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# Investigation on Impact Behavior of Projectile Towards AHSS Target Plate at High Velocity and Hypervelocity Impact

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**Abstract:** This study focuses on investigating the impact behaviour of a projectile on an Advanced High-Strength Steel (AHSS) target plate under high-velocity and hypervelocity impact conditions. The Finite Element Method (FEM) is employed to simulate the impact event using SolidWorks and ANSYS software. The primary objective of the research is to understand the response of AHSS target plates subjected to projectile impact at high velocities. By utilizing FEM simulations, various parameters such as impact velocity, projectile material, and target plate thickness are systematically analysed to evaluate their influence on the impact behaviour and structural integrity of the AHSS plate. The study begins with a comprehensive literature review to establish a theoretical foundation for impact mechanics and the specific characteristics of AHSS materials. Subsequently, a detailed methodology for conducting FEM simulations using SolidWorks and ANSYS is presented. The FEM simulations consider the dynamic interactions between the projectile and AHSS target plate, accounting for factors such as material properties, contact behaviour, and energy dissipation during impact. The results obtained from the simulations are analysed to determine the deformation patterns, stress distribution, and damage mechanisms within the target plate. The findings of this investigation provide valuable insights into the impact behaviour of AHSS target plates, enabling the development of improved designs and protective measures against high-velocity and hypervelocity impacts. The research outcomes can have significant implications for applications in areas such as aerospace, defence, and automotive industries where AHSS materials are increasingly utilized for their enhanced strength and lightweight properties.

**Keywords:** AHSS, Finite Element Method, High-velocity, Hypervelocity

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## 1. Introduction

Advanced High-Strength Steel refers to a new generation of steel that provides high-strength and durability while maintaining formability that is crucial to the manufacturing process. AHSS offer a unique combination of durability, ease of manufacturability, and high strength to weight ratio that ensures steel parts and components meet critical safety and efficiency regulations. Advanced High Strength steel (AHSS) can be broadly categorized as a class of high strength steel with an Ultimate Tensile Strength (UTS) value above 440 MPa. (T. Senuma, 2004). AHSS's can provide both requirements simultaneously because of their multiphase microstructure. The structure of these alloys is composed of austenite, martensite, ferrite, and various participants. In this respect, desired properties can be achieved by controlling this structure through chemical composition, heat treatment, and thermo-mechanical operations (M Emami, 2017). Based on the impact of the projectile, some of the dynamic properties of steel can be analysed, which in this case where the projectile is the form of hypervelocity. Hypervelocity impact events are ubiquitous in many areas, including micrometeoroid collision with spacecraft, projectile impacts, and when modelling effects of explosives on structures [1,2,3,4,5,6].

The impact behaviour of AHSS target interaction at hypervelocity can be examined using numerous parameters such as velocity, steel thickness, and AHSS steel geometry model, which results in distortion when subjected to large impact (Hypervelocity Impact), by using appropriate software. The Impact behaviour of projectile and AHSS target interaction at hypervelocity impact can be defined by using impact finite element code. In today's globalized world, Advanced High-Strength Steels (AHSS) have gained significant popularity in various industries, particularly manufacturing, due to their desirable properties [7]. Companies often seek low-cost steel without compromising quality to maximize profits. However, it is important to consider that inexpensive steel may exhibit inadequate dynamic characteristics, such as deformation and failure modes, when subjected to high-velocity impacts. Exploring the dynamic behavior of AHSS under hypervelocity impact can be achieved through experimental testing or Finite Element Analysis (FEM). While FEM can offer valuable insights, it should not be considered a substitute for experimental testing, as real-world conditions may not be fully captured by the simulation.

This study is carried out by developing a geometry model of a rigid body projectile and a deformable body target plate made of Advanced High-Strength Steel (AHSS). The created model is analysed by focusing on the deformation and failure modes when subjected to impacts at high velocity and hypervelocity. The projectile is treated as a rigid body, while the target plate is composed of AHSS, known for its superior strength. By conducting this research, we aim to gain insights into the deformation and failure behaviour of AHSS under high-velocity and hypervelocity impact scenarios, which could contribute to enhancing the understanding of its performance in real-world applications.

