Impact Analysis of composite material for bulletproof vests

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Abstract - *This project addresses the growing importance of bulletproof vests in safeguarding individuals within high-risk occupations, particularly law enforcement and military personnel. Bulletproof vests serve a dual purpose as both a barrier and an energy absorber, mitigating the impact of bullets and protecting users. Our study employs the Finite Element Method (FEM) to conduct an impact analysis, focusing on Three primary composite materials used in bulletproof vests: Aramid , Ultra-high-molecular weight polyethylene (UHMWPE) , ceramic .*

Key Words: Impact analysis, Bullet proof vest, Composite materials, Aramid, UHMWPE, Ceramic.

1.INTRODUCTION

1.1 Etymology

In a dynamically changing world where prioritizing personal safety is paramount, the continuous advancement of effective protective gear has emerged as a pivotal focus of research. Within the spectrum of protective equipment, bulletproof vests stand out as indispensable guardians, playing a critical role in ensuring the safety and well-being of law enforcement personnel, military operatives, and individuals engaged in high-risk professions.

Bulletproof vests, alternatively referred to as ballistic vests or body armor, are meticulously crafted to offer dependable protection against ballistic threats, including bullets and projectiles. These exceptional pieces of equipment boast a storied history, undergoing continuous evolution to achieve enhanced characteristics such as greater lightweight design, flexibility, and the capacity to withstand the impact of progressively powerful firearms.

The efficacy of bulletproof vests is intricately tied to the materials employed in their construction. Early iterations of these vests featured thick layers crafted from materials like silk, leather, and even metal plates. Nevertheless, the landscape of body armor underwent a transformative shift with the advent of composite materials, marking a substantial leap in protective technology. This innovation not only elevated the level of safeguarding but also resulted in a remarkable reduction in both weight and bulkiness, redefining the standards of modern body armor.

Composite materials represent an innovative class of engineered materials formed by the amalgamation of two or more constituent materials, each possessing distinct properties. This strategic combination is tailored to harness the strengths of each component, yielding performance characteristics that surpass those of individual materials used in isolation. Within the realm of bulletproof vests, the integration of composites has ushered in a transformative era, fundamentally altering the landscape of protective gear. This advancement has facilitated the development of lightweight, flexible, and exceptionally effective body armor, marking a paradigm shift in the approach to personal protection.

1.2 Composite Material

Composite materials, comprising two or more distinct phases, are strategically combined to attain specific properties such as strength, stiffness, and toughness. In the realm of bulletproof vests, these materials form protective layers capable of absorbing and distributing the impact of a bullet. Aramid fibers, Kevlar, and ultra-high molecular weight polyethylene (UHMWPE) fibers are widely employed in bulletproof vests. Aramid fibers, known for their high strength�to-weight ratio, offer exceptional ballistic protection, while UHMWPE fibers, with their lightweight nature, provide excellent ballistic defense. Kevlar is incredibly strong, about five times stronger than steel by weight. these materials have demonstrated superior protective capabilities in various studies.

Aramid fibers, derived from synthetic polymers containing amide groups, boast high tensile strength, a superior modulus, and exceptional resistance to abrasion, heat, and chemicals. Their lightweight design enhances their ballistic protection against high-velocity projectiles. On the other hand, UHMWPE fibers, crafted from extended polyethylene molecules, exhibit an impressive strength-to-weight ratio, excelling in strength for their weight. These fibers are highly resistant to abrasion, chemicals, and UV radiation, providing robust ballistic protection against high-velocity projectiles.

