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Explicit Dynamic Analysis of Ballistic Impact of Shield Plate Using Different Materials

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Abstract:

Ballistic impact resistance is a critical design criterion in protective systems for defense, aerospace, and civil security applications. The present study investigates the dynamic response of various shielding plate materials when subjected to high-velocity projectile impact using simulation-based tools. A bullet made of stainless steel was modeled to impact different plate materials including Silicon Carbide, Boron Carbide, Titanium Alloy, Polyethylene, and Polycarbide. The modeling was performed in CATIA V5 and the impact analysis was carried out using ANSYS Explicit Dynamics. The performance of these materials was evaluated based on equivalent von-mises stress and directional deformation under identical impact conditions. Results indicate that ceramic materials offer superior resistance to deformation and stress, while polymer-based materials, despite being lightweight and cost-effective, showed high deformation. This study contributes to material selection strategies for protective structures considering stress response, deformation and density.

Keywords — **Ballistic impact, Shield plate, ANSYS Explicit Dynamics, Armor materials.**

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I. INTRODUCTION

In an era where security and survivability are of paramount concern, the demand for lightweight, cost-effective, and high-strength materials for ballistic protection has increased. Ballistic protection systems are widely used in military vehicles, body armours, and protective shelters. A shield plate must be capable of absorbing and redistributing the kinetic energy of an incoming projectile while minimizing structural damage and deformation. Traditional testing of ballistic materials is often constrained by cost, time, and safety concerns. Simulation-based methods offer a powerful alternative to predict material behaviour under high-velocity impacts.

This research applies a computational approach to evaluate ballistic resistance by simulating a high-speed impact on different plate materials using CATIA V5 for modelling and ANSYS Explicit Dynamics for simulation. The impact of a stainless steel bullet on plates made of different materials is examined to determine the stress distribution and deformation characteristics. The study aims to guide material selection for protective systems by comparing the structural response of each material under identical conditions.

II. PROBLEM IDENTIFICATION

Designing an effective armor system involves selecting materials that not only resist penetration but also dissipate the impact energy efficiently. The problem addressed in this study is to determine the best-performing shield plate material from a pool of commonly used options. Traditional experiments can be destructive, limiting detailed analysis. This research uses simulation to address the following:

Which material experiences the least deformation under ballistic impact?

Which material sustains and distributes stress efficiently without failure?

How do material properties like stiffness, density, and brittleness affect ballistic resistance?

III. METHODOLOGY

A. Modelling in CATIA

The bullet was modelled with a semi-spherical nose and the plates were modelled with identical dimensions (60 mm × 60 mm × 15 mm) for comparison. All geometries were prepared using CATIA V5 shown in fig 1.

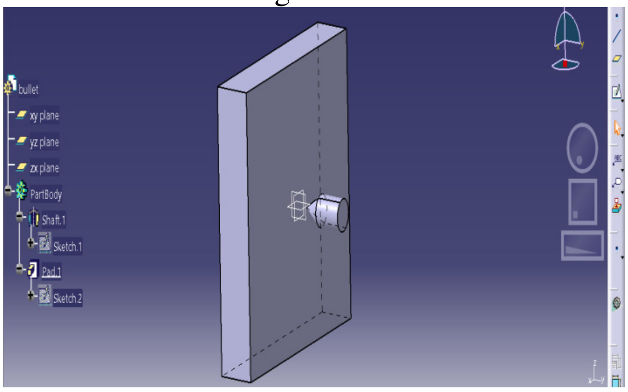

Fig 1: *Bullet and plate model created in Catia V5*

B. Simulation in ANSYS Explicit Dynamics

Projectile: Stainless Steel bullet

Plates: Silicon Carbide, Boron Carbide, Titanium Alloy, Polyethylene, Polycarbide

Initial Conditions: Bullet velocity was set to simulate realistic ballistic impact (value assumed standard).

Boundary Conditions: Plate fixed at back surfaces. Bullet impact directed along the Y-axis.

Outputs: Equivalent von mises stress, total deformation, and directional deformation (Y-axis).

