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A Simulation Study of Magnesium Alloy AZ31B Behavior in High-Velocity Impact and Ballistic Limit

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Abstract: Magnesium Alloy are made of magnesium combined with different metal elements to improve the physical properties. The elements included were manganese, aluminium, zinc, silicon, copper, zirconium, and rare-earth metals. The magnesium density has been stated to be significantly 35% less than aluminium and significantly 77% less than steel. Many technologies nowadays required materials that are high strength but lightweight. Alloys based on magnesium are current interest to the military nation of the UnitedStates due to they are considered as the lightest structural metal alloys. There are fewer studies to observe the relationship between magnesium alloys and impact loading compared to several traditional materials, such as steel, under ballistic condition. The objective of this study to observe the behaviour and the mechanical properties of the Magnesium alloy AZ31B under ballistic impact test. The computational simulation using Ansys found based on the result obtained, the ballistic limit of the Magnesium alloy AZ31B when being impacted by 5.56 x 45 mm NATO projectile is 775 m/s whereas, when being impacted by the 7.62 x 39mm, the ballistic limit is 645 m/s. Hence, complete penetration can be seen on the specimen when it reached the ballistic limit stated.

Keywords: Material properties, Magnesium Alloy AZ31B, High-Velocity Impact, Ballistic Limit

Introduction

Previous works on characterization of magnesium alloy (Lynch et. al., 2020) shows that the observed properties were appropriate for applications that related with ballistic. Magnesium Alloy AZ31B is a wrought magnesium alloy. It has good strength, ductility, corrosion resistance and weldability at room temperature (Lucien, Mareny and Sebastian, 2018). Alloys based on magnesium are current interest to the military nation of the United States due to they are considered as the lightest structural metal alloys. There are fewer studies to observe the relationship between magnesium alloys and impact loading compared to several traditional materials, such as steel, under ballistic condition. Penetration occurs starting from the initial impact phase and fracture initiation phase (Rosenberg and Dekel, 2020).

A numerical study on high velocity impact behaviour of titanium based fiber metal laminates had been performed by Gin et al. (2018). Additional study by Sohrab (2010) shows using high-performance composite materials and using geometrically efficient designs such as the sandwich definition are two effective ways to minimize the structural weight of a structure. The study began with experimental study which they set up a specimen clamps, high-speed camera, laser velocimeter and gas gun for the test. Titanium-based fiber metal laminates (TFML) specimens TFML 2/1 and TFML 3/2 have been clamped around their edges between two circular opening steel plates. The circular target area that exposed was 76 mm in diameter. The gas gun targeting the samples at the center at standard incidence was launched with a 7g steel sphere with a diameter of 12 mm. The lowest impact velocity required for complete penetration which is the ballistic velocity limit was found for each TFML sample at different projectile velocities. The mechanics paper of the ordinary and oblique penetration of conical projectiles through metallic targets of multi layers introduces the analytical models by G.H et al. (2015). Table 1 shows the impact velocity and corresponding residual velocity magnitude.

Table 1 Impact velocity and corresponding residual velocity magnitude (Gin et. al., 2018)

Sample	V_i (m/s)	V_r (m/s)		Dimensionless Parameters			
				α		β	
		EXP	NUM	EXP	NUM	EXP	NUM
TFML-2/1	130	−36.8	66.91	1.008	0.978	2.255	1.725
	154	29	101.8				
	203	155.6	162.6				
	234	195.5	197				
	310	282.3	276.5				
	397	376.9	362.5				
TFML-3/2	154	−31.3	58.27	0.986	0.920	2.190	1.932
	198	0	123.2				
	260	180	198.9				
	312	246	254.4				
	403	357.8	345.1				

Then, the data input from the ballistic impact test by the experiment had been used in a simulation which was ABAQUS/Explicit, the commercial explicit finite element network. The numerical studies were mainly to establish a model simulating the failure modes obtained from the experiment and to determine the hybrid TFML target's dynamic behaviour in detail. In two non-interactive constitutive material models, the damaged and undamaged reaction of metal and fiber reinforced composite layers was simulated. Two panel configurations of 1.85 mm thick 2/1 and 3.2 mm thick 3/2 targets were impacted with speeds ranging from 90 m/s to 400 m/s. TFML laminate has been captured by specifying an acceptable independent fundamental material model for the titanium layer and the plain weave carbon fiber reinforced polymer (CFRP) layer. Figure 1 shows the energy absorption by the TFML panels at different impact energy for TFML-2/1 and TFML-3/2. The objective of this study to observe the behavior and the mechanical properties of the Magnesium alloy AZ31B under ballistic impact test. Due to its impact behavior, the Magnesium Alloy AZ31B was a possible material to substitute RHA on the armor vehicle.

