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ABSTRACT: *Impact analysis is process of analyzing impact of a base object by a projectile that may be affected by plastic deformation. This requires a software representation model that can formalize the knowledge about the various dependencies between impacting objects. This study was carried out with the aim of objectively assessing whether a honeycomb structure is better structurally compared to conventional engineering materials. Honeycomb structures have relatively high compression and shear properties out-of-plane while having a low density, implying presence of very high specific strengths. So these materials find wide application in aerospace industry. Explicit dynamics tool of Ansys for impact analysis, was used to implement different impact approaches. Different materials were analyzed for failure at various impact velocities and base plate thickness as well as impact angles for suggesting superior honeycomb structural properties from impact analysis results.*

Keywords: *Honeycomb structure, Explicit dynamics, Composite materials, polymeric matrix composite, Honeycomb*

1. Introduction

Honeycomb lattice structure comprises of hollow cells which are thin walled with low density and proportionately high out of plane shear and compression properties. Wide variation in honeycomb shaped structures is seen, with a common feature of hollow lattice structured cells of thin wall with columnar and hexagonal shapes. These structures allow material minimization for cost and weight saving during process of design. Honeycomb materials common usage is honeycomb mesh employment for creation or reduction of wind turbulence as per the situation requirements. Mesh design important factor is honeycomb cell's length vs diameter ratio also called as length ratio. For ratios less than unity, decrease in intensity of turbulence is observed. For ratios larger than unity, reduced wind flow eddies and lateral turbulence reduction is observed. Honeycomb structured natural examples comprise bone, tripe and rock-based honeycomb weathering and beehives.

Synthetic Honeycomb structures which are man-made, are composites of sandwich structure with honeycomb core surrounded with thin plates. Core construction can be done from various materials like FRP or aluminum for high loads, thermoplastic material for low loads or paper based on the situation requirements.

The limit of concrete to resist the effect of projectiles is discussed in [1]. Focus on concrete elements under high speed projectile effect studying the limit of concrete to resist the effect of projectiles. The motive of this was to develop better version of numerical model for predicting dynamic response of RC slab under HSP attack. The recent stats casted and tested, factor investigating were slab thickness (50mm, 100mm, 150mm) and projection types. It concludes the penetration depth was controlled by target thickness regardless of the steel enforcement.

Projectile exit in small arms has the effect of rotating a centerline through several orientations [2]. Finite elements models of small arms are bare, specially one with perfectly straight bore centerline and five experiments performed. This concludes that the effect on centerline non linearity has a projectile exit conditions provides similar effect as a centerline rotation through different orientations. A unit firing cycle is simulated for every centerline in dynamic analysis. Calculation of projectile jump is made for every model. Small effect of warped centerlines is seen on barrel dynamics.

High penetration resulting in damage is seen in conical projectiles as compared to flat projectiles [3]. In the recent study, high strength composites modeled as target plate are analyzed with finite element analysis for ballistic impact against projectile with varying nose shape. Intricate shape designing is implemented using finite element analysis in a new technique. Penetration and subsequent damage by conical projectiles in comparison to flat projectiles is high. Better penetration capability is observed for 60° and 90° conical projectiles for target plate where as significantly reduced residual velocity is observed in flat and 120° conical projectiles. Puncturing and yarn ship age are understood to be the basis along with matrix cracking and breakage of fibers for low velocity. With increase in velocities, linear momentum transfer forms the basis for shift of failure.

Design of navigation system using inbuilt inertial sensors, for given target course correction for prior launching location [4]. There are three major perspectives being, projectile's computational fluid dynamics analysis for low velocity of launch, design of navigation system and electronic component durability under conditions of extreme firing. Finer projectiles are chosen for navigation

simulation as a basic reference test bed for which some of the flight parameters and dimensions are available. Navigation simulation is performed using space model missile provided by raytheon. Course correction for specified targets whose prior launch location is known are used in navigation system with inertial sensors which are inbuilt. Conduct of computational fluid dynamics calculations for reference projectile is performed for low velocities of launch to clear the passage for firing equipment's aerodynamic condition of non-explosives like air gap and catapults. Visualization of common electronic components durability was done till 20,000g and test of function ability of microcontrollers which maybe regular or off the shelf was done using test equipment of Hopkinson bar.