IV. RESULTS AND DISCUSSION

A. Stress and deformation development by impact of bullet on Silicon Carbide Plate

Fig 2 shows the distribution of equivalent vonmises stress in the plate and bullet during the impact. The equivalent von mises stress distribution reveals that the peak stress of 13,216 MPa occurred primarily in the bullet upon contact with the target plate. This high concentration of stress at the nose of the projectile indicates an intense momentary force transfer during initial impact. Silicon Carbide, due to its brittle yet extremely hard crystalline structure, resisted plastic deformation, causing stress to reflect back into the projectile. This behaviour is aligned with the hertzian theory of contact stress, where brittle materials deflect impact by localizing stress in the contacting object. Similar findings were reported by Crouch (2009) who emphasized the ability of ceramics to reflect impact energy.

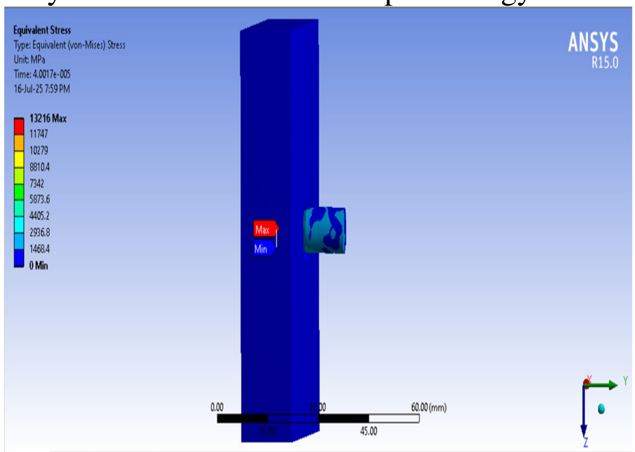

Fig 2: *Equivalent Stress Distribution in Plate and Bullet*

Fig 3 shows the deformation developed in the plate and bullet during the impact. The deformation plot shows that maximum deformation (11.608 mm) occurred mostly in the projectile body rather than the shield plate. This again highlights the effectiveness of the 15 mm thick Silicon Carbide plate in distributing the impact energy. Previous work by Zukas (2004) supports this result, explaining that high-stiffness ceramics prevent deep penetration, resulting in projectile mushrooming or fracturing. The plate structure remained mostly intact with minor displacement.

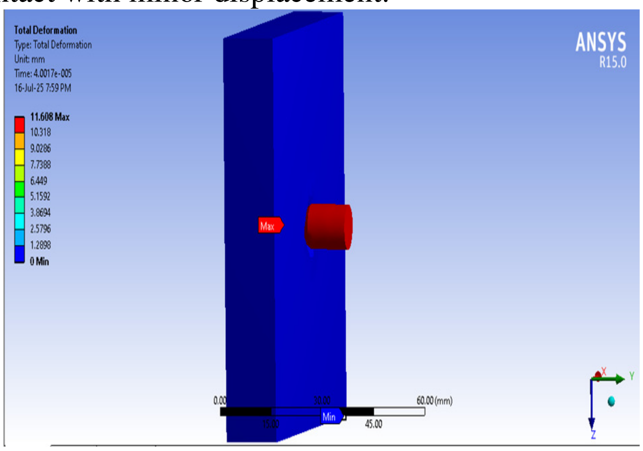

Fig 3: *Total Deformation developed in plate and bullet*

Fig 4 shows the equivalent von-mises stress developed in the plate alone during impact of bullet.

Focusing solely on the plate, the von Mises stress reached a peak of 813.2 MPa. This value is significantly below the compressive strength of Silicon Carbide, which often exceeds 2500 MPa, suggesting that the material remained in the elastic zone. The stress distribution pattern also indicates radial dissipation away from the impact center. This is a desirable characteristic, as localized energy gets distributed efficiently, minimizing internal crack propagation.

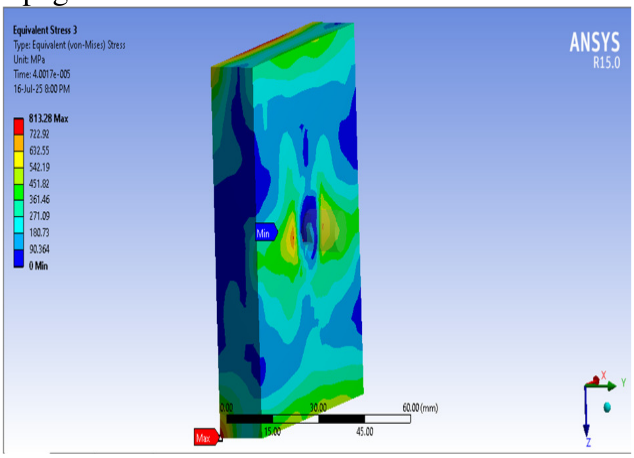

Fig 4: Stress Distribution in Plate Alone

Fig 5 shows the direction deformation developed in the plate alone along the direction of bullet. Directional deformation along the Y-axis (projectile motion direction) was limited to 3.43 mm, further affirming the excellent ballistic performance of the material. A well-structured ceramic plate like this converts kinetic energy into elastic strain energy, which is quickly dissipated across the crystalline lattice. Studies by Rajendran and Grove (1998) affirm that such displacement values are typical for hard ceramics under blunt projectile impact.

