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Investigation on Dynamics Characteristic of Multilayer Steel Plate Impacted by Projectile

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Abstract: The paper describes a work focused on the process of perforation of multilayer advanced high strength steel (AHSS). A numerical investigation has been carried out to analyze in details the perforation process subjected to normal impact by different nose shapes of projectiles. The perforation process has been simulated by the application of 3D analysis using IMPACT dynamic FE program suite. The comparison on failure modes depending on the projectile nose shape have been studied and evaluated. An appropriate constitutive relation was applied to describe the material behaviour of the multilayer target plate. The study covered different failure modes of perforated advanced high strength steel (AHSS) sheet according to different level of impact velocity ranging from 22 m/s to 78 m/s. The blunt projectile impact towards multilayer target plate leads to generation of plug formation and fragmentation while hemispherical projectile impact shows almost similar petals formation between first, second and third layer.

Keywords: AHSS, IMPACT dynamic FE program, 3D analysis

1. Introduction

The effect of local impact and global structural response may be involved in the perforation of a ductile plate subjected to the strike of a non-deformable projectile. The response of materials under dynamic loading has a considerable interest especially involving the perforation and penetration resulting from the impact of non-deformable projectiles and metallic plate. The deformation and the damage development in the target are relevant phenomena which should be considered when assessing the performance of aluminium sheets against impact loading. Many publications can be found in the international literature dealing with high strain rate and crack behaviour of metallic materials related to different engineering applications [1,2,3,4,5,6].

The deformation and the damage development in the target are relevant phenomena which should be considered when assessing the performance of multilayer advanced high strength steel against impact loading. The perforation is dominated by the local penetration although the failure mechanism of the final perforation also influences the ballistic limit of a thick target, which depends on the target material, target dimensions, projectile nose and impact velocity. The numerical results show a good correlation with the published experimental results and the study demonstrates that the material model is able to emulate failure characteristics of the steel and aluminium plates as observed in various

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experimental observations. An analytical perforation model based on the cylindrical cavity expansion has been reformulated and used to calculate the ballistic perforation of resistance of the multilayer advanced high strength steel plate. The target material was modelled with the modified Johnson and Cook constitutive relation using constant strain 2D axisymmetric elements and adaptive rezoning. The physical behaviour of the target during perforation is well captured in the FE simulations when the model is used [7].

Three-dimensional numerical simulation using ABAQUS/ Explicit finite element code was carried out to study the effect of projectile nose shape on the ballistic resistance of ductile target by Iqbal et al. [8]. The 5mm thick AHS steel targets were impacted by 10 mm diameter of blunt and hemispherical nosed projectiles. The projectiles with blunt-nosed failed the target through shear plugging, imparting significant but more localized plastic deformation. The projectiles with hemispherical nosed caused stretching and thinning of target material resulting in huge local and global deformation. Further movement of projectile caused formation of irregular petals. Iqbal et al. [9] also performed experimental and numerical simulation to study the failure modes and ballistic resistance of multilayer steel targets subjected to normal impact of nosed projectiles such as hemispherical and blunt. The ABAQUS/Explicit finite element code was carried out to perform numerical simulation. The blunt bullet nose shape projectile failed the target through plug formation. Based on the experimental investigation, four-stage models developed for the perforation of stiffened plate [10]. The four stages in the model are plug formation, dishing formation, petal formation and projectile exit.

In this investigation, the analysis of process requires the following assumptions: (a) the amount of energy absorbed by the projectile is neglected, (b) the projectile move with the same velocity after the initiation of perforation, (c) the strain rate effect of the material is considered. It is still a challenge to obtain a general structural model of perforation analysis, which incorporates the local failure analysis in the rigid-plastic model because the different local response and failure modes, such as dishing, petalling or penetration, may appear for different plate thicknesses and impact velocity. The perforation capabilities of projectile against constraints plates were explored for efficient damage and failure modes.