Maintenance and safety of operations need require vitality for debit of fatigue strength evaluation of axles [5]. Structural integrity threat is posed on railway axles due to damage by flying ballast thereby posing safety and structural integrity threat towards trains moving with high speeds thereby requiring evaluation for maintenance and safe operations. Simulation for this evaluation was worked on by tungsten steel ball shooting towards extracted specimens from axles of S38C axles which were service inducted. Three impact velocities of 200,300 and 400 m/s were used for impact test performance. Impact damage was analyzed by scanning SEM and cross section Volume and depth of damaged zone on basis of fatigue strength results show increase in value with angle of incidence at 200 m/s velocity. At impact velocities of 300 and 400 m/s, fatigue strength loss results show, losses of strength of around 50% as compared to un impacted ones.

The impact events are performed between 2.5 Joules and 20 Joules [6]. It is used to study or work on the application of FEA software. Impacts were performed on a flat aluminum plate of dimensions 100x100mm and thickness being 1mm by using 10mm spherical steel projectile. The impact events are performed between 2.5 J and 20 J and analyzed for acoustic and modal response of the plate. These frameworks would allow for the localization and interrogation of impact events in FRPs.

A target response of impact is with asymmetric projectiles [7]. Limited studies were seen on impact by non-axisymmetric projectiles with few cases seen in military and civil applications widely. Projectiles related target response varies from largely analyzed impact case with projectiles which are axisymmetric. Objective was to analyze capabilities of indentation of differing sharpened plates shaped projectiles on targets of metal.

The FEM results are seen to have deviation less than 10% compared to other methods [8]. A calculation method of SCS wall is proposed. The energy is divided into 4 parts including the energy

dissipated by front steel plate, concrete, back steel plate and tie bars. The method reports for the perforation of the concrete and steel plates separately and also reports for the interaction between them. A practical anti perforation calculation formula of SCS wall with tie bars is given. The most of the formula results are closer to the test results but the FEM results with a deviation less than 10% and this deviation shows that the calculation formula given is reasonable and credible. The energy dissipated by the tie bars is much smaller than that of steel plate through a comparative analysis of dissipated energy. According to the finite element calculation results, the effects of various factors on the perforation velocity are analyzed and roughly it is divided into three categories : (a) the thickness influence on plate of steel and largest effecting of tie bars distance (b) followed with steel plate's yield strength (c) tie bar's diameter and bar's yield strength and least effect being that of concrete's compressive strength.

The effect of such pyro shock impact can lead to structural damage, functional degradation and mission failure [9]. This work shows projectile impact due to high velocity on geo-material comprising of rock and soil and of double layers. Conduct of experiments for projectile's penetration depth analysis and geographical behavior was done. The three dimensional scanning was done and observation of soil surface changes were seen. The impact and exit average diameter of crater were 193.06 and 270.75 mm. The cratered rock is of elliptical shape with major radius of 250 mm and minor radius of 148mm respectively. In comparison with other results, the penetration depth predicted by finite element analysis was 4.7% of error. Also losses of projectile were observed to be 38.7% in terms of kinetic energy during soil perforation and 61.3% energy loss during rock penetration.

Modelling of target's inter and intra laminar damage was realized in [10]. Performance of projectile's impact analysis with conical nose shape of laminated composite with reinforcement of E-glass fiber in addition to delamination analysis shows that consideration of analysis of inter-laminar damage is due to protective structure's laminated configuration. Johnson Cook model for material modeling was done for threat analysis with criterion of ductile damage for projectile made of mild steel. Target material's modeling for inter and intra laminar damage was realized in frame criteria of Hashin damage and stress criteria of quadratic nominal with fracture criteria of Benzeggagh-Kenane. Analysis by mesh gradation for damage and stress distribution for both threats as well as target materials was done via Explicit/Abaqus. Evaluation of delamination analysis in modeling of computational impact requires consideration of cost of computation regarding time of wall clock and CPU.

