Original Research Article: full paper

(2022), «EUREKA: Physics and Engineering»
Number 6

ANALYSIS PROJECTILE PERFORMANCE IN BALLISTIC TESTS USING COMPRESSED AIR GUN

Helmy Purwanto✉
Department of Mechanical Engineering[1]
helmypurwanto@unwahas.ac.id

Mohammad Tauviqirrahman
Department of Mechanical Engineering
Diponegoro University
Jl. Prof. Soedharto SH, Tembalang, Semarang, Indonesia, 50275

Sugiarto
Department of Mechanical Engineering
Brawijaya University
Jl. Mayjend Haryono, 167, Malang, Indonesia, 65145

Muhammad Dzulfikar
Department of Mechanical Engineering[1]

[1]Universitas Wahid Hasyim
Jl. Menoreh Tengah X/22, Sampangan, Semarang, Indonesia, 50235

✉**Corresponding author**

Abstract

Ballistic resistance is affected by the projectile and armor material used. The character and behavior of the projectile affects its ability to damage and penetrate armor. The velocity, mass and shape of the projectile are the main factors in determining the ability of the projectile to penetrate armor in this case the target plate. Therefore, this study aims to determine and analyze the effect of projectile mass and shape on the velocity with which it penetrates the armor material using a compressed air gun. Armor material as a ballistic test target using carbon steel plate with a thickness of 0.8 mm; 1.2 mm and 1.8 mm. Projectiles of lead materials with different masses and shapes are fired from the air gun under controlled air pressure, set at 2000 Psi, 3000 Psi, and 4000 Psi to provide thrust in the barrel. The plat target is placed at a distance of 5 m from the air gun. Speed gauges are placed after the air gun and after the target plate to determine the projectile's rate before and after passing through the target plate. The test results concluded that the velocity of the projectile ejected from the compressed air gun was influenced by the magnitude of the pressure and the mass of the projectile. The mass of the projectile has a more dominant effect on the velocity of the projectile compared to the amount of pressure applied. Different projectile shapes with the same mass have no significant effect on the velocity. However, the heavier mass projectile outperforms the lighter mass projectile through the target plate. It is required the right combination of velocity and mass of the projectile to be able to penetrate the target plate.

Keywords: air gun, ballistic, projectile ability, projectile velocity, projectile mass, projectile shape, projectile impact, ballistic limit.

DOI: 10.21303/2461-4262.2022.002418

1. Introduction

Defense and security is a field of study that is continually investigated and developed. The ballistic-resistant materials and weapons are used to attack the enemy and maintain security as well as defense against evil. Furthermore, the ballistic resistant materials or armor were developed to become strong and lightweight. While the weapons and projectiles were designed to penetrate and destroy the armor.

The ballistic limit is the lowest speed at which a projectile can penetrate the target. Ballistic limit influenced by the projectile and armor factors used [1–3]. Projectile factors such as material, shape, dimensions, mass, angle of attack, and velocity. Due to the projectile's velocity, which is lower than the ballistic limit, will not penetrate the target [4].

The material affects the projectile hardness and mass since lead is a higher density than the hard steel core. The hardness of the material affects the shape and size of the perforation channel formed after penetration of the armor [5].

As a result, hard steel projectiles have a longer depth of penetration and narrower crater front diameter than soft steel on aluminum targets.

The dimensions and shape of the tip are related to the penetration mode, while the mass affects the dynamic deformation of the target carbon fiber reinforced plastic (CFRP) [6]. In this study, the residual velocity of the projectile after hitting the target has not been measured. Furthermore, the tip shape affects the aerodynamics of the velocity in the air and the impact on the target plate [7–9]. The pointed ogival head projectile has the lowest ballistic limit, while the blunt, flat head requires the highest ballistic energy to penetrate a target made of sand [10]. This study focuses more on ballistic behavior when slide in the air due to aerodynamic forces.