Table1 - Parameter of projectile and target plate

Type	Description
Bullet / Projectile	Nose Shape: Hemispherical and Blunt Diameter :10mm Length: 45mm Mass: 3.56 gram Classification: Rigid Body
Target Plate	Dimension: 100mm x 100mm x 5mm Types: AHSS Tensile Strength: 550 MPa Classification: Deformable body

2. Materials and methods

All 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 analyse on failure mode of geometry model when subjected to normal direction of impact. In order to accomplish this objective, the multilayers of advanced high strength steel were analyzed using a simulation of IMPACT and GiD software by finite element method. The related material and method are addressed in the following subsections.

2.1. Materials

The multilayer metal plate has been utilized as defensive layers for a long stretch in the past and its application as hostile to the entrance of materials and structures is continuously expanding and persistently used in car, aviation and military application [11]. One of the metals which prominently used in automotive industry is advance high strength steel (AHHS). The automotive manufacturers are continuously increasing the use of high strength steel in order to comply with the safety norms of different geographic region and also to reduce the weight of the car to make it more fuel-efficient [12]. The Advanced High Strength Steel (AHSS) for the car business highlights both high quality for part thickness diminishment and improved formability for creative new part outlines. This blend of properties can give vehicle weight decrease while looking after firmness, ride quality and wellbeing.

2.2. Mechanical properties

Mechanical properties of steel are a characteristic of steel such as toughness, hardness, strength and others. Steel has been chosen to its application is by determining the material properties. For example in the automotive industry they prefer lightweight steel with high steel, high stiffness and high formability [13]. This work presents the results of numerical investigation undertaken to study the perforation process of square shape of multilayer target plate when subjected to the impact by different projectile nose shape at different velocity. Table 1 shows the description of geometry model for projectile and target plate while Table 2 represents the material properties of target plate.

Table 2 - Material properties of the target plate

Type of material	: Advanced high strength steel
Properties of material	: Elastoplastic
Young modulus	: 600 GPa
Poison ration	: 0.3
Mass density	: 0.0000078 kg/m^3
Thickness of plate	: 5mm
Integration point	: 5
Yield stress,	: 0.180 GPa
Hardening factor	: 0.1
Contact type	: Basic
Contact factor	: 10
Contact friction	: 0.25
Type of failure	: Failure strain, f = 0.5

2.3. Finite element model

The projectile has the diameter of 10 mm for all types of nose shape. The parameter of each square shape of target plate is 100 mm x 100 mm x 5 mm. Both projectiles and target plates is modelled using finite element pre-processor GiD with IMPACT interface module. The plates is constrained around the edges and subjected to impact by a projectile with 10 mm diameter with two different nose shapes at different velocities. The projectile is modelled as contact triangle (CT) elements. Both the target plates and the projectiles are modelled in full so as to be able to simulate the failure mode in target plate from the point of impact towards the constraints edge and back. A 3D finite element model for the simulation of the penetration process was developed in IMPACT explicit finite element program suite as shown in Figure 1.

(a) **(b)**

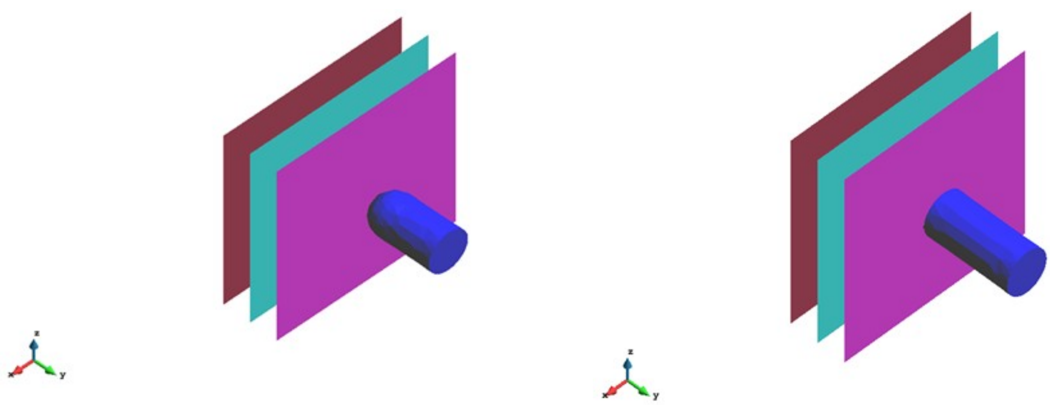


Fig. 1 - Finite element model of projectile and multilayer target plate
(a) Hemispherical nose shape (b) Blunt nose shape

