RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING VOL. 1 NO. 1
(2020) 78–84

RPMME

Homepage: http://penerbit.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Dynamic Response of AL2024 T3 Aluminium Plate Subjected to Oblique Impact of 9mm Bullet Using Single Processor

Muhammad Ammar Imran Zakaria[1], Mohd Norihan Ibrahim[1,*],

[1]Crashworthiness and Collision Research Group (Colored),
Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rpmme.2020.01.01.010
Received 04 Oct 2020; Accepted 28 Oct 2020; Available online 10 November 2020

Abstract: The design of armor as protection against weapons have started as earlier century and have been kept evolving ever since. In the modern world, the armor is essential to use as protective clothing against a direct contact weapon which mostly used in the military. The objective of this research is to evaluate the dynamic response of AL 2024 T3 aluminium target plate impacted by a small arms 9 mm bullet at different orientation angle and velocity range. In this study, the variations of impact velocity are 300 m/s, 400m/s, 500m/s and 600m/s while the orientation considered are 0°, 30° and 60°. The impact of the bullet on a plate will be evaluated by using ANSYS explicit finite element code in which 2 mm thickness of the target plate is considered as a deformable body. Upon completion of this study, various profiles failure of impact were observed and achieved. It was found that the range of impact speed and different orientations of bullet impact was significantly affecting the profile of failure of the impacted target plate. The impact velocity at the speed of 600 m/s with 30° orientations shows large deformation and penetration of impacted AL2024 T3 target plate while at the speed 600 m/s and 60° orientation indicate large deformation and deviation on the direction of post-impact motion of the bullet.

Keywords: Dynamic, 9 mm bullet, AL2024 T3, Simulation

1. Introduction

The need to personal defense against small arms and light weapons is important from both civil and military point of view [1, 2]. Aluminium plates are extensively utilized in armor systems due to their high strength to weight ratio [3]. Investigations into the protective performance of aluminium alloys were initiated in the early 1940s and the primary objective was to achieve improved protection against fragmentation by artillery shells. AL 2024 T3 aluminum alloys in particular are an alloy that is mostly used in the aerospace industry. It is a high strength alloy ideal for projects that require a high strength-to - weight ratio and excellent resistance to fatigue.

Corresponding author: norihan@uthm.edu.my

Numerical methods and analytical methods let engineers and researchers model the mechanical behavior of any material to estimate the response of the material and check its suitability for a certain application. Nowadays, a simulation program has greatly improved and plays an important role in the research area and finite element method become a significant and selected platform in realizing this analysis [4-8]. One of the areas that benefitted from this is the use of a program to simulate the behavior of impact properties since impact damage is caused by many sources, such as maintenance damage from dropped equipment, a collision between object or structure, bird strikes, bullet strikes in military application and many more. The impact made by a bullet is influenced by the bullet diameter, weight and its velocity [9].

This research is focuses in the investigation of dynamic response of AL2024 T3 aluminium plate when it is subjected to oblique impact of 9mm bullets at different orientation using single processor. The damage mechanism done by 9mm bullet and the anti-penetration performance of the AL2024 T3 aluminium plate was studied numerically using the ANSYS software. The numerical model accurately predicts the impact failure mode depending on the shape of the projectile nose, the angle of orientation and the impact velocity.

2. Materials and Methods

2.1 Bullet Ammunition

Bullet is designed with variety of concept that needs to be considered at getting a maximum speed and accuracy to the target. It will move at high speed according to the explosion mechanism [10]. High explosive can create an impact and generate the bullet with high velocity. From the bullet structure, there is no powder inside the bullet casing. The powder will explode and give the stress to the bullet after give an impact on the primer. The direction of the bullet is straight depending on the direction of the shooting. Different type of bullet nose shape will produce different contours and penetration forms on the plate.

The 9 mm bullet is one of the most popular handgun ammunitions in the world. It is known as 9 mm Parabellum or 9x19 mm cartridge as shown in Figure 1. The bullet is low cost and it is the standard caliber on worldwide. According to the Cartridge of the World 2014 edition, 9 mm is the most common and widely used military firearm cartridge in the world [11]. 9 mm ammo widely used for self-defense and target shooting and it is easy to shoot and accurate round.

