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Study on Dynamics Characteristics of Multilayer Plates Impacted by Hemispherical Projectile

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Abstract: The multilayer plate is normally used in many applications as a form of protection and also to enhance the strength and capability of any structure in automotive, aerospace and military industry. The study conducted is related to effect on the interaction and collision of projectile towards multilayer target plate at normal impact. Numerical study has been carried out by using ANSYS explicit finite element method. The analysis is focused on the failure mode and deformation of the multilayer target plate. The preliminary contact and the post perforation of multilayer target plate were observed and the contour mode of failure was identified. The kinematic motion of projectile toward multi layers target plates occur at different range of impact velocity of 300 m/s up to 700 m/s. The multilayer target plate involved in this study is AL2024 T4 and Steel 1006 respectively. The numerical simulation on the deformation and failure mode of both types of material were observed. From the result obtained, Steel 1006 was more effective to reduce the impact from the projectile compare to AL 2024 T4 because Von-Mises stress of Steel 1006 can withstand up to 1.2126e+9 Pa while AL2024 T4 is 8.103e+8 Pa.

Keywords: ANSYS, AL2024 T4, Steel 1006,Von-Mises, Multilayer Plate

1. Introduction

Plate that consists of two or three material is considered as multilayer plate than is used to form a solid structure. Various industry has been used the multilayer plate as form of protection. For example, in military industry, the multilayer plate is used to incorporate lightweight and strong material that enable the user to move freely without much resistance. Besides that, industry such as aerospace and automotive also have been used the multilayer plate for specific reason which is the selection of material for multilayer plate must be light but tough enough to withstand the pressure. In aerospace industry, parameter such as thickness and number of layers of the plate will give difference in ballistic resistance between multilayer plate and single plate where multilayer plate with right material provides more protection compare to single plate[1].

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Failure of a multilayer plate can be caused by a several of factors. The depth of penetration that can occur on a multilayer plate is determined by the projectile's velocity and shape. The velocity will affect not only penetration but also the shape and size of holes that are penetrated, as well as crack propagation from the multilayer plate's failure mode[2].

The majority of researchers working on multilayer plates will conduct experiments that include ballistic testing. A ballistic test is a common method of determining a product's safety in terms of protection, safety, and performance. The Finite Element Method (FEM), which can calculate complex material properties, is a computer method that can be used.. There are a lot of simulation software such as MATLAB, ABAQUS, SIMSCALE, SIMULINK, ANYLOGIC, and ANSYS

Table 1: Parameter of projectile and multilayer plate

Type	Description
Bullet / Projectile	The shape of nozzle: Hemispherical Diameter :10mm Length: 35mm Classification: Rigid Body
Multilayer Plate	Dimension: 4mm x 100mm x 100mm Type: Steel 1006 Type: AL2024 T4 Type: Brass Classification: Deformable body

2. Materials and Methods

The main objective of this work is to determine on the deformation and failure mode of model when the subjected to impact at a different range of impact velocity as well as to compare the different type of material used in multilayer plate that are impacted by rigid projectile. In order to accomplish this objective, the multilayers plate of two different material which is Steel 1006 and Al 2024 T4 were analyzed using a ANSYS software.

2.1 Methods

Materials that are impacted by projectile will yield different results based on the selected material because different material have different properties. The multilayer plate from different materials have been used for body armour in military industry for quite some time. There are two categories in body armour which is hard and soft body armour. The hard body armour consists of material such as metal, composite and fibre based composite plate while the soft body armour mainly is made from durable fabrics[3]. Metallic, ceramic and composite materials can be classified into three main groups. Among this three main group, material which have composite possess a high specific strength and specific stiffness. In automotive industry, high stiffness and light weight plate are being used widely[4].