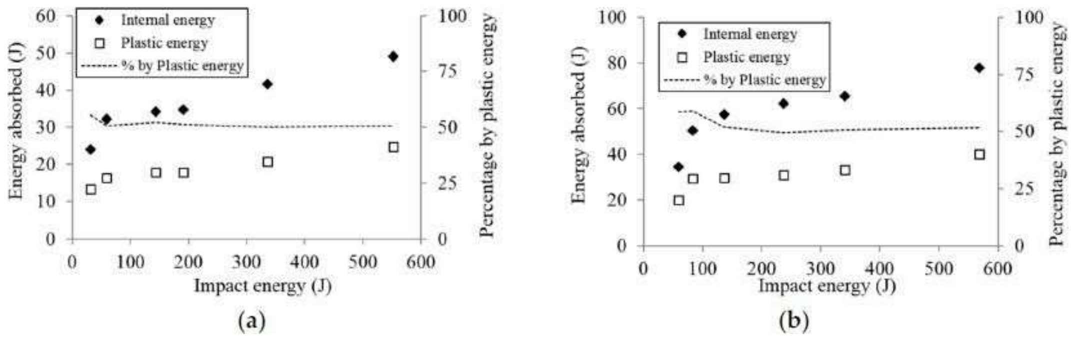

Figure 1 Energy absorption by the TFML panels at different impact energy. (a) TFML-2/1; (b) TFML-3/2 [13]

Methodology

For effect modelling simulation, this model is widely used (Škrlec and Klemenc, 2016). which is suitable for this project rather than use the Cowper-Symonds (CS) material model. If they do not affect the material behaviour, the influence of thermal could be neglected from the John-Cook (JC) material models. In conducting explicit dynamic simulations up to medium strain rates, the CS and JC models are the most widely used material models (i.e., up to $\dot{\varepsilon}$ = 104) based on Kurtaran, Buyuk & Eskandarian (2003) and Schwer, Hacker & Poe (2006). Based on Schwer, L.E., Hacker, K., Poe, K. (2006) there is no major effect of the thermal changes due to …... Thus, the methodology of this study needs computational simulation, which is Ansys software to conduct modelling of the specimen. Subsequently, the ballistic impact test on the specimen is set up in the simulation software. In order to determine the ballistic limit, the depth of penetration, the energy of the Magnesium alloy AZ31B and the maximum stresses exerted on the specimen, the 5.56 x 45 mm NATO and 7.62 x 39 mm have been used as the projectiles. Table 2 shows the composition percentage element of AZ31B at ASTM standard B90. Table 3 shows the magnesium alloy AZ31B properties from the data sheet in AZO Materials.

Table 2 The composition percentage element of AZ31B (ASTM standard B90)

	Composition %									
	Al	Mn	Zn	Ca	Cu	Fe	Ni	Si	Each	Mg
AZ31B	2.5-3.5	0.2-1.0	0.6-1.4	0.04	0.05	0.005	0.005	0.10	0.3	Balance

Table 3 The Magnesium Alloy AZ31B (UNS M11311) properties from the data sheet in (AZO Materials website)

Properties	Metric
Thermal Conductivity	9.6 W/(m.K)
Specific Heat	1 J/(g.˚C)
Thermal Expansion Coefficient	26 µm/(m.˚C)

Young's Modulus	45 GPa
Poisson's Ratio	0.35
Shear Modulus	17000.001 MPa
Density	1.77 g/cm^3
Yield Strength	230 MPa
Tensile Strength	260 MPa

Due to its impact behaviour, the Magnesium Alloy AZ31B was a possible material to substitute RHA on the armour vehicle. The objective of this project is to study of Magnesium Alloy AZ31B behaviour in term of high velocity impact and ballistic limit using simulation. In this project, the ballistic limit of the Magnesium Alloy AZ31B will be evaluated. The depth of penetration of Magnesium alloy AZ31B sample plate will be measured and observed.

The simulations have been done with two different projectiles to impact the specimen. The velocities of the projectiles were 755 to 775 m/s for the 5.56 x 45 mm NATO projectile while 625 to 645 m/s were for the 7.62 x 39 mm projectile. The material properties, the dimension of the specimen and the velocities of the projectiles were included in the simulation. Then, the ballistic impact simulations were conducted in the Ansys software. The results then being recorded and discussed. Figure 2 shows the mesh model of 5.56 x 45 mm NATO projectile and Magnesium Alloy AZ31B plate with element size of 0.0025 m. The velocities of the 5.56 x 45 mm NATO for the ballistic impact simulation testing are 755 to 775 m/s. The velocities have been taken based on the previous study the magnesium alloy AZ31B ballistic impact test by using the 5.56 x 45 mm NATO projectile. Figure 3 shows the mesh model of 7.62 x 39 mm projectile and Magnesium Alloy AZ31B plate with element size of 0.0025 m.