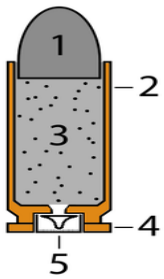


Figure 1: Configuration of 9mm bullet

2.2 Aluminium AL2024 T3 Target Plate

Aluminum is one of the most versatile and cost-effective materials for a wide variety of applications due to the special combination of properties offered by aluminum and its alloy [12, 13]. AL 2024-T3 is an alloy made of Al, Cu and Mg and is the most common high strength aluminium alloy and it is one of the best known of the high strength aluminum alloys [14]. Due to its high strength and

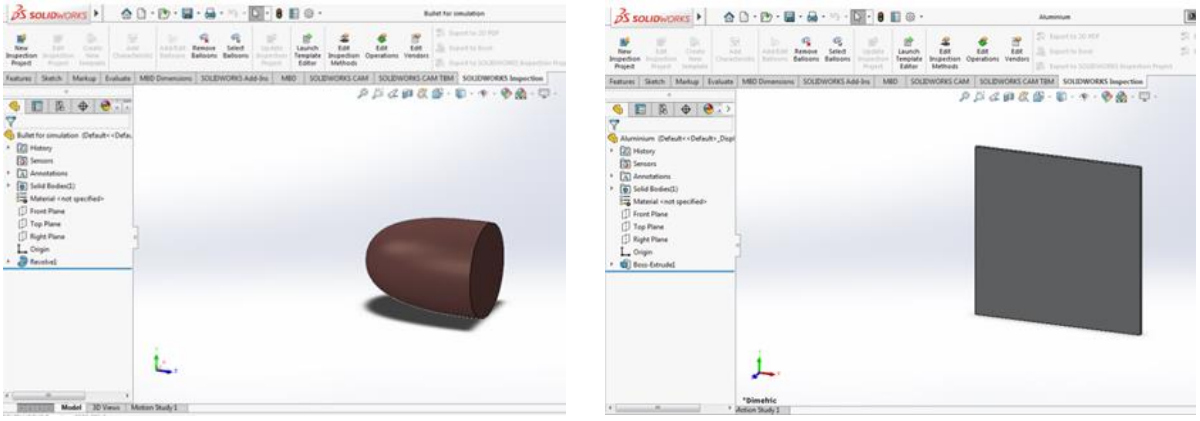
excellent fatigue resistance, it is used on structures and sections where a reasonable strength to weight ratio is required [15]. It is readily machined to a high finish and is readily formed in the annealed state and can be heat treated afterwards. Table 1 shows the material properties of AL2024 T3 aluminium plates.

Table 1: Material properties of AL2024 T3

Physical Properties	**Metric**
Density	2.78 g/cc
Mechanical Properties	
Ultimate Tensile Strength	483 MPa
Tensile Yield Strength	345 MPa
Elongation at Break	18 %
Modulus of Elasticity	73.1 GPa
Ultimate Bearing Strength	855 MPa
Bearing Yield Strength	524 MPa
Poisson's Ratio	0.33
Fatigue Strength	138 MPa
Ultimate Bearing Strength	855 MPa

2.3. Geometry Modeling and Method

The geometry model for small arms of 9mm bullet and AL2024-T3 aluminium target plate is created using Solidworks. The geometry model of 9 mm bullet is created according to the actual dimension of bullet nose shape so that it will represent and provide close result of impact behavior when interacted with target plate. The geometry model of both bullet and target plate are shown in figure 2. The dimension of Al2024 T3 plate is 100 mm x 100 mm x 2mm. Both of bullet and target plate are then assembled as shown in Figure 3 using ANSYS explicit finite element method. The bullet is position at the center of target plate and the interaction will occur between both when motion of bullet occurs at different orientation and also different velocity.