Aluminium alloy's low density makes it applicable for wide usage [11]. Analysis based on computational and experimental results for such problems are limited according to reports and articles. Here, illustration of analysis based on computational results using Ansys of impact of projectile of hardened steel having cone shaped nose on AA5058 target alloy. The shape of the target plate is circular disc and 500 mm diameter is the dimension of this plate. We will consider the range of thickness of this plate i.e., 15mm, 20mm, 25mm, 30mm and the dimensions for the projectile considered is 20mm in diameter and 98mm in length. Conical shape is provided on the projectile of 30 mm length on one side. In Ansys, using the Johnson-Cook constitutive model the target model is modeled. Considering the initial and residual velocities, the limiting ballistic velocity is investigated computationally of the target material. For the considering thicknesses, the limiting ballistic velocity is 214m/s, 245m/s, 250m/s, and 300m/s respectively.

Pyrotechnics is not generally utilized for every experiment involving pyroshock-propagation on of high risk and costs involved. A simulator for pyroshock was developed in this analysis, for required shock environment generation by control of variables for generation of shock environment and test structure based testing. Design and fabrication of test structure attached resonator and pneumatic system based launch device was done. Control of shock's magnitude and frequency generated by means of simulator for pyroshock can be done by control of collision velocity adjustment of steel ball and resonator disk's thickness with verification of its repeatability.

This analysis [13] focuses on celerity of projectile impact at varying attack angles on a steel plate target. Projectile angle effect presentation using software was carried for calculation of finite element method. Utilizing Abaqus, presentation of required force for steel plate penetration of 5mm thickness and modeling of projectile impacting plate dynamic model was done. Numerical analysis paragraph shows used numerical model and modeling of simulation. In conclusion part, result summary was formulated and conclusion based on analysis insight and observation was drawn. Based on the observations with increase of plate angle, required penetration force also increased. Apparatus of analysis for point of impact includes : module for bullet analysis for bullet information generation, module for gun analysis for gun information generation, module for analysis of environment for environmental state detection and generation module for point of impact for point of impact in formation generation.

Dynamic impact behavior of a honeycomb structure integrated with ribbed plates were examined in [15]. By conducting simulations and controlled experimental analyses, the study identified that the

inclusion of ribbed reinforcements significantly improves energy absorption characteristics during axial impact scenarios. The authors attributed this enhancement to improved stress dispersion and deformation control introduced by the ribs. The research offers valuable insights for optimizing crashworthy structures, especially in transport applications. Notably, the study stands out for its use of coupled experimental and numerical validation, providing a balanced and practical viewpoint.

Finite element analysis (FEA) based comparative study of multilayered honeycomb composites intended for aerospace structures was done in [16]. Their work highlighted how different core configurations and material layering affect the structural response under mechanical loads. The study compared stiffness, deformation patterns, and failure probabilities across multiple design variants. A key contribution lies in the rigorous FEA modeling, which included advanced mesh optimization techniques to enhance result accuracy. The findings suggest that material heterogeneity and layup symmetry significantly influence performance, making it a cornerstone study for aerospace design engineers.

Modal behavior of carbon-epoxy faceplate sandwich structures were analyzed in [17] with varying honeycomb core geometries and materials. The researchers employed both analytical and numerical methods to evaluate how geometry (e.g., hexagonal vs. triangular cores) and core material properties affect natural frequency and damping behavior. Their findings demonstrate that geometric configuration has a more pronounced effect on modal characteristics than core material type. This research is particularly relevant for vibration-sensitive applications, offering a framework for tailoring core structures to achieve desired dynamic performance.

Impact response of sandwich structures incorporating a bidirectional negative Poisson's ratio (auxetic) core were inspected in [19]. Presented at the SPAWDA symposium, the study focused on how auxetic behavior alters impact energy dissipation. Using experimental drop-weight tests and dynamic simulations, the authors observed superior impact resistance and lateral expansion in auxetic structures compared to conventional ones. The bidirectional auxeticity was found to contribute to stress redistribution, thereby delaying local failure initiation. This research offers promising directions for protective structures requiring high energy absorption and recoverability.