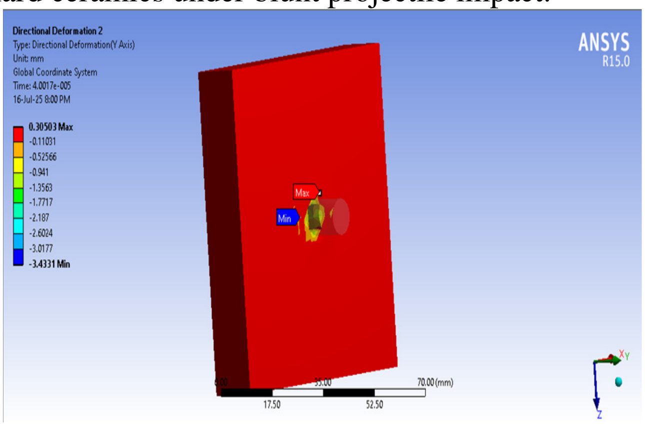

***Fig 5**: Directional Deformation (Y-axis) in the plate alone*

The overall assessment confirms that the 15 mm Silicon Carbide plate exhibited superior resistance to penetration and efficiently distributed impact stress with minimal displacement. This is attributed to its high Young's modulus, low density, and excellent energy reflection properties.

B. Comparative Performance of shield plate made of Materials for bullet impact

Table 1 shows the deformation developed through bullet impact in the plate made of different materials Boron Carbide shows the highest stress and minimal deformation. Its brittle nature allows it to fracture locally but resist deep penetration, explaining the low displacement values.

Titanium Alloy presents high stress resistance and acceptable deformation, making it a practical choice where metal bonding or fabrication is needed.

Polyethylene and Polycarbide show significant deformation due to their ductility and low modulus of elasticity. Their use in armour may be limited to energy absorption layers in a composite system.

Silicon Carbide balances moderate stress with manageable deformation. It is lighter and cheaper than Boron Carbide but more brittle than metals.

***Table 1**: Stress & deformation developed in the plate (different materials)*

Plate Material	Equivalent von-mises stress (Mpa)	Deformation (mm)
Silicon Carbide	813.2	3.43
Boron carbide	3366.3	0.51
Titanium Alloy	3260.4	1.005
Polyethelene	282.96	24.7
Polycarbide	131.21	23.2

Scientific Perspective: High-strength ceramics like Silicon and Boron Carbides leverage their crystal structures to resist crack propagation. Metals like Titanium absorb energy via plastic deformation. Polymers rely on ductile deformation but fail under repeated or concentrated load.

Manufacturing Perspective: Ceramics are challenging to machine and shape, whereas metals and polymers offer better formability and weld-ability. For vehicle or personnel armour, ease of integration with structural elements becomes crucial.

Engineering Perspective: Deformation levels influence the usability of the material in real-world conditions. While a plate may not fracture, excessive deformation can lead to blunt trauma or system failure.

V. CONCLUSIONS

The ballistic performance of five materials was studied using ANSYS Explicit Dynamics under consistent projectile impact. Based on the findings:

Boron Carbide is the most resistant material, showing minimal deformation (0.51 mm) and maximum stress resistance (3366 MPa), though it is expensive 15000/kg) and brittle.

Silicon Carbide offers a cost-effective alternative (9000-12000/kg) with moderate deformation (3.43 mm) and sufficient strength (813 MPa).

Titanium Alloy is the most manufacturable with high strength (3260 MPa) and moderate deformation (1.005 mm), but heavier (density 4.5 g/cm³).

Polyethylene and Polycarbide, though low in cost and weight, showed excessive deformation and are not suited for primary armour.

Optimum Recommendation: Considering stress resistance, deformation, cost, and density, Silicon Carbide offers a practical balance for many protective applications. In high-threat zones, Boron Carbide is superior, provided budget and handling constraints are acceptable.

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