2.2 Material

The projectile will be considered as rigid body and the projectile should be stronger than the impacted plate. There are several parameters that need to be highlight for the material of the projectile such as strains, rate of high strain and temperature[5]. A reactive projectile material has the ability of metal like penetration performance. It is made by two process namely pressing and sintering between the powder and polymer. Therefore, the penetration of the projectile with enough velocity will give more structural damage to the target[6]. It is common for the personal armour designer to use several layers of dry fabrics. Fabric is suitable for soft body armour because it is lighter and more flexible compare to other material such as metal, or ceramic. In contrast, hard body armour will restrict the movement of the user because the material that was used is metal or ceramic which is quite heavy[7]. Aluminium alloys, high strength steels, and titanium alloys are mainly used as armour in metallic materials group because these material have a combination of high toughness, high strength, good weldability and good ballistic performance[8].

Table 2: Material Properties of Al 2024 T4

Density	2.78 g/cc
Ultimate Tensile Strength	463 MPa
Tensile Yield Strength	324 MPa
Elongation at Break	16 %
Modulus of Elasticity	73.1 GPa
Shear Modulus	27 GPa
Shear Strength	290 MPa
Poisson's Ratio	0.33
Fatigue Strength	138 MPa

Table 3: Material properties of Steel 1006

Density	7.872 g/cc
Ultimate Tensile Strength	330 MPa
Tensile Yield Strength	285 MPa
Elongation at Break	20 %
Modulus of Elasticity	210 GPa
Shear Modulus	80 GPa
Shear Strength	300 MPa
Poisson's Ratio	0.29
Fatigue Strength	270 MPa

2.3 Finite Element

The projectile has the diameter of 10 mm. The parameter of each square shape of multilayer plate plate is 100 mm x 100 mm x 4 mm. Both projectiles and multilayer plates is modelled using ANSYS software. The multilayer plates are constrained around the edges and subjected to impact by a projectile with 10 mm diameter at different ranges velocities

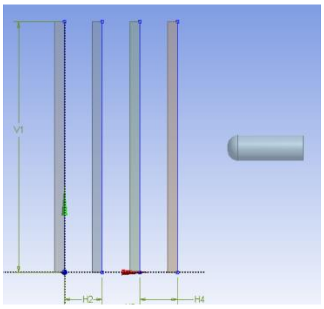


Figure 1: Finite element model of projectile and multilayer plate

Finite Element Analysis (FEA) is a computer method used to analyse engineering structures. FEA is used in many different fields of engineering, such as solid mechanics, heat transfer thermodynamics, fluid dynamics (fluid flow), electrostatics and others[9]. This technique is useful for solving a problem that has complex geometries, loading and material properties where it is impossible to determine the analytical solution. However, when the plate is meshed into many pieces where each pieces represent an element, the degrees of freedom should be well defined [10].

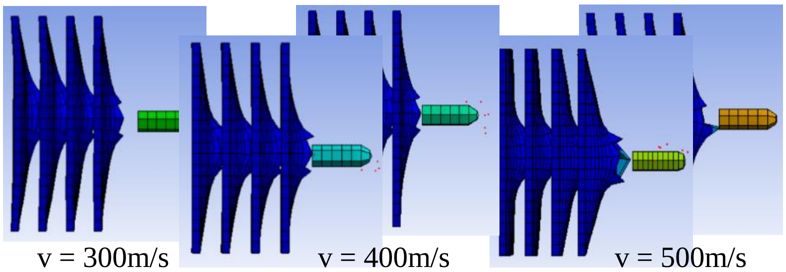
3. Result and Discussion

3.1 Analysis of Result

The results of the study are presented and discussed regarding the objective of the study, which was to analyze the deformation and failure of material when the subject (multilayer plate) impacted at a different range of velocity(projectile). The effects of the bullets penetrating the multilayer plate and the results of the bullets penetrating the multilayer plate have been studied in depth. The simulation ANSYS software displays the results. The results are shown by s ANSYS software.

3.2 Analysis on Petalling

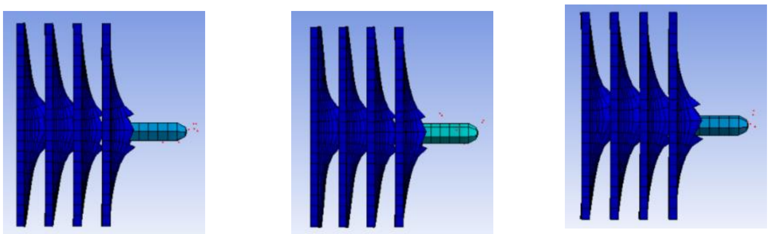
The petallings process will begin when the bullets hit the first layer of multilayer plate and fully penetrate the multilayer plate. The shape of the petals is different depends on the type of material used and the velocity of the bullet.