The effect of projectile velocity on ballistic efficiency, which is generally measured using a differential (DEF) or mass efficiency factor (MEF), is one of the parameters in designing armor materials [11, 12]. It has been observed that ballistic efficiency in ceramic armor materials increases with velocity [11–15]. But in other studies, it was concluded that the ballistic efficiency of the armor material decreases with increasing velocity [16–20]. The higher the velocity, the higher the differential efficiency factor in ballistic testing on hot-pressed boron carbide, alumina, and zirconia toughened alumina tile [21]. So this study needs to be tried again on various types, masses, and velocity of projectiles due to air pressure from the air gun.

Besides velocity, some researchers focus on projectile mass [22–25], it was stated that the projectile and target mass ratio affected armor failure, especially composite armor. The greater the mass, the higher the impact force and energy absorption on the target composite, and vice versa [26]. However, another study [27] reported dropping objects of varied masses onto the composite did not affect the drop experiment due to the relatively small dimensions of the projectile at low velocity, making it difficult to show the occurring phenomena [6].

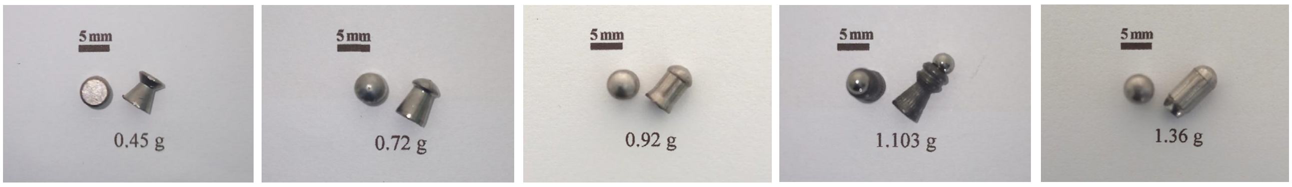
Based on the literature review of previous research, ballistic testing, ballistic performance and ballistic limit have been widely carried out, but those who conducted studies by comparing projectile mass, projectile shape, air gun compressed air pressure, and projectile velocity as a whole have not been found. It is interesting to study the effectiveness between projectile mass or projectile velocity against the ballistic limit. What is the most influential between projectile mass or projectile velocity. While the projectile velocity of the air gun is influenced by the air pressure in the gun tube. So that the results of this variable optimization study can be used as a reference in projectile design to increase the ballistic limit using an air gun.

The ballistic limit is affected by the projectile velocity, which is greatly affected by the mass and tip shape. Besides the mass and tip shape, the force or energy that drives the projectile to slide impacts its velocity. In an air gun, the pressure of the air significantly affects the velocity produced. However, the study on the use of air pressure and its effect on the impact of ballistics on armor by using air gun test equipment have not been widely examined. Hence, this study aims to determine and analyze the effect of projectile mass and shape on the velocity and performance in ballistic testing using a compressed air gun. The limitation of this study is that it has not been able to record projectile motion due to the influence of its shape.

2. Material and Method

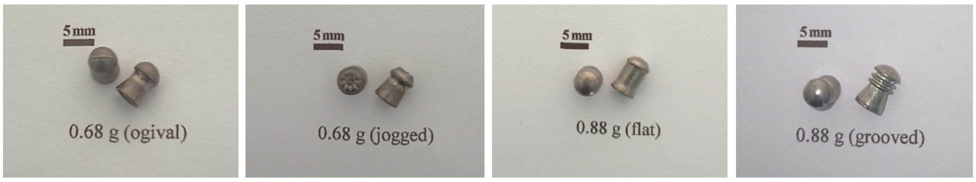
Ballistic testing was done using an air gun launcher (custom modification air pressure up to 75000 psi). The air pressure in the air gun can be controlled with a compressor and measured with a pressure gauge. After penetrate the target, the projectile and residual velocities are measured using a ProChrono® Digital Chronograph has a velocity up to 2133.6 m/s. Furthermore, the test used 4.5 mm caliber projectiles made of lead with different shapes and masses projectile. The mass is used with a neglected shape, as shown in **Fig. 1**.