(a) **(b)**

Figure 2: Geometry model of; (a) 9mm bullet, (b) AL2024 T3 aluminium plate

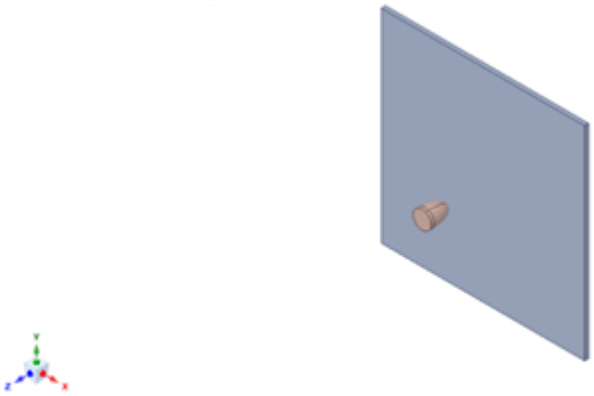


Figure 3: The assembly model of bullet and target plate

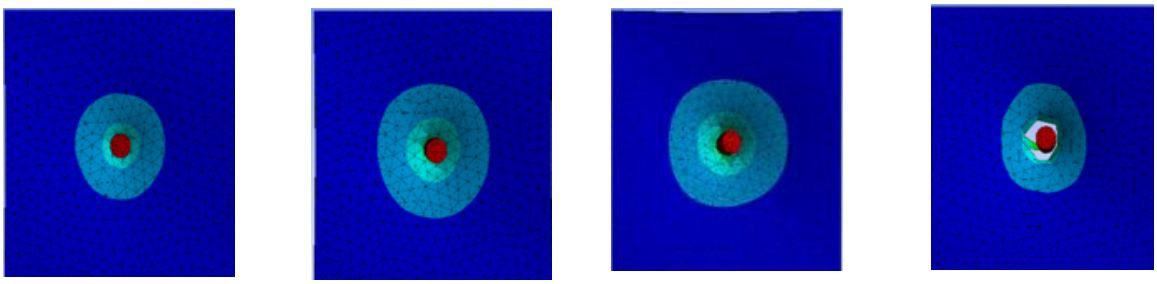
3. Results and Discussion

The dynamic responses of bullet collision when it move and interact with AL2024 T3 aluminium target plate is the main focus and criteria of the study. The simulation on the motion of bullet occurs at different impact velocity and also different orientations. The parameters involves including impact velocity, angle of impact, failure mode contour and properties of bullet and target plate.

3.1 Analysis on Velocity Impact

One of the important factors that may influence the penetration is velocity of the bullet impact. The velocity of the bullet will significantly affect the profile of perforation when it hit the target plate. Higher velocity of impact of bullet will give higher impact on the plate. The deformation on the shape of the plate is depends on the velocity impact and the contact surface between the bullet and target plate. The deformation involves crack area impact is depending on the surface radius of the bullet head and crack propagation.

The high velocity motion of bullet leads to the penetration and perforation of impacted target plate especially on the surface contact of target plate with bullet nose shape. This is because the force is increasing when the velocity is increasing. Other factor that may affect the perforation is nose shape of projectile and the angle of impact. In this study four ranges of bullet or projectile velocity were simulated by using ANSYS software. The velocity of projectile are 300 m/s, 400 m/s, 500 m/s and 600 m/s. Figure 4 shows the deformation and failure mode of AL2024 T3 aluminium plate when impacted with the small arm 9 mm bullet at various speed. It is shown that the deformation and perforation occur on the impacted region. The higher the velocity, the larger the perforated surface occurred.