The literature reviewed shows analysis of impact for different materials with varying material thickness and impact angle using analytical methods like finite element analysis and others. However, not much work related to impact analysis on less dense materials like honeycomb

structure is seen, and this work focuses on utilizing relatively high compression and shear out-of-plane properties of these materials having a low density with presence of high specific strengths for possible application in areas like aerospace, transportation etc. The reviewed publications contribute to this growing body of research by offering diverse perspectives on material configuration, structural design, and response behavior under various loading conditions.

1 Materials and Method

The aim of this work is to find the material with less deformation and maximum stress when hit by the bullet. Bullet model is created in Ansys software. The material used for bullet is Stainless Steel. Bullet velocity is selected as 300, 200, 100m/s based on the literature review.

Parameters Affecting Analysis

- (i) Effect of Angle
- (ii) Effect of Velocity
- (iii) Effect of Thickness

Boundary Conditions: For Impact angle:

The impact angle is 90° for all the numerical values.

For Thickness of plate:

Edges of plate are fixed. Simulation is done for thickness of 50, 40, 30 mm.

To change in size or shape of an object/material, following parameters are discussed:

- (i) Von-Mises Stress
- (ii) Von-Mises Strain
- (iii) Total Deformation
- (iv) Directional Deformation

Von-Mises Stress is defined as equivalent stress acting on an object when subject to multiple loading effects. The unit of stress is N/m^2 . Von-Mises Strain is stated as the equivalent strain caused by the von-mises stress on an object and is dimensionless. Total and directional deformation refers to overall deformation and specific directional deformation on object due to loading.

Analysis aimed towards understanding suitability of honeycomb structure with structural details as shown (Fig. 1(a), (b) and (c)) in comparison to conventional alloys like copper, aluminium, magnesium and titanium.



Fig. 1 (a) Surface of the Honeycomb Composite (b) Honeycomb Mesh (c) Inner Structure of Honeycomb [I6]

2.1 Geometry for Analysis

The plate and bullet geometry is prepared in Ansys for $500 \times 500 \times 50 \text{mm}^3$, $500 \times 500 \times 40 \text{mm}^3$ and $500 \times 500 \times 30 \text{mm}^3$ sized plates (Fig. 2(a) and (b)) for analysis of bullet impact on varying plate thickness.

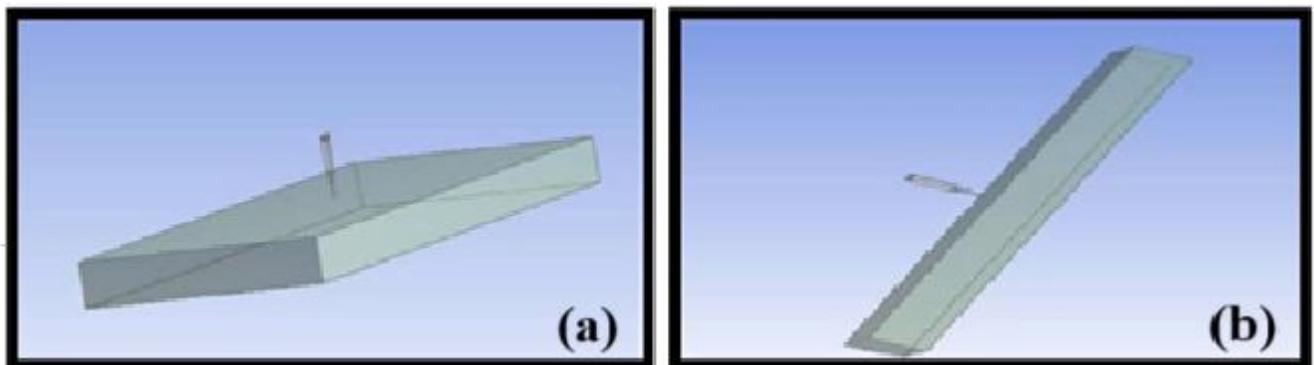


Fig. 2 (a) Geometry of Bullet and Plate (b) Bullet centered at Plate

2.2 Plate Materials

Various plate materials as shown in Fig. 3, 4, 5 and 6 can be considered for honeycombed structure other than honeycomb steel. Nylon, Aramid, Ceramic, Ultra-high modulus polyethylene etc. are some of the plate materials other than conventional alloys of aluminum, copper, magnesium, titanium and steel having good scope in impact absorption.

