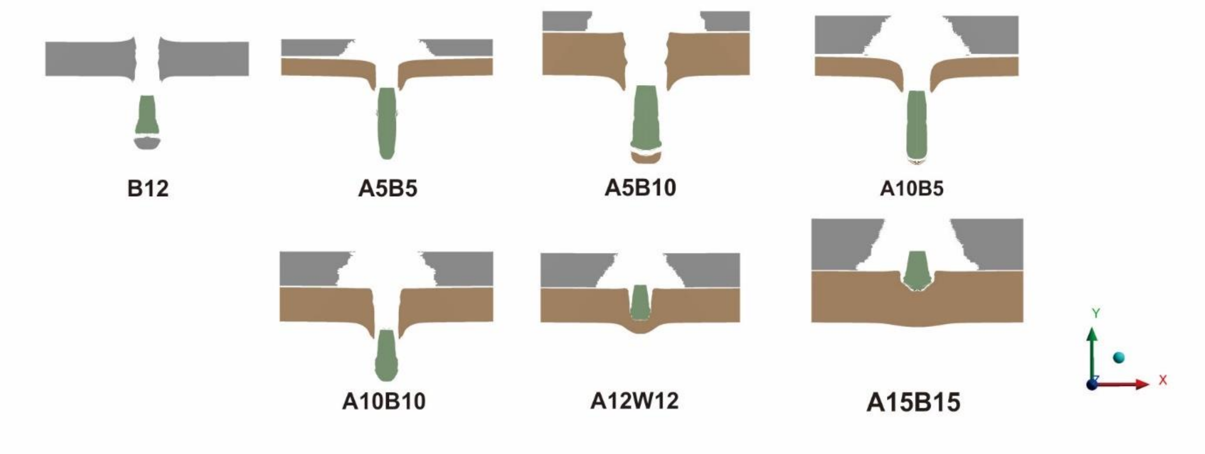

Figure 3. Bullet Penetration visualization

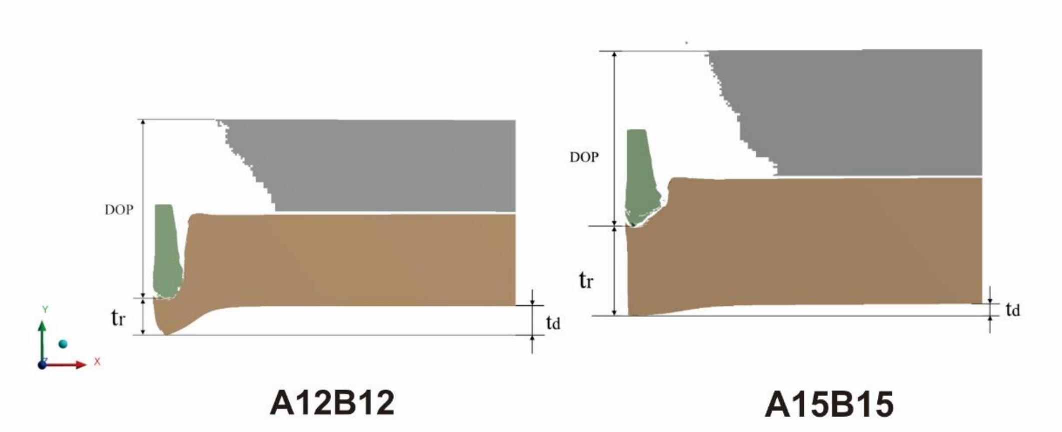

Figure 4. Depth of penetration

3. CONCLUSION

Results from the simulation of projectile residual velocity were compared to findings from research by Dey et al. [3], which revealed variances or errors with an average value for the experiment of 13.09% and 7.58% in the simulation. The B12 panel still has a significant residual velocity of 738 m/s as a result of the panel configuration that is produced in line with the NIJ Type IV standard, which indicates that the panel is incapable of withstanding the projectile rate. The projectile velocity profile with panel configurations A5B5, A5B10, A10B5, and A10B10 also continues to have residual velocity. This shows that the panel is unable to withstand the projectile's velocity because there is still residual velocity. However, the speed profiles for panels with the A12B12 and A15B15 configurations are zero. A12B12 and A15B15's panel layouts can then withstand the rate of projectiles. The A12B12 panel arrangement, which has a total panel thickness of 24 mm and a penetration depth of 23 mm, results in a deflection of 4.3 mm. Given that projectiles have zero residual velocity, the A15B15 panel is the ideal arrangement for a panel that can survive projectiles. The penetration depth and total thickness of the A15B15 panel arrangement are 21 and 30 mm, respectively, and they result in a 1.4 mm deflection.

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