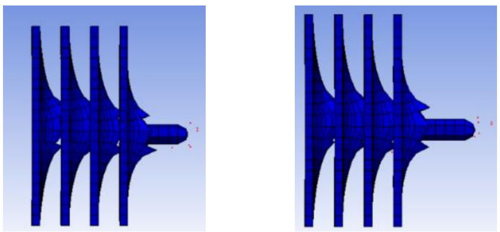
v = 300m/s v = 400m/s v = 500m/s

v = 600m/s v = 700m/s

Figure 2: Penetration at different velocities of Al 2024 T4



v = 300m/s v = 400m/s v = 500m/s



v = 600m/s v = 700m/s

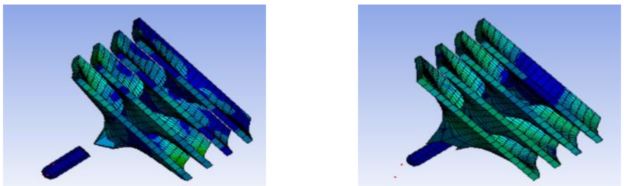
Figure 3: Penetration at different velocities of Steel 1006

From all figures above, every single plate has different petals is due to the higher the velocity, the more impact on the multilayer plate is generated. The first plate, as opposed to the second, third, and fourth plates has slightly larger petals. The reason for this is that when the bullet passes through the first plate, it loses velocity. In conclusion, the amount of impact that occurs decreases from plate to plate thus the size of petals becomes smaller.

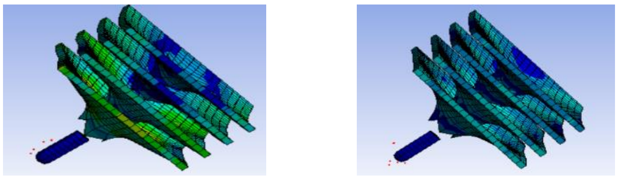
3.3 Analysis on Velocity

The momentum of projectile penetrating the multilayer plate may provide a significant deformation on the impacted target plate. When the projectile's velocity increase, the momentum produced during the impact with the multilayer plate will also increase. Thus, a higher velocity may contribute to the increase in size of the hole in the multilayer plate after it has penetrated the target plate

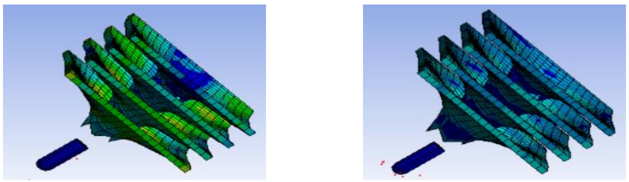
Al 2024 T4 Steel 1006



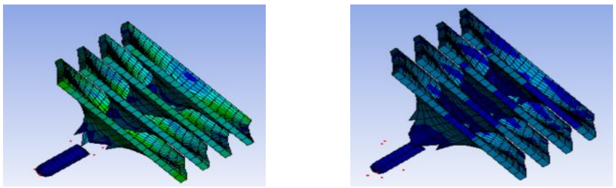
Failure mode at 300m/s



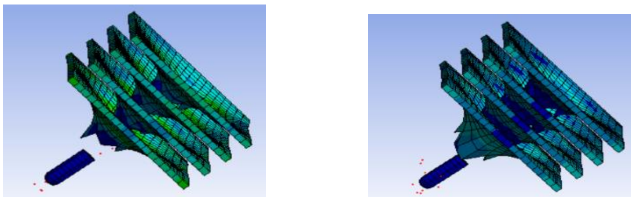
Failure mode at 400m/s



Failure mode at 500m/s



Failure mode at 600m/s



Failure mode at 700m/s

Figure 4: Penetration at different velocities for both materials

The comparison from two different materials of the failure mode of the model impacted by non-zero angle projectile motion by hemispherical bullet shape. The petallings can be seen clearly and there is crack propagation on the surface area of the collision due to expansion of the circumference deformation.