Meanwhile, the projectile slide and tip are used as variables to determine the effect of their shape on the velocity. The variable shape of different projectiles with the same mass is shown in **Fig. 2**.



a *b* *c* *d* *e*

Fig. 1. Projectile mass variable:
a – 0.45 grams; *b* – 0.72 grams; *c* – 0.92 grams; *d* – 1.103 grams; *e* – 1.36 grams



a *b* *c* *d*

Fig. 2. Projectile shape: *a* – 0.68 gram projectile with oval tip shape; *b* – 0.68 gram projectile with a jogged tip; *c* – 0.88 gram projectile with a flat side shape; *d* – 0.88 gram projectile with grooved side shape

Ballistic testing was conducted to determine the projectile and armor resistance performance. Furthermore, this scheme is shown in **Fig. 3**, where the projectile is launched from the air gun with variations of air pressure in the gun tube of 2000 Psi, 3000 Psi, and 4000 Psi. Each variable is repeated 3 times, and the test data is the average from each test. Meanwhile, targets or armor use mild steel plates with a thickness variation of 0.8 mm, 1.2 mm, and 1.8 mm and a firing range of 5 m from the barrel. The chemical composition of the target plate tested by spectrometer Hilger® E-9 OA701 is shown in **Table 1**.

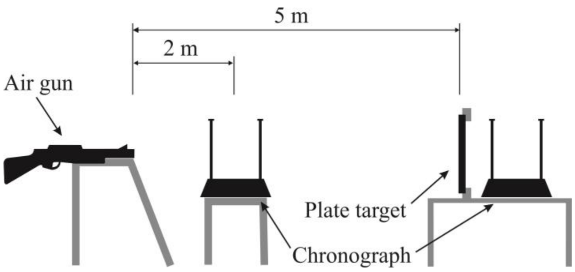


Fig. 3. Ballistic test scheme using a compressed air gun

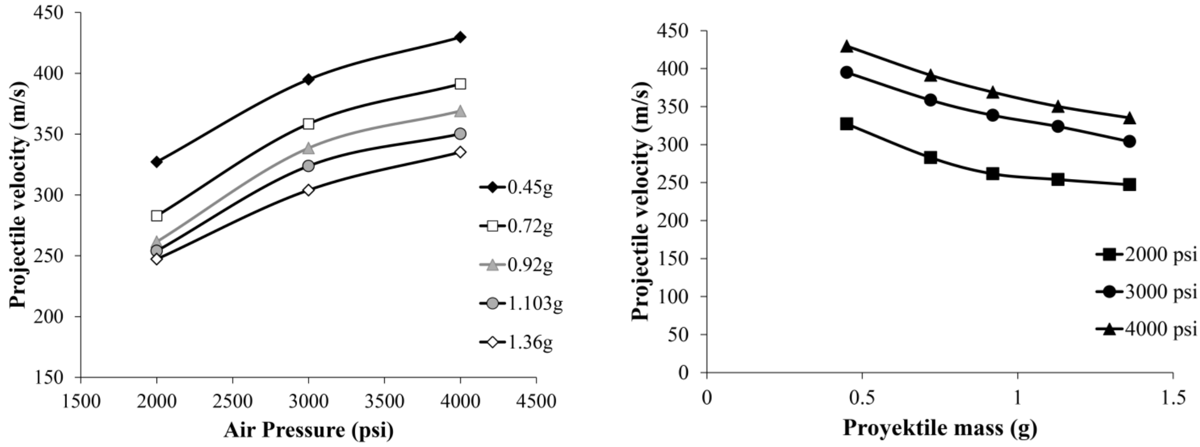
Table 1
Chemical composition of carbon steel

Material	Chemical composition % (weight)								
	C	Si	Mn	Cr	Cu	N	S	P	Fe
Plat mild steel	0.05	0.12	0.28	0.31	0.01	0.02	0.02	0.02	Bal.