## 2. Material and Method

The primary aim of this research is to investigate the deformation and failure mode of a model under various impact velocities, as well as analyze the failure mode of the geometry model when subjected to impacts in the normal direction. To achieve this objective, a simulation using SolidWorks and ANSYS Software was performed, employing the finite element method to analyze the multilayer structure composed of advanced high strength steel. By conducting this research, valuable insights can be gained into the behavior of the model under different impact velocities, offering a deeper understanding of its deformation and failure mechanisms.

## 2.1.Materials

The use of metal plates as protective layers has been prevalent for an extended period, and their application in resisting the penetration of materials and structures continues to expand, finding utility in automotive, aviation, and military sectors. Among the metals commonly employed in the automotive industry, advanced high strength steel (AHSS) stands out. Automotive manufacturers are increasingly incorporating high strength steel to meet safety regulations in different regions and to achieve weight reduction for improved fuel efficiency. AHSS offers a combination of high strength for thickness reduction and enhanced formability for innovative part designs.

## 2.2 Mechanical properties

This unique set of properties enables vehicle weight reduction while maintaining rigidity, ride quality, and safety. The mechanical properties of steel, such as toughness, hardness, and strength, are crucial factors in material selection. In the automotive industry, lightweight steel with high strength, stiffness, and formability is preferred. This study focuses on a numerical investigation of the perforation process of a square-shaped single target plate under the impact of projectiles with various nose shapes and velocities. The geometry model for the projectile and target plate is described in Table 1, while Table 2 provides the material properties of the target plate.

**Table 1 : Parameter Of Projectile and Target Plate**

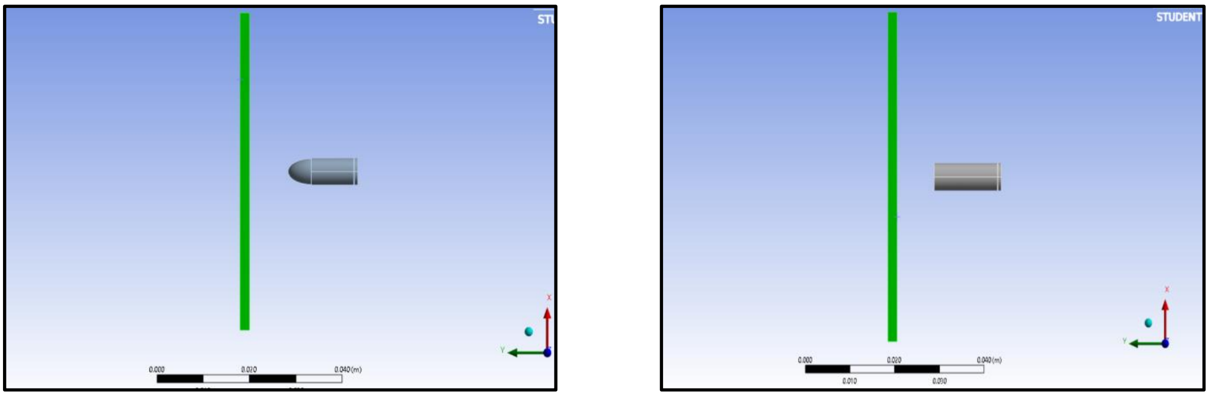
| **Object** | **Parameter** |
|---|---|
| Bullets | Shape of nozzle: 1. Hemispherical<br>2. Blunt<br>Diameter = 10mm<br>Length = 45mm<br>Mass = 3.56 gram |
| Steel plate | Dimension = 100mm x 100mm x 5mm<br>Types = AHSS<br>Tensile strength (σ) = 550 MPa |