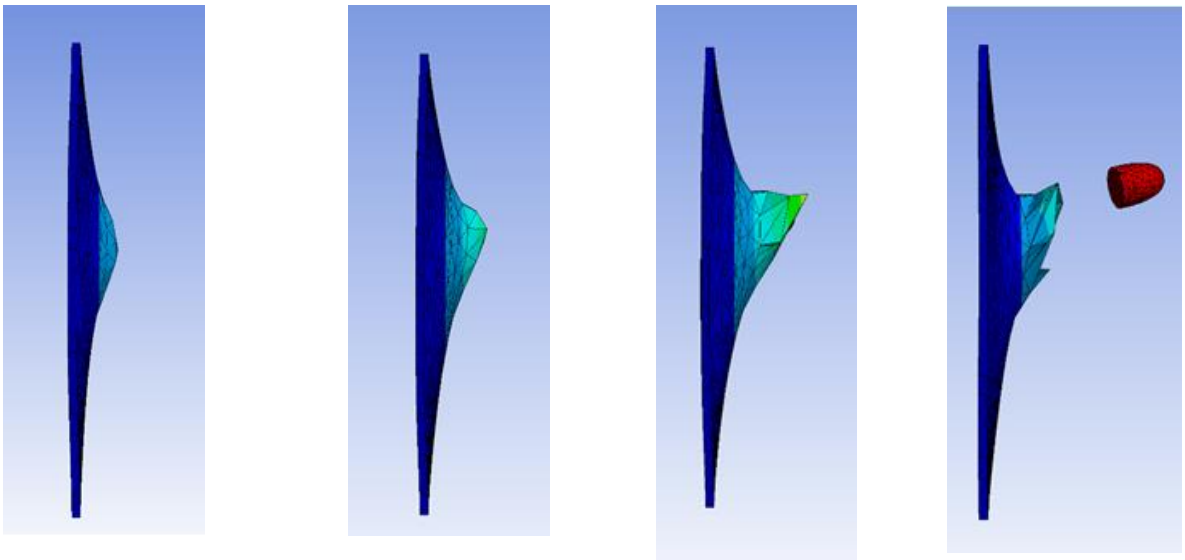


(a). 300 m/s **(b). 400 m/s** **(c). 500 m/s** **(d). 600 m/s**

Figure 4: Bullet impact and penetration of target plate at normal direction at various velocities

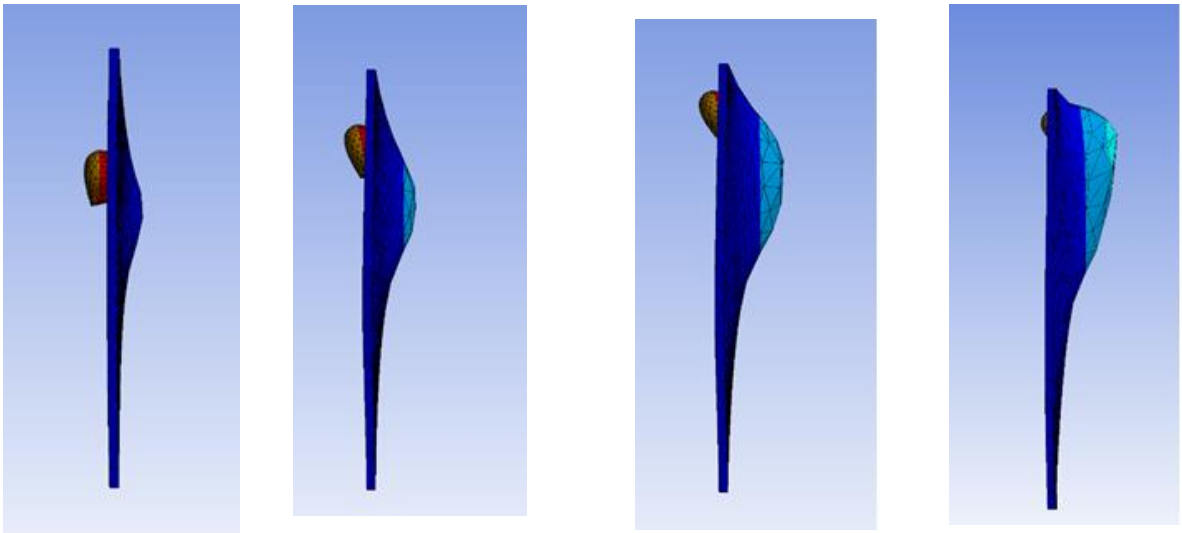
3.2 Analysis on Angle of Impact

The profile of failure on the impacted surface also affected significantly by the angle of impact. An extension of study on the dynamic response of AL2024 T3 aluminium target plate carried out based on the different orientation of projectile or bullet motion. From the simulation which has been carried out using ANSYS explicit finite element program suite, the results of impacted target plate at different angle of impact were observed. Figure 5 shows deformation and perforation of bullet travel at an angle of 30° at various ranges of impact velocities. The post penetration of bullet leads to the formation of eroded petals which is parallel to the angle of impact itself.



(a). 300 m/s **(b). 400 m/s** **(c). 500 m/s** **(d). 600 m/s**

Figure 5: Deformation and perforation of target plate by bullet travel at the angle of 30 degree.



(a). 300 m/s **(b). 400 m/s** **(c). 500 m/s** **(d). 600 m/s**

Figure 6: Deformation target plate impacted by bullet travel at the angle of 60 degree.