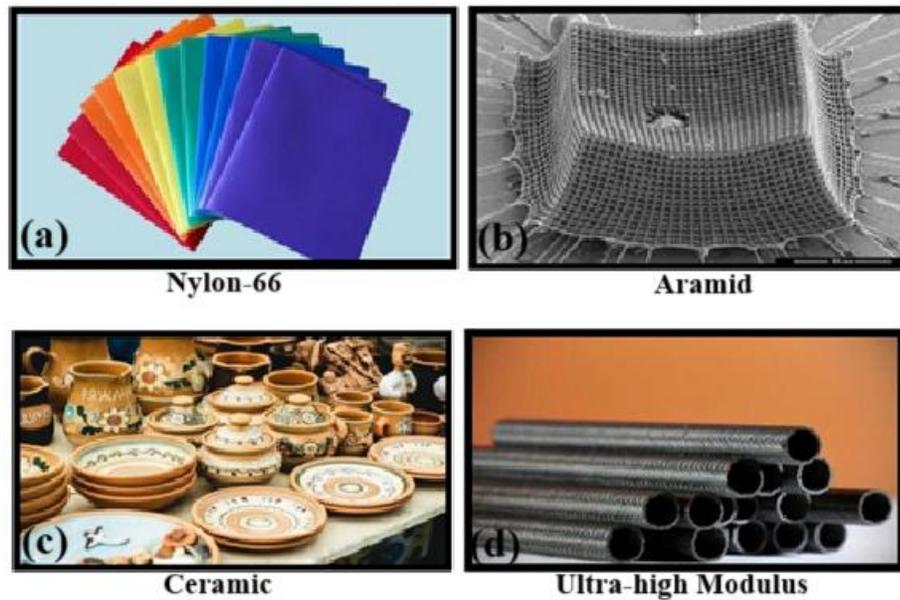


Fig. 3 (a) Polypropylene (b) Kevlar (c) Earthenware (d) Spectra

2.3 Impact Testing Methods

2.3.1 Charpy Impact Test

It is done to find the impact resistance of the material. It is extended to impact strength, deflection and force measuring device [11].

2.3.2 Impact Test using Drop Weight

Determination of energy needed for material damage or breakage involving falling of a defined weight on to target specimen or falling of a component with specific velocity and impact energy from a given height.

2.3.3 Ballistic Test

Testing based on high speed impact for composites ultimate impact strength testing. It is performed on the set called gas-gun.

2.4 Bullet and Plate Impact Analysis

FEA using Ansys was used for computer model simulation of machine components, electronics or structures so as to analyze the attributes like toughness, electromagnetism, strength, fluid flow, temperature distribution and elasticity. Product functioning is determined using Ansys with varying specifications, without conduct of crash test or test products building.

Ansys was used for the impact analysis of the bullet and plate using general non-linear materials for the Bullet and Plate followed by disabling the "Body Interactions" option and assigning materials to the Bullet and Plate. Mesh analysis of Bullet and Plate were subsequently done. 'Velocity' option is now inserted along with adding the fixed support on the Plate for assigning boundary conditions. This is followed by inserting Von Mises Stress, Strain and Defonnation and evaluation of results of

all parameters. The striking of bullet of specified velocity on constrained plate side view (Fig.7) and subsequent damage resulting from impact (Fig.8) are being shown.