**Table 2 : Material properties of the target plate**

| | |
|---|---|
| Type of material | (AHSS) Advanced High Strength Steel |
| Properties of material | Elastoplastic |
| Young Modulus | 600 GPa |
| Poisson Ration | 0.3 |
| Mass Density | 0.0000078 $kg/m^3$ |
| Thickness of Plate | 5mm |
| 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 |
| Integration Point | 5 |

## 2.2 Finite Element Model

In this study, a 3D finite element model was created using SolidWorks with the ANSYS interface module as shown in Figure 1. The model focused on simulating the impact of projectiles on target plates with square shapes, where both the projectiles and target plates had a diameter of 10 mm. The target plates were constrained around the edges and subjected to impact by projectiles with two different nose shapes and varying velocities. To capture the failure mode of the target plate from the impact point towards the constrained edges and back, both the projectiles and target plates were fully modeled. The penetration process was simulated using the ANSYS finite element program suite. Figure 1 illustrates the developed finite element model for the simulation.




(a) (b)

**Figure 1: Finite element model of projectile and AHSS target plate (a) Hemispherical nose shape (b) Blunt nose shape**

In this study, SolidWorks software was used to create a detailed model of the bullet and metal plate. The software facilitated the construction of accurate representations of both components. Subsequently, the user stored the file data in (*.igs) format, which allowed for easy exportation into ANSYS software. After importing the (*.igs) file into ANSYS, the user inserted the necessary model parameters to simulate the impact process. These parameters included the characteristics of the bullet, such as its shape, diameter, and velocity, as well as the properties of the metal plate.

By specifying these parameters, the user ensured that the simulation accurately reflected the real-world conditions of the impact event. The simulation was then executed within the ANSYS software environment. This process involved applying appropriate boundary conditions and conducting a thorough analysis of the interaction between the bullet and the metal plate. The simulation generated valuable data, which was subsequently compared with actual experimental measurements for validation and comparative purposes.

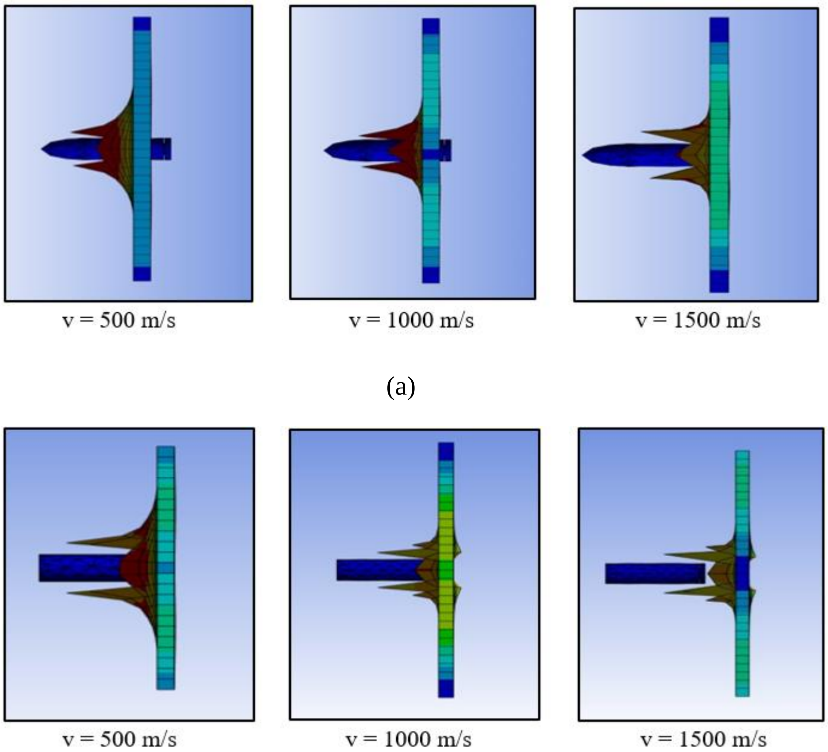
The integration of SolidWorks and ANSYS software offered a comprehensive approach for investigating the impact process. The ability to create precise models in SolidWorks and seamlessly transfer them to ANSYS allowed for a more efficient and accurate simulation. This methodology not only provided insights into the behavior of the bullet and metal plate during impact but also established a foundation for further research and development in the field.