The ability of the application programs in dealing with contact algorithms provide a powerful platform to simulate several types of armour target subjected to the impact of projectiles moving at various velocities. The square multilayer target plate is considered as deformable-body and represented by the element mesh defined by triangle elements with the element mesh generated equal to 5. The elements, name as SHELL _C0_3 is three-node shell elements based on the classical C0 formulation by Belytschko et al. [14]. Every each of target plates may be divided into two regions namely inner and outer region. Both inner and outer region represented by structured mesh defined by triangular element of SHELL _C0_3.

The inner region represents the central impact part while the outer region located sufficiently far from the impact zone does not show significant effect of deformation. The projectile is assumed as a rigid body and is categorized as contact triangle element. This assumption reduces the computational time required for the simulation [15]. Advanced high strength steel is used as a material model of circular target plate. Advanced high strength steel is a strain rate dependent isotropic Thermo elastic-plastic model. The material properties of advanced high strength steel are shown in Table 1. The material model in IMPACT dynamic FE program suite, advanced high strength steel is examined for its suitability in simulating target plates under dynamic impact loading.

3. Results and discussion

3.1 Equations analysis of results

The main discussion is about the failure mode of advanced high strength steel plates been subjected to impact at different range of projectile velocity. Observations on the result of the dynamics response of projectiles impacted on multilayer AHSS target plate has been carried out comprehensively. The numerical simulation implemented by using GiD pre and post-processor and IMPACT explicit finite element method. When the projectile start to penetrate through the multilayer steel plate, various profile of failure generated depending on the impact velocity and projectile nose shape.

3.2 Petalling

When the bullets start to penetrate through the multilayer steel plate, petallings process will occur. The nose shape of the bullet will generate the different shape of petals of the plate. The shape of the petals is affected by nose shape of the bullet. This is due to the force distribution that occurs on the contact area and touching surface when collision takes place as shown in Figure 2 and Figure 3. The failure mode and profile of impacted target plate is significantly affected by the projectile nose shape and impact velocity.