3. Result and discussion

3. 1. Air pressure effect and projectile shape on projectile velocity

The propulsion pressure of the air tube in the gun affects the velocity of the projectile ejected by the barrel. The higher the pressure, the higher the projectile velocity. This is because the greater the pressure, the higher the thrust on the projectile. Also, the mass of the projectile affects its velocity. The smaller the mass projectile, the higher the velocity at the same pressure, due to the same compressive force with a lower projectile mass resulting in a higher acceleration. The difference in pressure and mass of the projectile to the resulting velocity is also explained in **Fig. 4.**



a *b*

Fig. 4. The relationship between: *a* – air pressure with projectile velocity; *b* – mass of the projectile with the velocity of the projectile

The highest projectile velocity of 429.67 m/s obtained the most significant pressure of 4000 Psi at the lightest projectile mass of 0.45 grams. For the heaviest projectile mass, which is 1.36 grams at the same air pressure of 4000 Psi, the resulting velocity is 335.17 m/s (**Fig. 4**, ***a***). This implies a significant decrease in velocity for the smaller projectile mass difference. The lowest velocity of 247.19 m/s occurs at the lowest pressure, and the heaviest projectile mass of 2000 psi and 1.36 grams, respectively.

The average projectile velocity is affected by the projectile's mass even though the difference in mass is small. Meanwhile, the lighter projectile mass at the same pressure causes a higher velocity (**Fig. 4**, ***b***). This is consistent with Newton's second law of motion, which states that the acceleration produced by the resultant force acting on an object is directly proportional to the resultant force and inversely proportional to the object's mass. Therefore, when the same magnitude of thrust is applied to different masses, it will result in a higher acceleration for the lighter object.

The projectile's velocity must be high enough to cause damage or penetration. As a result, the faster the projectile travels, the more damage is dealt to the target. Similarly, projectile mass has an effect on the target. The smaller the mass of the projectile, the less damage to the plate target. This is consistent with the momentum equation governing object collisions. Therefore, projectile velocity and mass mutually influence its ability to damage or penetrate the target's armor.

Besides velocity and mass, projectiles also have different tip and side shapes. The different projectile shapes having the same mass are shown in **Fig. 2**. Meanwhile, the results using a variable pressure gun on different projectile shapes with the same mass are shown in **Fig. 5**.

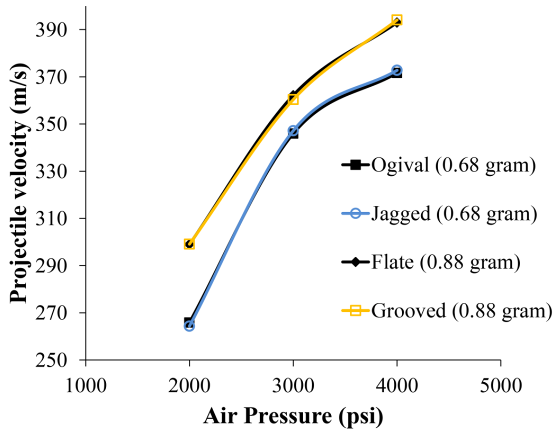


Fig. 5. Projectile shape effect and air pressure on projectile velocity

At the same air pressure, ogival and toothed projectiles with the same mass of 0.68 grams have nearly the same velocity. Similarly, it is flat and grooved with a mass of 0.88 grams. The shape and design of the projectile have no significant effect on the resulting velocity, which is only affected by its mass and the pressure of the propulsion air. Therefore, the shape of the projectile does not affect velocity but the resulting ballistic impact. The shape and type of projectile affect the resulting impacts on the target plate [28]. Also, the shape and design affect its aerodynamics in air [29]. Therefore, the design and production also increase the performance and velocity of projectiles [30].