## 3. Results and Discussion

This study focuses on examining the failure mode of advanced high strength steel (AHSS) plates when subjected to impacts at various projectile velocities. The dynamics response of projectiles impacting multilayer AHSS target plates was extensively analyzed. To conduct the analysis, a comprehensive numerical simulation was performed using SolidWorks, along with the ANSYS finite element method. As the projectile penetrated the multilayer steel plate, the study observed different failure profiles, which were influenced by both the impact velocity and the shape of the projectile's nose.

### 3.1 Petalling

When bullets begin to penetrate a multilayer steel plate, a mechanical phenomenon called petalling takes place. This refers to the formation of distinct petal-like patterns on the plate's surface. The shape of these petals is directly influenced by the geometry of the bullet's nose. The force distribution during the collision between the bullet and the plate determines the specific shape of the petals, as well as the deformation and failure of the plate. The impact velocity of the projectile and the shape of its nose play crucial roles in determining the failure mode and profile of the target plate in mechanical terms. This phenomenon can be visualized and understood through detailed mechanical analysis, as illustrated in Figure 2 (a) and (b).




(b)

**Figure 2: Penetration of projectile at different velocity impact (a) Hemispherical projectile impact (b) Blunt projectile impact**

### 3.2 Deformation

The impacted plate undergoes continuous geometric changes until it reaches a stage of plastic strain deformation, resulting in the formation of cracks on its surface. When subjected to a slight additional force, the initial plate experiences early crack propagation specifically around the nose shape of the bullet or projectile. The geometric deformation persists even after reaching a state of permanent plastic deformation, indicating complete penetration of the bullet or projectile through the first plate and subsequent penetration through the second and third plates. Figure 2(a) visually represents the deformation and penetration of the target plate caused by a hemispherical projectile at velocities of 500 m/s, 1000 m/s, and 1500 m/s, respectively. Meanwhile, Figure 2(b) illustrates the failure profile on the target plate impacted by a blunt-nosed bullet or projectile at various impact velocities.

### 3.3 Velocity

The velocity of the projectile plays a crucial role in determining the failure mode of the impacted target plate. For instance, higher velocities result in increased momentum, facilitating the complete penetration of the multilayer steel plate by the bullet or projectile. Consequently, elevated speeds can lead to enlargement of holes in the impacted target plate. Additionally, as the projectile passes through the plate, it experiences a decrease in velocity, commonly referred to as residual velocity [8,9].