The formation of the plug is because of the large contact area of collision and high impact force that was generated by the bullet. The high impact velocity which is 700 m/s shown that there is an increase in crack propagation on the surface area due to high collision for both types of material. The petallings also increase for both material and the others effect is the enlargement of the penetration hole.

This entire phenomenon is because of the force that applies on the multilayer plate increase thus the impact velocity will increase too as the force that applies is directly proportional to velocity $F = \frac{mv}{t}$.

The effect of velocity toward the failure of the multilayer plate can be observed by using a different range of velocity. The size of the crack will increase as the velocity increase. These phenomena are due to the increase of strain on the early crack, also the increase in kinetic energy that was distributed to the multilayer plate. The cracks are bigger in high velocity.

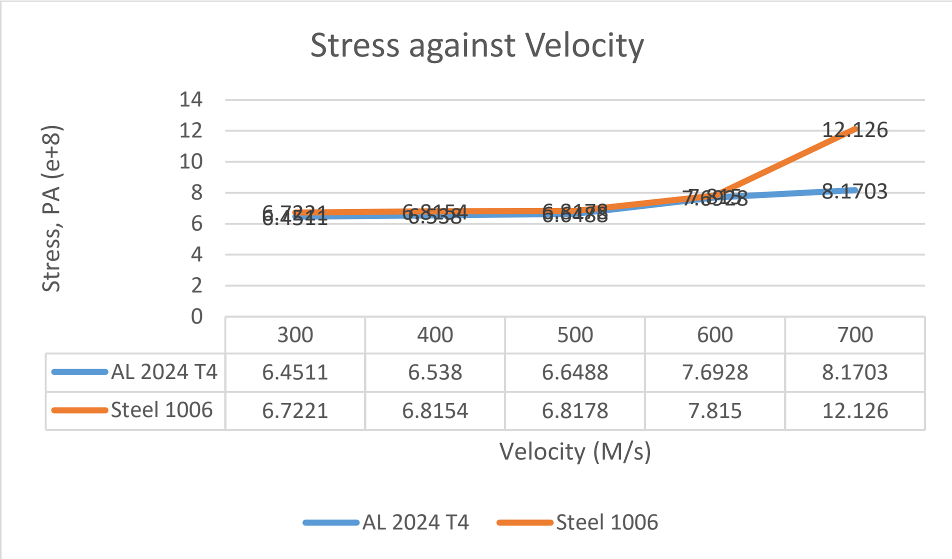


Figure 5: Graph of Stress against different velocities

Equivalent (von – Mises) stress during the impact can be seen from the graphs shown in Figures 5. The equivalent stress showed the material behaviour when energy or force is applied whether the material will yield or not. The Steel 1006 has about 4 times more strength than AL 2024 T4 and has more density.

3.4 Analysis on Penetration

The velocity of the projectile, direction of projectile and the material of the multilayer plate will affect the penetration. Higher velocity will produce higher impulsive force to the target plates and the deformation of the multilayer plates are affected by the velocity and the contact area of collision between the plates and the bullet.

The effect of impact velocity toward the size of the penetration hole is shown in Figures 5 and 6. This figure shows the penetration of the bullet towards the multilayer target plate, the collision surface, and the different sizes of penetration holes according to velocity

The failure mode that has been obtained for the multilayer target plate impacted by projectile motion has different crack propagation, petallings shape, and size of penetration hole. The crack propagation will increase when the impact velocity increases also the petallings shape and also the size of the penetration hole.

The size of penetration from Al 2024 T4 is larger compare to Steel 1006. This is because the microstructure of the material which include the phase composition of the material which can provide more resistant to penetration that will lead to better performance of material when impacted by projectile.