At an angle of 60°, the bullet impact on target plate indicates the tendency of deflection in the direction of impact as shown in Figure 6. This is agreed with the study done by Borvik et al (2011) stated that at higher oblique angles, the bullets were unable to perforate the target plate. With the increase in the angle of impact, larger deflection and deformation observed when bullet nose shape hit and touch the surface of target plate. By increasing the velocity, the deformation area of the impacted plate surface also increases .The velocity of bullet greatly affects the process of penetration in normal direction. Higher velocities of bullet will greatly increase the probability of the target plate to be penetrated and perforated.

4. Conclusion

The work presented in this paper is a study on the dynamic response of AL2024 T3 aluminium plate subjected to oblique impact of 9mm bullet using single processor. Normal and oblique impact of small arms of 9 mm bullet on 2 mm thick of AL2024 T3 aluminium plate has been studied numerically. The penetration of the 9 mm bullet on the plate is greatly influence by the angle of impact. The hemispherical shape of 9 mm bullet also affects the deformation shape of the plate.

The angle of impact is greatly affecting the deformation of target plate. When the angle if impact increases, the deformation formed on the impacted surface also increases and it is proportional with the increment of velocity as well. The higher the velocity of the bullet, the higher the chances for the bullet to penetrate on the plate.

Acknowledgement

This research was made possible by funding from Fundamental Research Grant Scheme number K195 provided by the Ministry of Higher Education, Malaysia. The authors wish to thank to the Crashworthiness and Collision Research Group (Colored), Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia that has supported on the accomplishment of research activity.

References

[1] M. K. Bhuarya, M. S. Rajput, and A. Gupta, “Finite element simulation of impact on metal plate,” Procedia Engineering., vol. 173, pp. 259–263, 2017.

[2] T. Børvik, L. Olovsson, S. Dey, and M. Langseth, “Normal and oblique impact of small arms bullets on AA6082-T4 aluminium protective plates,” International Journal of Impact Engineering, vol. 38, no. 7, pp. 577–589, 2011.

[3] S. Gürgen, “A numerical investigation on oblique projectile impact behavior of AA5083-H116 Plates,” Journal of Polytechnic., vol.22 (2), pp. 293–301, 2018.

[4] C. Pirvu, T. F. Ionescu, L. Deleanu, and S. Badea, “Simplified simulation of impact bullet-stratified pack for restraining ballistic tests,” MATEC Web Conference., vol. 112, 2017.

[5] A. R. Bhat, “Finite element modeling and dynamic impact resonse evaluation for ballistic applications,” Master of Science Thesis, University of Mumbai, p. 130, 2009.

[6] Y. Regassa,“Modeling and simulation of bullet resistant composite body armor,” Global Journal of Researches in Engineering: A Mechanical and Mechanics Engineering , vol. 16 (3), pp. 24–31, 2016.

[7] N. S. Sujith, K. Y. Chethan, M. D. Sandeep, M. S. Sanjay, S. K. Basha, and D. S. Sowmyashree, “Impact analysis of bullet on different bullet proof materials,” International Journal of Mechanical and Industrial Technology ISSN 2348-7593, vol. 3(1), pp: (303-310), 2015.

[8] P. Siriphala, T. Veeraklaew, W. Kulsirikasem, and G. Tanapornraweekit, "Validation of finite element models of bullet impact on high strength steel armors," WIT Transactions on State of the Art in Science and Engineering, vol. 75, pp. 63–71, 2014.

[9] R. C. Hibbeler, Engineering Mechanics of Dynamics, Eleventh Edition, Pearson Hall, 2007.

[10] D. E. Carlucci, Theory and design of guns and ammunition, Second Edition, CRC Press, ISBN-13 : 978-1466564374, p. 608, 2016.

[11] F. C. Barnes, "Cartridges of the World," 16th edition ,Gun Digest Books; p. 688, 2019.

[12] J. R. Davis, "Light metals and alloys-aluminium and aluminium alloys," Alloying Understand the Basics, pp. 351–416, 2001.

[13] ASTM Standard, "B209M-14: Standard specification for aluminium and aluminium alloy sheet and plate," ASTM International, pp. 1–26, 2014.

[14] R. M. Patel, "Investigating the mechanical behavior of conventionally processed high strength aluminum alloy 2024," Master of Science Thesis, University of Akron p. 105, 2018.

[15] Z. Huda, N. I. Taib, and T. Zaharinie, "Characterization of 2024-T3: An aerospace aluminium alloy," Materials Chemistry and Physics., vol. 113, no. 2–3, pp. 515–517, 2009.