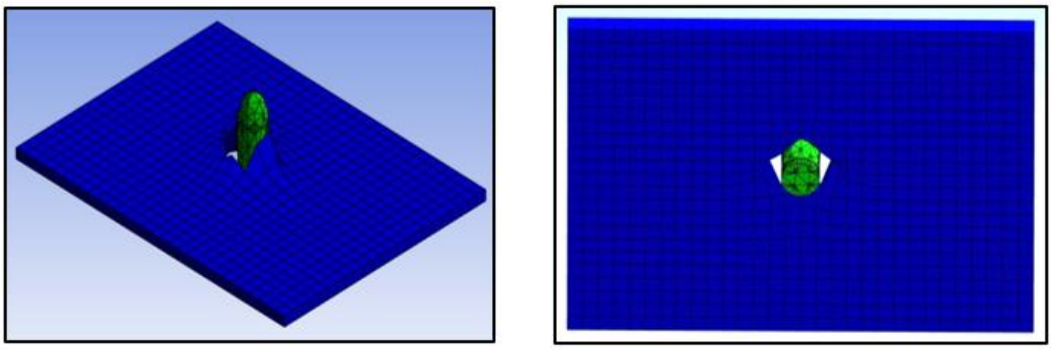


**Figure 3: Failure mode of model impacted by hemispherical bullet at a velocity of 1000m/s**

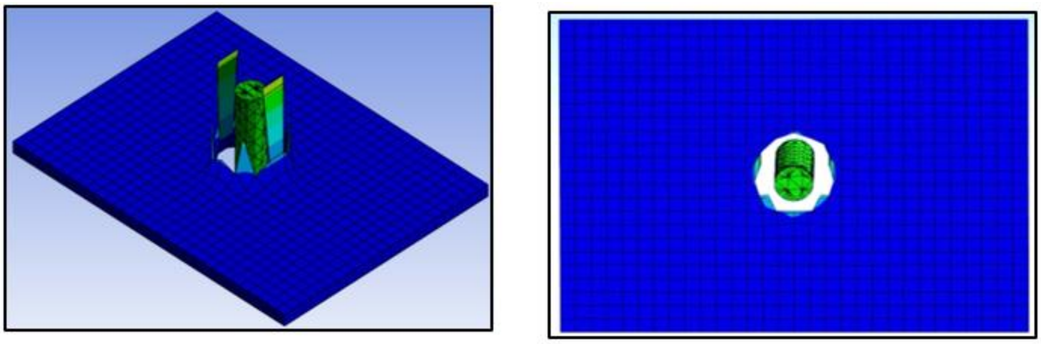


**Figure 4: Failure mode of model impacted by blunt bullet at a velocity of 1000m/s**

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.

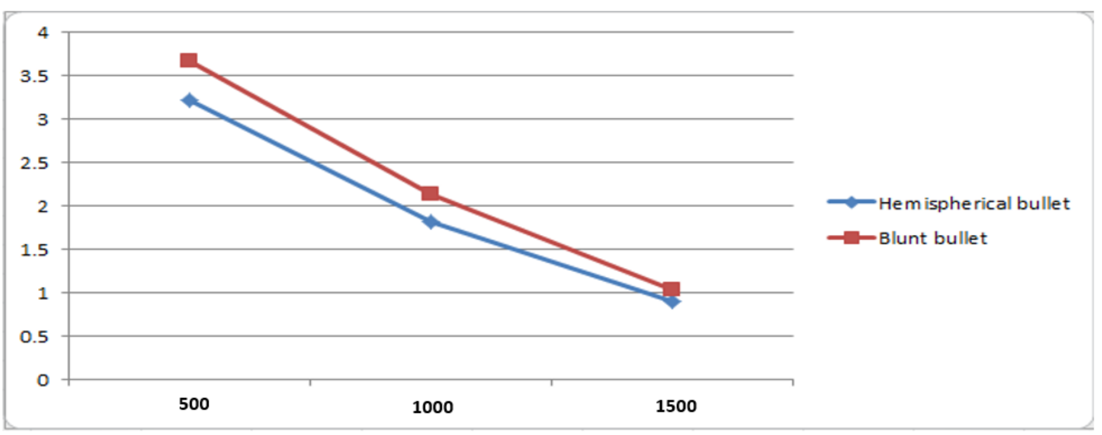
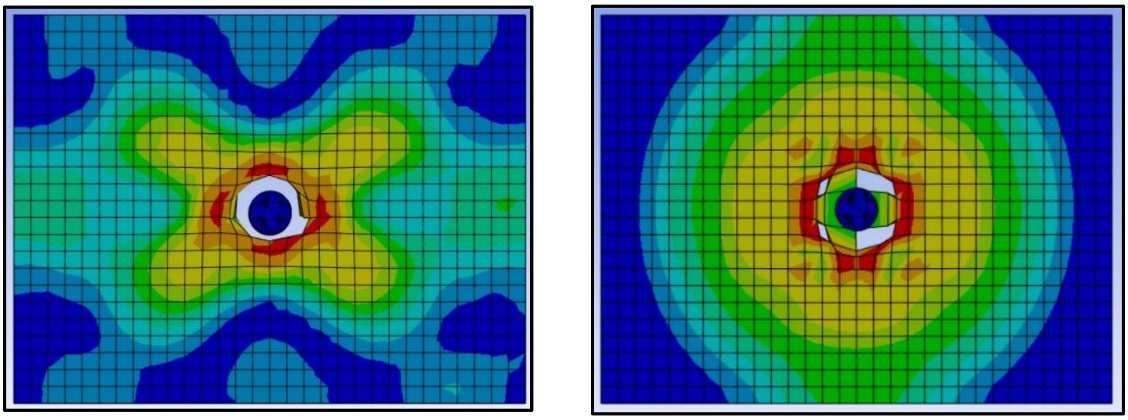