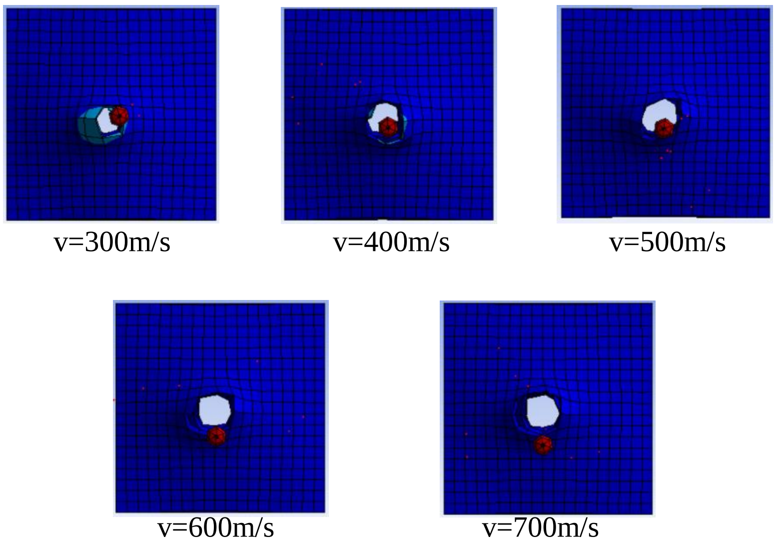


Figure 6: Complete penetration of AL 2024 T4

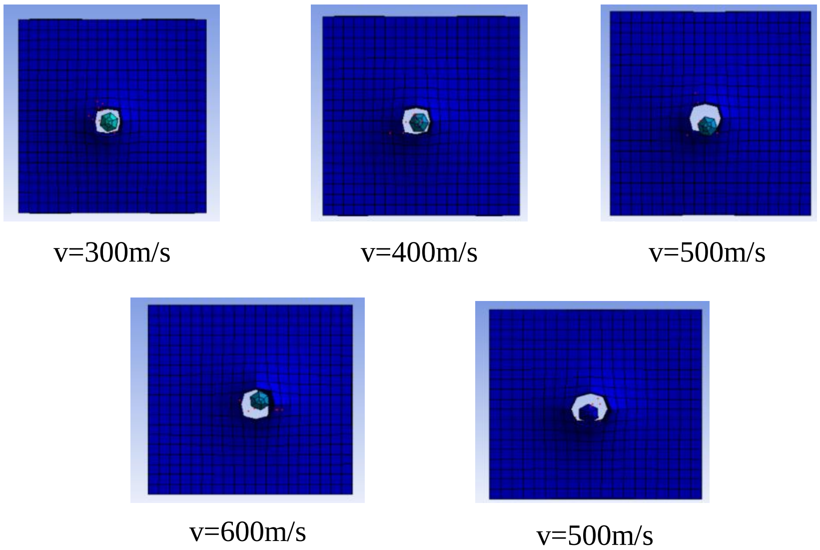


Figure 7: Complete penetration of Steel 1006

4. Conclusion

Observation of the study shows that the failure mode and deformation of steel 1006 and Al 2024 T4 are affected by the range of velocity. This simulation was run by ANSYS software. This software creates a condition that similar to real life application and generates a result as a numbering value, so that's the analysis and the result can be seen more clearly and approximately beside the software is user friendly. The multilayer target plates were impacted by projectile with five ranges of velocity which is 300m/s, 400m/s, 500m/s, 600m/s and 700m/s respectively. Based on the range of the velocity, geometry of the model, petallings process, and Von-Mises stress.

From the analysis on penetration the size of penetration of bullet on Al2024 T4 is larger than Steel 1006. This is due to the mechanical properties of the material. From the different range of the velocity, the analysis on the petalling process can be concludes. The petallings of the geometry will increase when the velocity increase. Increasing the velocity will also make the penetration hole become larger. For the conclusion, the geometry model will have bigger deformation and high failure mode as the velocity increase.

Lastly, there is the different in Von-Mises stress values on the material. The highest stress value in the geometry model of Steel 1006 is greater compare to Al 2024 T4. For example, at the velocity of 700m/s, Steel 1006 can withstand up to 1.2126e+9 Pa while Al 2024 T4 can only withstand at value of 8.1703e+8 Pa.

Acknowledgement

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