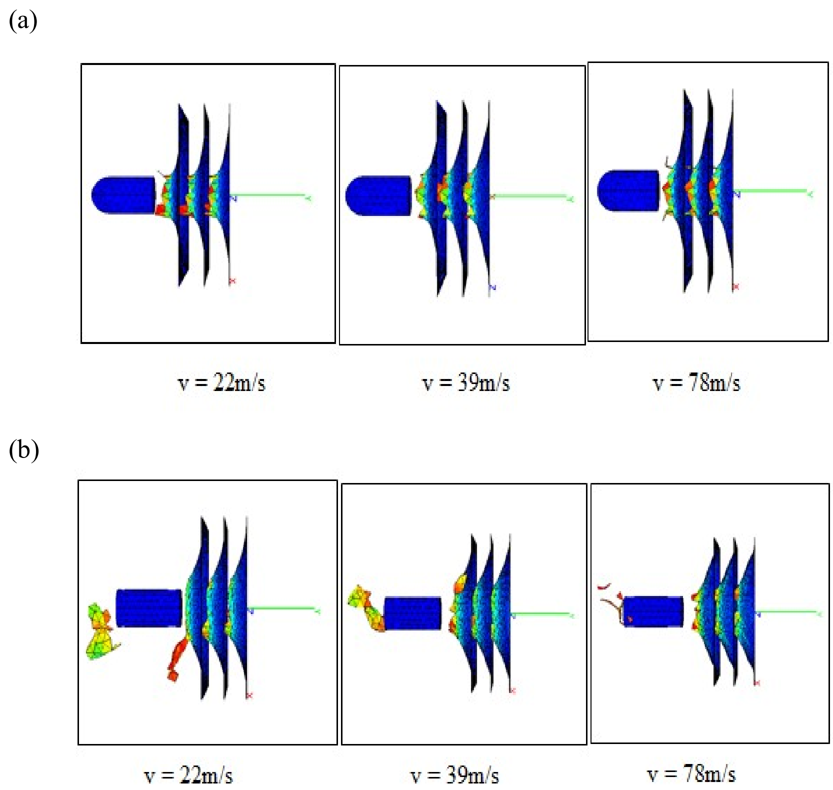


Fig. 3 - Penetration at different velocity impact (a) Hemispherical projectile impact (b) Blunt projectile impact

3.3 Deformation

The change in geometry of the model on the impacted plate will continue until it reaches the stage of plastic strain deformation and there will be crack on the geometry model. With the addition of a little force, the first plate will get into early crack propagation around the nose shape of the bullet. The change in geometry of the plate will remain after reach the permanent plastic deformation where bullet or projectile has already fully penetrated on the first plate and then followed by the penetration on the second and third plate. Figure 2 shows on the deformation and penetration of target plate impacted by hemispherical projectile at the velocity of 22 m/s, 39 m/s and 78 m/s respectively while the profile of failure on the target plate impacted by blunt nose shape of bullet or projectile at various velocity impacts is shown in Figure 3.

3.4Velocity

Velocity may provide significant failure mode of the impacted target plate, for example, the momentum of the bullet or projectile to fully penetrating the multilayer steel plate. When velocity increases, the momentum generated during the collision between the projectile and multilayer target plate will also increase. As a result, larger speed or velocity may contribute to hole enlargement of the impacted target plate and post penetrated of projectile undergoing reduction of velocity in which called as residual velocity [16, 17]

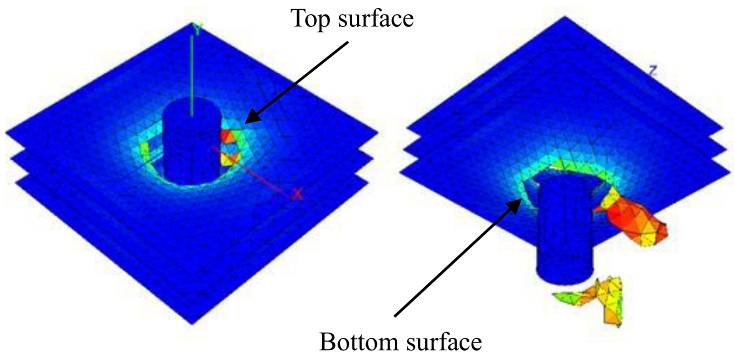


Fig. 4 - Failure mode of model impacted by blunt bullet at velocity of 22m/s

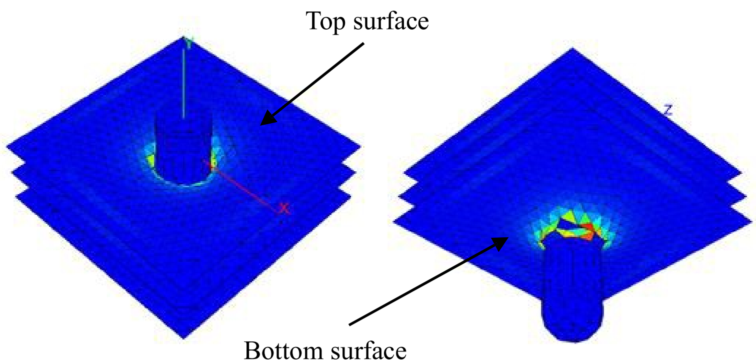


Fig. 5 - Failure mode of model impacted by a hemispherical bullet at a velocity of 22m/s

From the penetration of blunt bullet nose shape, the multilayer steel target plate clearly indicates the various type of profile of failures. For examples is the crack propagation, the formation of plug and the increment of hole penetration as shown in Figure 4. These phenomena can also happen to hemispherical bullet nose shape as shown in Figure 5. This phenomenon occurs due to the force that applied toward the multilayer steel target plate increases when the impact velocity increased.