**Figure 5: Graph of time taken for bullet to complete penetration at a different velocity**

Figure 5 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.

3.4 Penetration

The penetration of a bullet into a target plate is influenced by various factors such as bullet velocity, nose shape, impact direction, and target plate material. Higher velocities result in greater impulsive forces exerted on the target plates. The deformation of the plates is affected by both the velocity of impact and the contact area between the plates and the bullet during the collision. The failure mode of an AHSS target plate impacted by projectile motion is characterized by distinct crack propagation, variations in petal shape, and differences in hole penetration size. The crack propagation increases as the impact velocity rises. Furthermore, the shape of the petals undergoes deformation in response to the increasing impact velocity, as depicted in Figure 6.



(a) (b)

**Figure 6: Top view images of post penetration of projectile (a) Hemispherical nose shape (b) Bluntnose shape**

### 3.5 Strain Effect

Figure 7 demonstrates the strain distribution within the multilayer steel plate impacted by projectiles with hemispherical and blunt bullet nose shapes at a velocity of 1500 m/s. The visual representation highlights the relationship between strain levels and the resulting deformation, particularly during the plastic deformation phase. The observed changes in the contact surface area and the occurrence of crack propagation further contribute to the understanding of the failure mode in this scenario.

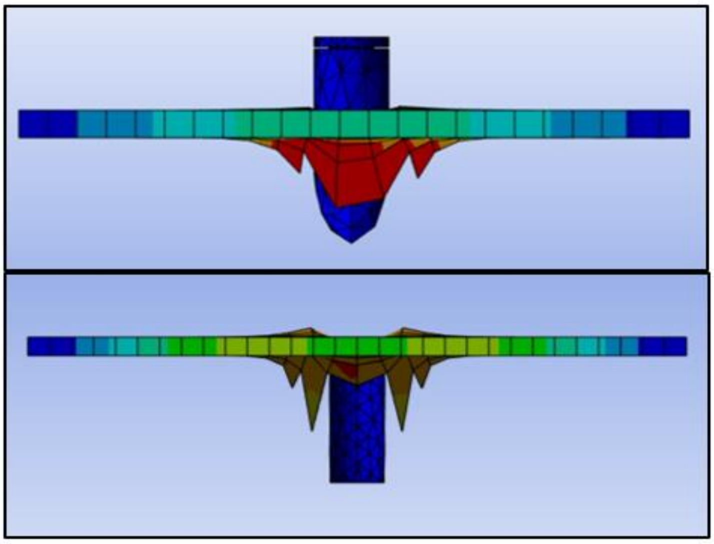


**Figure 7: Failure mode of geometry by hemispherical bullet and blunt bullet with velocity 1500m/s**

## 4. Conclusion

In this study, the motion of the projectile before and after impact remains constant, as specified in the research scope. The failure profile of a hemispherical projectile impacting an AHSS plate exhibits similar petal formations. Higher velocities lead to larger hole enlargement after perforation. The shape of the projectile's nose significantly influences the failure profile of the AHSS target plate. The perforation of a blunt-nosed projectile results in the formation of plugs on each layer of the target plate. Increasing the velocity of the blunt projectile leads to the generation of plug formation, fragmentation, and an enlarged hole immediately after perforation. Compared to a hemispherical projectile nose shape, the blunt-nosed shape induces greater deformation upon initial contact with the multilayer surface of the target plate. This is due to the larger contact area provided by the blunt nose shape.

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