3. 2. Projectile mass effect and plate thickness on ballistic impact

The air pressure in the gun affects velocity, while the projectile's mass impacts the target material or armor. Therefore, the velocity and mass of the projectile mutually influence the resulting ballistic impact on the armor. The results of ballistic testing using 0.4 and 1.36 gram projectiles at 4000 Psi are shown in **Tables 2, 3**.

Table 2

Plate thickness effect on ballistic impact by using 0.45 gram projectile

Air Pressure (psi)	Average Projectile Velocity (m/s)	Target Plate Thickness (mm)	Result	Residual Velocity (m/s)	Average Residual Velocity (m/s)
4000	429.666	0.8	Hole	208.483	212.547
			Hole	255.727	
			Hole	173.431	
		1.2	Stopped	0	0
			Stopped	0	
			Stopped	0	
		1.8	Stopped	0	0
			Stopped	0	
			Stopped	0	

Table 3

Plate thickness effect on ballistic impact by using a 1.36 gram projectile

Air Pressure (psi)	Average Projectile Velocity (m/s)	Target Plate Thickness (mm)	Result	Residual Velocity (m/s)	Average Residual Velocity (m/s)
4000	335.178	0.8	Hole	226.466	225.856
			Hole	225.247	
			Hole	225.857	
		1.2	Hole	37.186	36.881
			Hole	36.576	
			Stopped	0.000	
		1.8	Stopped	0.000	0
			Stopped	0.000	
			Stopped	0	

Projectiles with higher velocity could not be directly factored into their ability to penetrate armor plates. Furthermore, the projectile with a mass of 0.45 grams has a higher velocity of 429.666 m/s than a 1.36 gram with a velocity of 335.178 m/s. However, 1.36 gram projectiles can penetrate armor plates up to 1.2 mm thick, while those of 0.45 gram can only penetrate plates through a thickness of 0.8 mm. Residual velocity is the projectile velocity that is measured after it penetrates the target plate. It is also utilized as a simulation indicator of the target plate's ability to absorb the energy of projectile impact on the target [31]. The thicker the target plate, the better the ballistic resistance. In ultra-high molecular weight polyethylene, the thicker the layer, the better the protection [32]. Also, the thicker the plate, the higher the ballistic limit [4]. The test results indicate that the thicker the target plate, the lower the residual velocity, implying that the more impact energy absorbed by the target plate, the greater the impact's kinetic energy, which will decrease as the projectile's velocity and mass decrease [33].

3. 3. Limitations of the study and directions of development

The limitation of this study is that it has not been able to record the projectile movement before hitting the target, during impact, as it penetrates the target, projectile turn back and the spread of projectile fragments. This motion can be used as data to analyze the behavior of the projectile and the target plate when hit by a projectile impact. The shape of the projectile is very likely to affect the movement of the projectile when it glides through the air, which may affect the ballistic impact. The mechanism of perforation and fracture of hard steel plates impacted by projectiles of soft lead material can also be analyzed in more depth and focus. So that the results of this experimental analysis can be used for simulation validation with the finite element method.

Efforts that can be made for further research are the need for a super high speed camera. This camera can record very fast projectile motion. In particular, projectile motion which is influenced by the shape of the projectile has not been widely studied. Further research will be conducted in a ballistic testing laboratory with a high level of security.

4. Conclusions

According to experimental data on the study of the influence of air pressure, projectile shape, and mass on the released velocity from ballistic test equipment with a compressed air system:

1. The projectile velocity ejected from the compressed air gun is affected by the magnitude of the pressure and the projectile's mass. Therefore, the projectile's mass has a more dominant effect on its velocity than the amount of pressure applied. The highest projectile velocity of 429.67 m/s on a projectile with the lightest mass of 0.45 grams with the largest air pressure of 4000 psi. While the lowest projectile velocity is 247,193 m/s on the projectile with the largest mass of 1.36 grams with the lowest air pressure of 2000 psi.