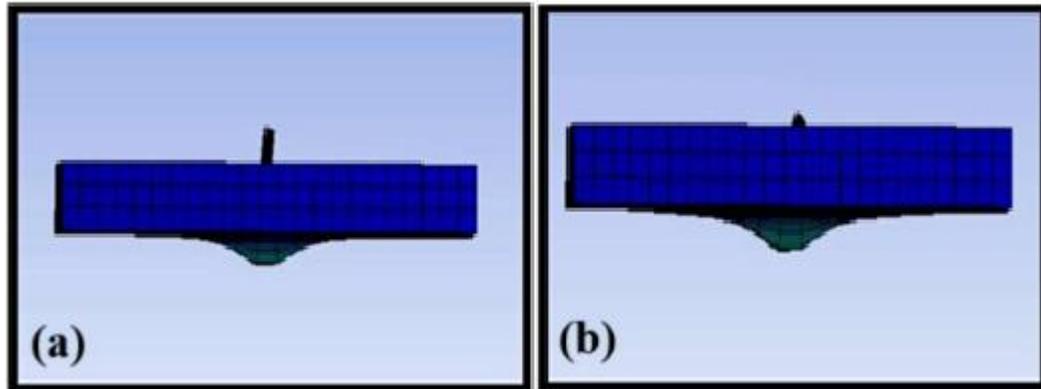


Fig. 7 : (a) Bullet striking the plate (b) Damage by Bullet on Plate

The striking of bullet of specified velocity on constrained plate top view (Fig.9) and subsequent damage resulting from impact (Fig.10) are being shown.

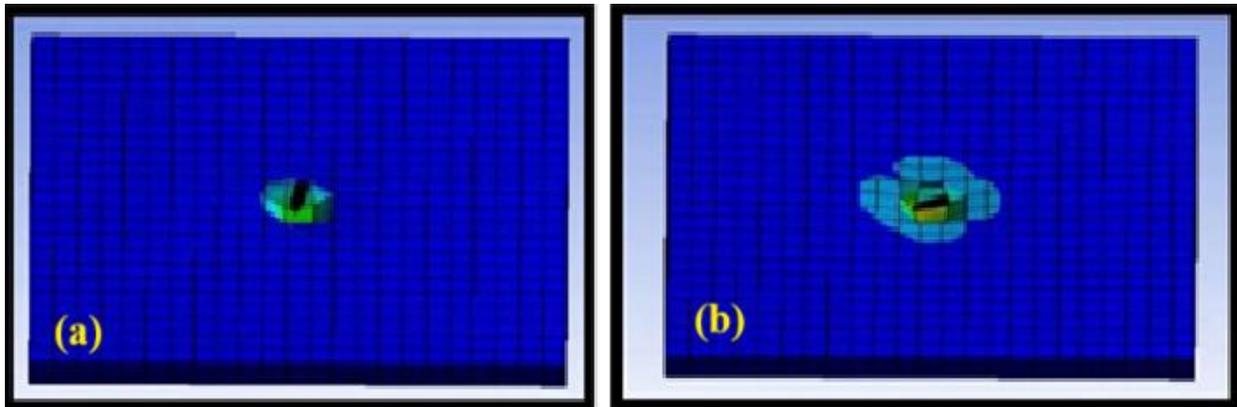


Fig. 8 : (a) Bullet striking the plate (b) Damage by Bullet on Plate

The honeycombed steel structure plate material model with subsequent bullet striking is as shown in Fig. 11 and Fig.12.

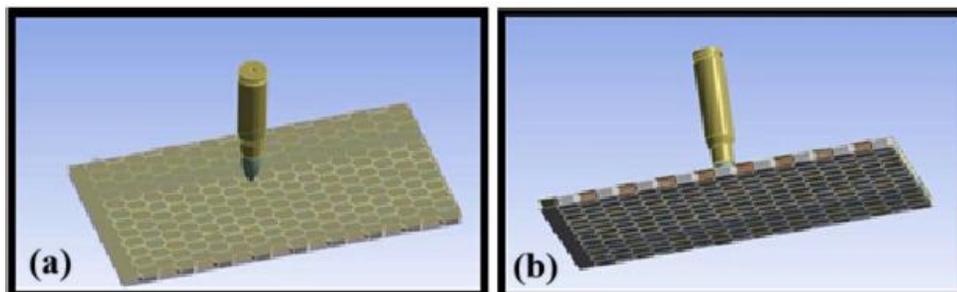


Fig. 9 : (a) Honeycomb Plate with Bullet (b) Mesh of Honeycomb Plate

3 Results & Discussion

Analysis of impact of steel bullet on various plate materials of copper alloy, aluminum alloy, magnesium alloy, titanium alloy and honeycomb steel is shown in Table 1 (Plate thickness 50 mm), Table 2 (Plate Thickness 40 mm) and Table 3 (Plate Thickness 30 mm) respectively.