The effect of velocity toward mode of failure can be observed by using a different range of velocity. The radius of the crack will increase as the velocity increase. This occurs due to the increase of strain on the early crack, also the increase in kinetic energy which is distributed to the multilayer steel target plate. The cracks are bigger in high velocity and the mode of failure due to necking made the size of the petalling smaller.

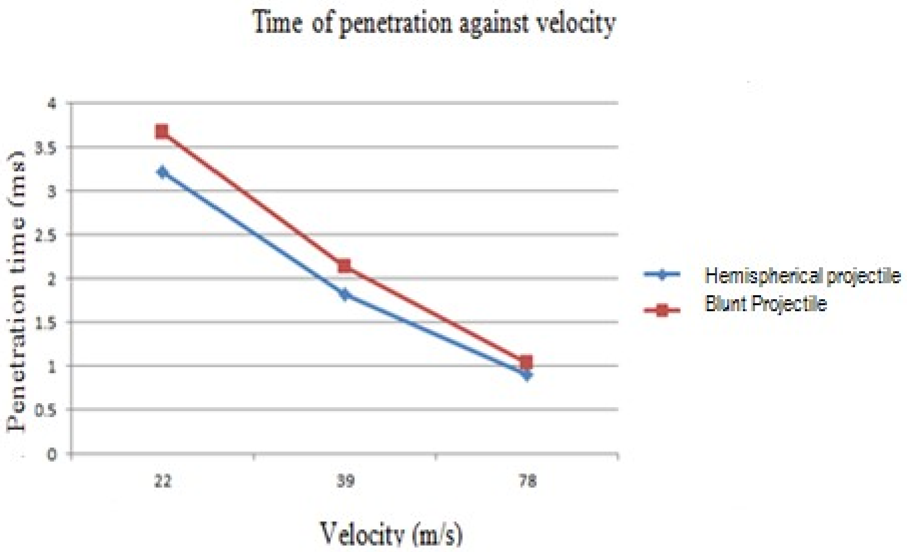


Fig. 6 - Graph of time taken for bullet to complete penetration at a different velocity

Figure 6 shows the relationship between velocity and time for the bullets to complete the penetration in which time taken will decrease as velocity increases. The higher velocity of bullet or projectile to complete the penetration is less than lower velocity for both hemispherical and blunt nose shape of projectile. By studying the pattern and the gradient of the graph, the hemispherical bullet nose shape has lower penetration time taken as compared to the blunt nose shape of bullet.

3.5 Penetration

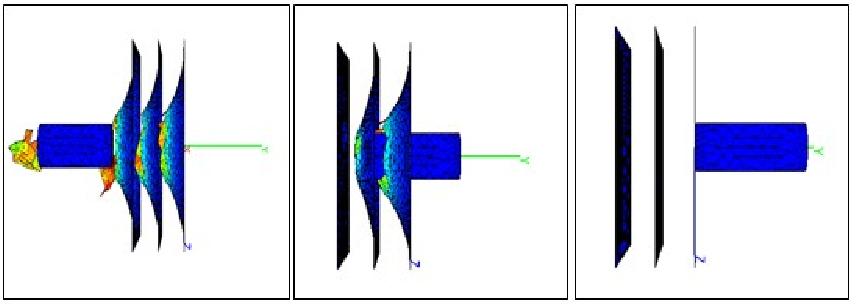
The velocity of the bullet, bullet nose shape, direction of impact and the target plate material are actually affecting the penetration. High velocity will generate higher impulsive force to the target plates and the deformation of the target plates affected by the velocity and the contact area of the collision between the plates and the bullet. The failure mode of the multilayer steel target plate impacted by projectile motion has different crack propagation, the shape of petals and size of holes penetration. The crack propagation will increase when the impact velocity increases and on the other angle, the shape of the petals also undergoing deformation with the increase of impact velocity as shown in Figure 7.