2. The resulting ballistic impact on the target plate is affected by the velocity and mass of the projectile. However, the projectile's mass is more dominant than the projectile's velocity. Therefore, the most significant projectile mass has a better performance through the armor plate than the lighter mass. The projectile with a mass of 1.36 grams at a speed of 335,178 m/s is able to penetrate plates up to a thickness of 1.2 mm. While the projectile with a mass of 0.45 with a higher speed of 429,666 m/s was only able to penetrate plates with a thickness of 0.8 mm and failed on plates with a thickness of 1.2 and 1.8 mm.

3. Different projectile shapes with the same mass have no significant effect on the velocity. Projectile behavior caused by projectile shape can be studied by recording projectile movement and impact on the target, and this will be developed in future research.

Conflict of interest

We the authors declare that we have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

This research was funded by the Ministry of Education, Culture, Research, and Technology Basic Research scheme with contract number: 40/LL6/PG/SP2H/TD/2021.

Data availability

Data cannot be made available for reasons disclosed in the data availability statement.

Acknowledgement

Writers would like to express gratitude to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia for funding this research and publications. Thanks also go to the entire research team/laboratory assistant (Nur Kholis and Kusdi) and student (Fauzul, Rizka Aby and Wahyu Ade) who have been providing assistance in this study.

References

[1] NPFC – MIL-STD-662. V50 Ballistic Test for Armor (1997). NPFC. Available at: https://standards.globalspec.com/std/748723/MIL-STD-662

[2] Børvik, T., Forrestal, M. J., Hopperstad, O. S., Warren, T. L., Langseth, M. (2009). Perforation of AA5083-H116 aluminium plates with conical-nose steel projectiles – Calculations. International Journal of Impact Engineering, 36 (3), 426–437. doi: https://doi.org/10.1016/j.ijimpeng.2008.02.004

[3] Cho, C., Choi, S., Kwon, O. M., Lee, S., Kim, J., Kwon, D. (2020). Evaluation of Ballistic Limit Velocity Using Instrumented Indentation Test of 7xxx Aluminum Alloys After Friction Stir Welding. Metals and Materials International. doi: https://doi.org/10.1007/s12540-020-00680-2

[4] Purwanto, H., Dzulfikar, M., Tauviqirrahman, M., Subagyo, R., Kiryanto. (2021). Ballistic limit simulation on commercial medium carbon steel plate with surface hardening using an induction heating. IOP Conference Series: Materials Science and Engineering, 1034 (1), 012148. doi: https://doi.org/10.1088/1757-899x/1034/1/012148

[5] Khan, M. A., Wang, Y., Cheng, H., Yasin, G., Malik, A., Nazeer, F. et al. (2020). Microstructure evolution of an artificially aged Al-Zn-Mg-Cu alloy subjected to soft- and hard-steel core projectiles. Journal of Materials Research and Technology, 9 (5), 11980–11992. doi: https://doi.org/10.1016/j.jmrt.2020.08.076

[6] Yuan, K., Liu, K., Wang, Z., Wei, K., Yang, M. (2021). Dynamic fracture in CFRP laminates: Effect of projectile mass and dimension. Engineering Fracture Mechanics, 251, 107764. doi: https://doi.org/10.1016/j.engfracmech.2021.107764

[7] Kpenyigba, K. M., Jankowiak, T., Rusinek, A., Pesci, R., Wang, B. (2015). Effect of projectile nose shape on ballistic resistance of interstitial-free steel sheets. International Journal of Impact Engineering, 79, 83–94. doi: https://doi.org/10.1016/j.ijimpeng.2014.10.007