Table-1 Numerical Values Using Ansys (Plate Thickness : 50mm)

S.No.	Plate Mate Rail	Bullet Mate Rail	Plate thickness (mm)	Bullet Velocity (m/s)	Impact Angle (°)	Complete Damage (Yes/No)	Maximum Equivalent Stress (MPa)	Maximum Equivalent Elastic Stress (mm/mm)	Max. Total Deformation (mm)	Max. Directional Deformation (mm)
1.	Copper Alloy	Stainless Steel	50	300	90	No	279.99	0.48	69.15	67.68
2.	Aluminium Alloy	Stainless Steel	50	300	90	No	280	0.44	73.20	71.68
3.	Magnesium Alloy	Stainless Steel	50	300	90	No	193	0.49	84	82.83
4.	Titanium Alloy	Stainless Steel	50	300	90	No	130	0.064	45.66	40.59
5.	Honeycomb Steel	Stainless Steel	50	300	90	No	175	0.41	55.34	52.68

Von mises stress (equivalent stress) is seen to be minimum (Table 1) in titanium (130 N/mm^2) and honeycomb steel (175 N/mm^2) respectively for 50mm plate thickness. Strain is seen to be minimum in Titanium (0.06) and Honeycomb steel (0.41) respectively and deformation is seen to be minimum in Titanium (45.66mm) and honeycomb steel (55.34mm) respectively. Titanium gives good results there by for this plate thickness followed closely by honeycomb steel, however honeycomb on account of low density and cost may be considered better.

Table-2 Numerical Values Using Ansys (Plate Thickness : 40mm)

S.No.	Plate Mate Rail	Bullet Mate Rail	Plate thickness (mm)	Bullet Velocity (m/s)	Impact Angle (°)	Complete Damage (Yes/No)	Maximum Equivalent Stress (MPa)	Maximum Equivalent Elastic Stress (mm/mm)	Max. Total Deformation (mm)	Max. Directional Deformation (mm)
1.	Copper Alloy	Stainless Steel	40	200	90	No	279.28	0.13	34.59	34.07

2.	Aluminium Alloy	Stainless Steel	40	200	90	No	279.92	0.079	34.50	34.02
3.	Magnesium Alloy	Stainless Steel	40	200	90	No	192.91	0.096	38.44	38.03
4.	Titanium Alloy	Stainless Steel	40	200	90	No	157.84	0.0085	16.21	15.11
5.	Honeycomb Steel	Stainless Steel	40	200	90	No	165.23	0.0096	25.44	22.37

Von mises stress (equivalent stress) is seen to be minimum (Table 2) in titanium (157.84 N/mm^2) and honeycomb steel (165.23N/mm^2) respectively for 40mm plate thickness. Strain is seen to be minimum in Titanium (0.008) and Honeycomb steel (0.009) respectively and deformation is seen to be minimum in Titanium (16.21mm) and Honeycomb steel (25.44mm) respectively. Titanium gives good results there by for this plate thickness also followed closely by honeycomb steel, however honeycomb on account or low density and cost maybe considered better.

Table-3 Numerical Values Using Ansys (Plate Thickness : 30mm)

S.No	Plate Mate Rail	Bullet Mate Rail	Plate thickness (mm)	Bullet Velocity (m/s)	Impact Angle (°)	Complete Damage (Yes/No)	Maximum Equivalent Stress (MPa)	Maximum Equivalent Elastic Stress (mm/mm)	Max. Total Deformation (mm)	Max. Directional Deformation (mm)
1.	Copper Alloy	Stainless Steel	30	100	90	No	194.97	0.0042	7.35	7.35
2.	Aluminum Alloy	Stainless Steel	30	100	90	No	247.06	0.0035	8.06	8.06
3.	Magnesium Alloy	Stainless Steel	30	100	90	No	182.04	00046	11.40	11.45
4.	Titanium Alloy	Stainless Steel	30	100	90	No	100.40	0.0031	4.43	4.43
5.	Honeycomb Steel	Stainless Steel	30	100	90	No	136.43	0.0042	6.53	5.23