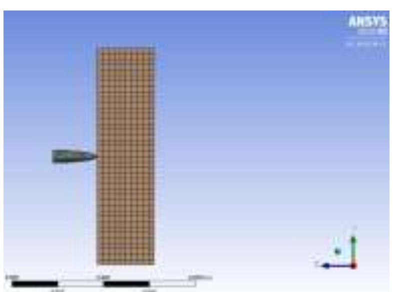

Figure 2 Mesh model of 5.56 x 45 mm NATO projectile and Magnesium Alloy AZ31B plate with element size of 0.0025 m

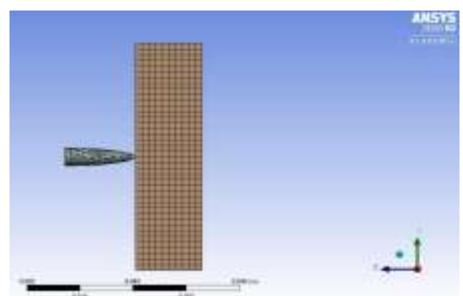

Figure 3 Mesh model of 7.62 x 39 mm projectile and Magnesium Alloy AZ31B plate with element size of 0.0025 m

While the velocities of the 7.62 x 39mm for the ballistic simulation testing are 625 to 645 m/s. The velocities have taken based on the ballistic performance tested by the Armed Forces of the Russian Federation. The mesh sizes for both setups are 0.0025 m. The mesh sizes have been taken by considering the limitation of hardware used to simulate.

Results and Discussion

Figure 4.1 shows the effect of ballistics impact on the Magnesium Alloy AZ31B sample plate on Ansys simulation software when being impacted by the 5.56 x 45 mm NATO projectile at 755 m/s while Figure 4.2 shows the effect of ballistics impact on the Magnesium Alloy AZ31B sample plate at 760 m/s. Figure 4.3 shows the effect of ballistics impact on the Magnesium Alloy AZ31B sample plate at 765 m/s. Figure 4.4 shows the effect of ballistics impact on the Magnesium Alloy AZ31B sample plate at 770 m/s and Figure 4.5 shows the effect of ballistics impact on the Magnesium Alloy AZ31B sample plate at 775 m/s. It shows that no complete penetration was observed on the sample plate at the projectile speed of 755 m/s, 760 m/s, 765 m/s and 770 m/s. fully penetration has been noticed on the sample plate at the projectile speed of 775 m/s. As shown in Table 4 and Figure 4.6 the depth of penetration of Magnesium Alloy AZ31B sample plate increase when the speeds of 5.56 x 45mm and 7.62 x 39 mm NATO projectile increase while at 760 m/s and 765 m/s show similar depth of penetration due to the plate managed to absorb and disperse impact energy equally.

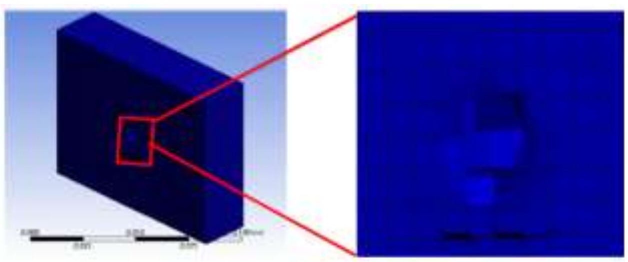

Figure 4.1 The Magnesium Alloy AZ31B sample plate after being impacted by 5.56 x 45 mm NATO projectile at 755 m/s

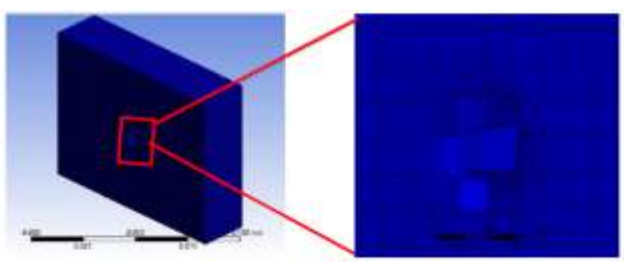

Figure 4.2 The Magnesium Alloy AZ31B sample plate after being impacted by 5.56 x 45 mm NATO projectile at 760 m/s

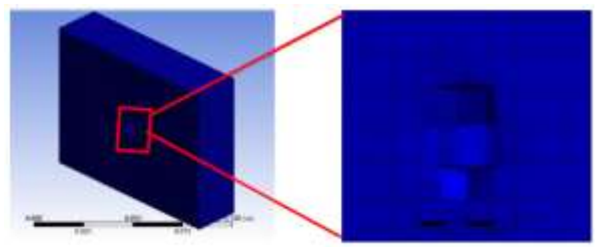

Figure 4.3 The Magnesium Alloy AZ31B sample plate after being impacted by 5.56 x 45 mm NATO projectile at 765 m/s