[8] Rodríguez-Millán, M., Vaz-Romero, A., Rusinek, A., Rodríguez-Martínez, J. A., Arias, A. (2014). Experimental Study on the Perforation Process of 5754-H111 and 6082-T6 Aluminium Plates Subjected to Normal Impact by Conical, Hemispherical and Blunt Projectiles. Experimental Mechanics, 54 (5), 729–742. doi: https://doi.org/10.1007/s11340-013-9829-z

[9] Gupta, N. K., Iqbal, M. A., Sekhon, G. S. (2007). Effect of Projectile Nose Shape, Impact Velocity and Target Thickness on Deformation Behavior of Aluminum Plates. International Journal of Solids and Structures, 44 (10), 3411–3439. doi: https://doi.org/10.1016/j.ijsolstr.2006.09.034

[10] Chian, S. C., Tan, B. C. V., Sarma, A. (2017). Projectile penetration into sand: Relative density of sand and projectile nose shape and mass. International Journal of Impact Engineering, 103, 29–37. doi: https://doi.org/10.1016/j.ijimpeng.2017.01.002

[11] Senf, H., Strassburger, E., Rothenhausler, H., Lexow, B. (1998). The Dependency of Ballistic Mass Efficiency of Light Armor on Striking Velocity of Small Caliber Projectiles. Proceedings 17th International Symposium on Ballistics, CONF, 199–206.

[12] Savio, S. G., Ramanjaneyulu, K., Madhu, V., Bhat, T. B. (2011). An experimental study on ballistic performance of boron carbide tiles. International Journal of Impact Engineering, 38 (7), 535–541. doi: https://doi.org/10.1016/j.ijimpeng.2011.01.006

[13] Franzen, R. R., Orphal, D. L., Anderson, C. E. (1997). The influence of experimental design on depth-of-penetration (DOP) test results and derived ballistic efficiencies. International Journal of Impact Engineering, 19 (8), 727–737. doi: https://doi.org/10.1016/s0734-743x(97)00010-9

[14] Madhu, V., Ramanjaneyulu, K., Balakrishna Bhat, T., Gupta, N. K. (2005). An experimental study of penetration resistance of ceramic armour subjected to projectile impact. International Journal of Impact Engineering, 32 (1-4), 337–350. doi: https://doi.org/10.1016/j.ijimpeng.2005.03.004

[15] Cullis, I. G., Lynch, N. J. (1995). Performance of model scale long rod projectiles against complex targets over the velocity range 1700–2200 M/S. International Journal of Impact Engineering, 17 (1-3), 263–274. doi: https://doi.org/10.1016/0734-743x(95)99852-i

[16] Rosenberg, Z., Dekel, E. (2001). Material similarities in long-rod penetration mechanics. International Journal of Impact Engineering, 25 (4), 361–372. doi: https://doi.org/10.1016/s0734-743x(00)00052-x

[17] Lou, J., Zhang, Y., Wang, Z., Hong, T., Zhang, X., Zhang, S. (2014). Long-rod penetration: the transition zone between rigid and hydrodynamic penetration modes. Defence Technology, 10 (2), 239–244. doi: https://doi.org/10.1016/j.dt.2014.05.007

[18] Forrestal, M. J., Warren, T. L. (2008). Penetration equations for ogive-nose rods into aluminum targets. International Journal of Impact Engineering, 35 (8), 727–730. doi: https://doi.org/10.1016/j.ijimpeng.2007.11.002

[19] Anderson Jr., C. E., Walker, J. D., Lankford, J. (1995). Investigations of the Ballistic Response of Brittle Materials. RPRT, Southwest Research Inst. San Antonio TX.