(a) (b)

Fig. 7 - Top view images of post penetration of projectile (a) Hemispherical nose shape (b) Bluntnose shape

3.6 Plug formation

Figure 8 shows the result of multilayer steel target plate impacted by projectile motion using a blunt bullet nose shape with the velocity of 22 m/s. When t = 0.3ms, bullet start to penetrate and create dishing on the first plate and after that crack propagation will occur. When t = 1.3ms, half of the bullet body already penetrate the multilayer steel target plate and the plug formation occur for the first and second plate. When t = 4.4ms, bullet already fully penetrate the multilayer steel target plate and the plugs were thrown with the same direction of the bullet. This is because a fact that blunt bullet creates a massive impulsive force toward the contact area of collision. The plugs formation only occurs on blunt bullet nose shape. Analysis of the different type of bullet nose shape will give more accurate result on the failure mode and deformation of the geometry model.



t = 4.4ms t = 1.3ms t = 0.3ms

Fig. 8 - Plug formation of blunt nose projectile impacted on the multilayer target plate

3.7 Strain effect

Figure 9, shows the failure mode of the model due to the impacting projectile by hemispherical and blunt bullet nose shape with the velocity of 78m/. It shows the difference of the strain following the element that has on the multilayer steel plate. The highest strain was label by the highest tone of colour which is red and the tone of the colour will decrease as the strain decrease. The collision was limited to the centre of target plate when the bullet starts to penetrate and at the same time create petals. The highest strain occurs on the plastic deformation and the change in the contact surface area.

(a) (b)

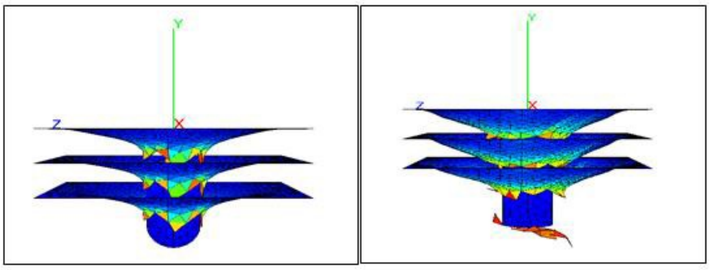


Fig. 9 - Failure mode geometry of target plate impacted at velocity of 78m/s
(a) Hemispherical projectile (b) Blunt Projectile

4. Conclusion

The petals generation decreases as the target layer increases. This is due to the reduction of velocity impact by layer to another layer and also reduction of momentum when it collides on the first layer of AHSS target plate. In the context of dynamics principle, the addition on the number of the layer will lead to the reduction on the motion of bullet or projectile motion. Anyway, in this study, the motion of projectile before and after impact remains constant as what is stated in the scope of research. The profile of failure for the hemispherical projectile impacted on multi-layer of target plate shows almost similar petals formation between first, second and third layers. The slightly different is due to the space between one layer to another layer which blocking on the formation of similar petals shape. The greater velocity represents on the enlargement of hole after perforation. The projectile nose shapes provide a significant effect on the profile of failure of AHSS target plate. The perforation of blunt nose shape of projectile towards target plate shows generation of plug formation on the first, second and third layer of target plate. The increase in the velocity of blunt projectile impacted on target plate leads to the generation of plug formation and fragmentation as well as enlargement of hole just after perforation. The bluntnose shape of projectile also creates large deformation during the initial contact between projectile and multilayer surface of target plate compared to hemispherical projectile nose shape. This is due to the contact area of touching surface of blunt nose shape which is larger than hemispherical nose shape of projectile.

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