Von mises stress (equivalent stress) is seen to be minimum (Table 3) in titanium (100.40 N/mm^2) and honeycomb steel (136.43N/mm^2) respectively for 30mm plate thickness. Strain is seen to the minimum in Titanium (0.003) and Honeycomb steel (0.004) respectively and deformation is seen to be minimum in Titanium (4.43mm) and Honeycomb steel (6.53mm) respectively. Titanium gives good results there by for this plate thickness also followed closely by honeycomb steel, however honeycomb on account of low density and cost may be considered better.

The von mises stress during a projectile impact on a plate will depend on various factors, including the projectile's characteristics, impact velocity, the material properties of the plate (honeycomb steel, titanium alloy, magnesium alloy, aluminum alloy and copper alloy) and the plate's thickness and

geometry. Here's a general comparison, considering the scenario of a projectile impact on honeycomb steel plate. Honeycomb steel, with its high strength to weight ratio, can potentially exhibit lower von mises stress during a projectile impact compared to materials like aluminum and magnesium. The specific stress levels will depend on the exact properties of the honeycomb steel used, plate thickness, and the impact conditions.

The von mises strain during a projectile impact on a plate will depend on various factors, including the projectile's characteristics, impact velocity, the material properties of the plate (honeycomb steel, titanium alloy, magnesium alloy, aluminum alloy and copper alloy) and the plate's thickness and geometry.

It's crucial to note that the actual von mises strain experienced during a projectile impact is influenced by various factors and engineers typically conduct detailed simulations, experiments, and analyses to assess the impact resistance of materials in specific applications. The design of the plate and the projectile characteristics will play a significant role in determining the strain distribution and the ability of the material to absorb and dissipate the impact energy.

The total and directional deformation of a plate during a projectile impact is a complex phenomenon influenced by various factors, including the projectile's characteristics, impact velocity, the material properties of the plate (honeycomb steel, titanium alloy, magnesium alloy, aluminum alloy, and copper alloy) and the plate's thickness and geometry. Additionally, the specific design of the honeycomb structure can influence deformation patterns.

The total deformation in honeycomb steel depends on its ability to absorb and distribute impact energy. The honeycomb structure can contribute to energy absorption and may lead to controlled deformation. The directional deformation in honeycomb steel will be influenced by the orientation of the honeycomb cells and the impact direction. The honeycomb structure may provide some directional control of deformation.

In general, materials with higher strength, rigidity and toughness are preferred for applications where impact resistance is crucial. Titanium and steel are often chosen for their ability to withstand high-stress impacts and the choice between them may depend on factors like weight considerations and cost. It's crucial to note that the actual von mises stress experienced during a projectile impact is influenced by various factors, and engineers typically conduct detailed simulations, experiments,

and analyses to assess the impact resistance of materials in specific applications. The design of the plate and the projectile characteristics will play a significant role in determining the stress distribution and the ability of the material to absorb and dissipate the impact energy.

Detailed numerical simulations, experiments, and analyses specific to the projectile and plate design are typically conducted to assess total and directional deformation accurately. The results can guide material selection and structural design for optimal performance under impact conditions.

4 Conclusion

Based on above results discussed in the present study, the Honeycomb structure is seen to be more suitable compared to other materials for its low cost per unit weight, strength, durability and reliability. Looking at all the analysis here we can conclude that aluminum is harder than copper when bullet velocity effect is considered. More the distance between a fired bullet and the plate the faster the bullet travels irrespective of velocity. The less distance, the Bullet cannot completely pierce the plate. Honeycomb structures allow for the minimization of materials to save on both weight and cost during the design process.

In summary, the choice of material for a plate subjected to projectile impact involves trade-offs between strength, ductility and weight considerations. Strong and ductile materials like titanium and steel are often preferred for applications where controlled deformation and energy absorption are critical.

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