[20] Anderson, C. E., Walker, J. D., Bless, S. J., Partom, Y. (1996). On the effect for long-rod penetrators. International Journal of Impact Engineering, 18 (3), 247–264. doi: https://doi.org/10.1016/0734-743x(95)00028-9

[21] Savio, S. G., Madhu, V. (2018). Ballistic performance evaluation of ceramic tiles with respect to projectile velocity against hard steel projectile using DOP test. International Journal of Impact Engineering, 113, 161–167. doi: https://doi.org/10.1016/j.ijimpeng.2017.11.020

[22] Olsson, R. (2015). Analytical prediction of damage due to large mass impact on thin ply composites. Composites Part A: Applied Science and Manufacturing, 72, 184–191. doi: https://doi.org/10.1016/j.compositesa.2015.02.005

[23] Olsson, R. (2003). Closed Form Prediction of Peak Load and Delamination Onset under Small Mass Impact. Composite Structures, 59 (3), 341–349. doi: https://doi.org/10.1016/s0263-8223(02)00244-1

[24] Olsson, R. (2000). Mass criterion for wave controlled impact response of composite plates. Composites Part A: Applied Science and Manufacturing, 31 (8), 879–887. doi: https://doi.org/10.1016/s1359-835x(00)00020-8

[25] Olsson, R. (2010). Analytical model for delamination growth during small mass impact on plates. International Journal of Solids and Structures, 47 (21), 2884–2892. doi: https://doi.org/10.1016/j.ijsolstr.2010.06.015

[26] Boria, S., Scattina, A., Belingardi, G. (2017). Impact behavior of a fully thermoplastic composite. Composite Structures, 167, 63–75. doi: https://doi.org/10.1016/j.compstruct.2017.01.083

[27] Ambur, D., Kemmerly, H. (1998). Influence of impactor mass on the damage characteristics and failure strength of laminated composite plates. 39th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference and Exhibit. doi: https://doi.org/10.2514/6.1998-1784

[28] Anugra, B. A., Rusnaldy, R., Haryanto, I. (2014). Pengaruh Bentuk Proyektil Terhadap Ketahanan Balistik Pada Plat Baja Tipis. Jurnal Teknik Mesin, 2 (2), 52–60. Available at: https://ejournal3.undip.ac.id/index.php/jtm/article/view/5568

[29] Liang, K., Huang, Z., Zhang, J. (2017). Optimal design of the aerodynamic parameters for a supersonic two-dimensional guided artillery projectile. Defence Technology, 13 (3), 206–211. doi: https://doi.org/10.1016/j.dt.2017.05.003

[30] Ang, J. A., Konrad, C. H., Hall, C. A., Susoeff, A. R., Hawke, R. S., Sauve, G. L. et al. (1993). Hypervelocity projectile design and fabrication. IEEE Transactions on Magnetics, 29 (1), 722–727. doi: https://doi.org/10.1109/20.195665

[31] Bhure, V., Tiwari, G., Iqbal, M. A., Gupta, P. K. (2020). The Effect of Target Thickness on Ballistic Resistance of Thin Aluminium Plates. Materials Today: Proceedings, 21, 1999–2013. doi: https://doi.org/10.1016/j.matpr.2020.01.317

[32] Chen, L., Cao, M., Fang, Q. (2021). Ballistic performance of ultra-high molecular weight polyethylene laminate with different thickness. International Journal of Impact Engineering, 156, 103931. doi: https://doi.org/10.1016/j.ijimpeng.2021.103931

[33] Purwanto, H., Dzulfikar, M., Tauviqirrahman, M., Syafaat, I., Arifin, M. (2020). Residual velocity and kinetic energy of the ballistic simulations test on hardened medium carbon steel plate. Journal of Physics: Conference Series, 1517 (1), 012003. doi: https://doi.org/10.1088/1742-6596/1517/1/012003

Received date 21.05.2022
Accepted date 08.11.2022
Published date 29.11.2022

How to cite: *Purwanto, H., Tauviqirrahman, M., Sugiarto, S., Dzulfikar, M. (2022). Analysis projectile performance in ballistic tests using compressed air gun. EUREKA: Physics and Engineering, 6, 120–127. doi: https://doi.org/10.21303/2461-4262.2022.002418*