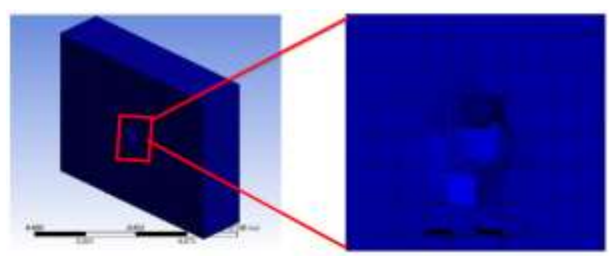

Figure 4.4 The Magnesium Alloy AZ31B sample plate after being impacted by 5.56 x 45 mm NATO projectile at 770 m/s

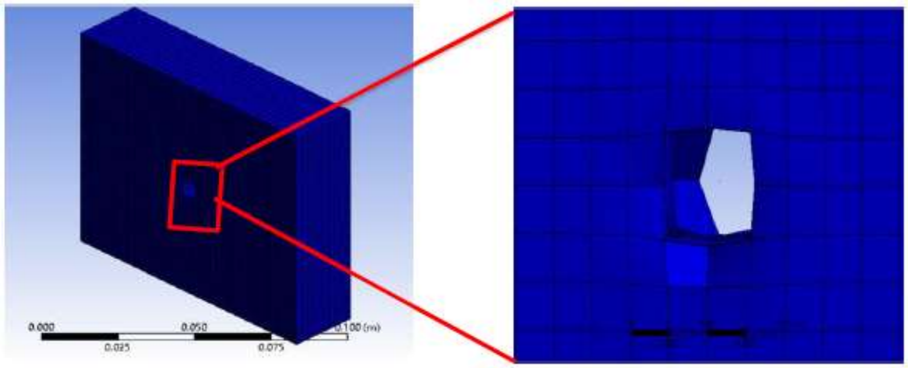

Figure 4.5 The Magnesium Alloy AZ31B sample plate after being impacted by 5.56 x 45 mm NATO projectile at 775 m/s

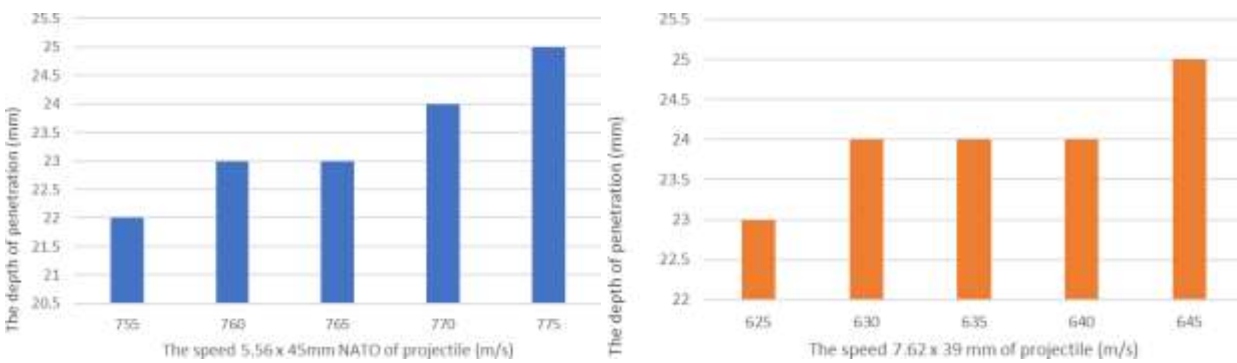

Figure 4.6 The bar graph of the depth of penetration of Magnesium alloy AZ31B sample plate (mm) at different 5.56 x 45 mm and 7.62 x 39 mm NATO projectile speeds (m/s)

Table 4 Depth of penetration of Magnesium Alloy AZ31B sample plate after being impacted by 5.56 x 45 mm NATO projectile at different speeds

Speeds of 5.56 x 45 mm NATO projectile, (m/s)	Depth of penetration of Magnesium alloy AZ31B sample plate, (mm)
755	22
760	23
765	23
770	24
775	25

Table 5 Depth of penetration of Magnesium Alloy AZ31B sample plate after being impacted by 7.62 x 39 mm projectile at different speeds

Speeds of 7.62 x 39 mm projectile (m/s)	Depth of penetration of Magnesium alloy AZ31B sample plate (mm)
625	23
630	24
635	24
640	24
645	25

Conclusion

Based on the response obtained from the simulation, it can be concluded that the complete penetration of Magnesium Alloy AZ31B sample plate was at lower speed when being impacted by the 7.62 x 39 mm projectile than when being impacted by the 5.56 x 45 mm NATO projectile. The depth of penetration of Magnesium Alloy AZ31B sample plate increase when the speeds of the projectiles increase.

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