1.3 Materials Properties

Comparison of some properties of Aramid and UHMWPE fibres and ceramic

S.No	Properties	Aramid	UHMWPE	Ceramic
1	Tensile	High Tensile strength of 3-Gpa	Even higher tensile strength of 3.5-4.5 GPa	Comparable tensile strength (approx. 3-4 Gpa)
2	Elasticity	Low elasticity Young's modulus: 70-140Gpa	High elasticity Young's modulus: 80-150Gpa	Low elasticity similar to aramid for durability
3	Abrasion Resistance	Excellent abrasion resistance	Good abrasion resistance	High abrasion resistance for prolonged effectiveness
4	Chemical Resistance	Good chemical resistance	Good chemical resistance	Resistant to checmicals, suitable for diverse environments
5	Heat Resistance	Good heat resistance, melting point: 500-600 degree	Lower melting point: 130-150 degree	High heat resistance with a melting point beyond 1600 degree

1.4 ARMOR CLASSIFICATION FOR BALLISTIC RESISTANT ARMOR

IS 17051:2018 serves as the principal standard in India for assessing the ballistic resistance of personal body armor, particularly bullet-resistant jackets. Specifically designed for use by law enforcement and military personnel, this standard delineates the minimum performance requirements across seven threat levels. It provides explicit testing protocols, performance criteria, and a comprehensive certification process for bullet-resistant jackets in accordance with Indian regulations

Table 2: Threat Levels for bullet resistance jackets as per IS17051 : 2018

S.No	Threat Level	Bullet Weight	Bullet Type	Impact Velocity (m/s)	Distance of impact (m)
1	1	7.4–8.2	FMJ/Pb	500 ± 15	5 ± 0.5
2	2	7.45 –8	FMJ/MSC	710 ±15	10± 0.5

FMJ : Full Metal , Pb: Leab Core , MSC : Mild steel Core

2. RESEARCH METHODOLOGY

2.1 INTRODUCTION TO ANSYS

In the project report, Ansys Explicit Dynamics was employed for analyzing the impact on composite materials used in bulletproof vests. This numerical method is specifically tailored for dynamic and transient events such as impacts, explosions, and crash simulations. Explicit dynamics excels at capturing high strain rates and rapid material responses associated with such dynamic occurrences. When a bullet impacts a composite material, it imparts significant energy over a short duration, resulting in localized deformation and stress concentration. The utilization of explicit dynamics enables accurate simulation of these rapid and transient phenomena, providing precise predictions of material behavior under impact conditions.

In contrast, Implicit dynamics, or implicit time integration, is a method suited for solving problems involving slow and gradual changes in structural behavior over time. Implicit dynamics typically employs larger time step sizes compared to the explicit dynamics approach.

Two numerical methods commonly used for solving impact problems are the Finite Difference Method (FDM) and the Finite Element Method (FEM). FDM is capable of handling complex geometries but requires a structured grid covering the entire domain, often applied to regular grids like Cartesian grids or adapted for irregular grids. On the other hand, FEM is well-suited for intricate geometries and irregular domains, accommodating unstructured meshes where elements are not necessarily aligned regularly. This flexibility makes FEM a popular choice for problems involving complex geometries or regions with varying material properties, aligning with our choice for analysis.

The research stages, as illustrated in the flowchart below, involve a sequential process encompassing various stages and tests to ensure the acquisition of optimal results.

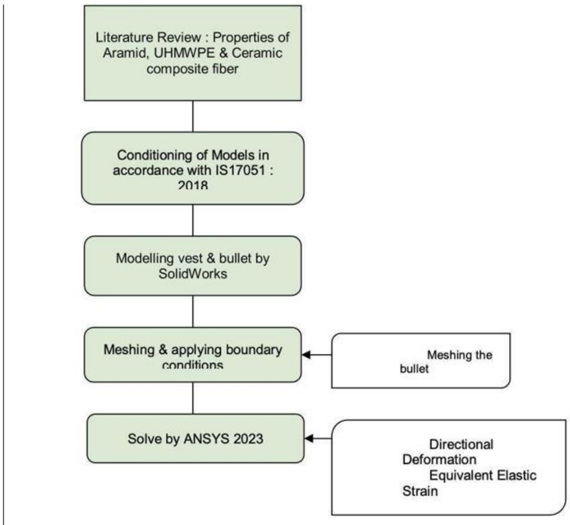


Fig 3 : Process Flowchart

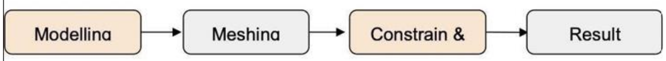


Fig 4 : Simulation Procedures

3.2 Modelling

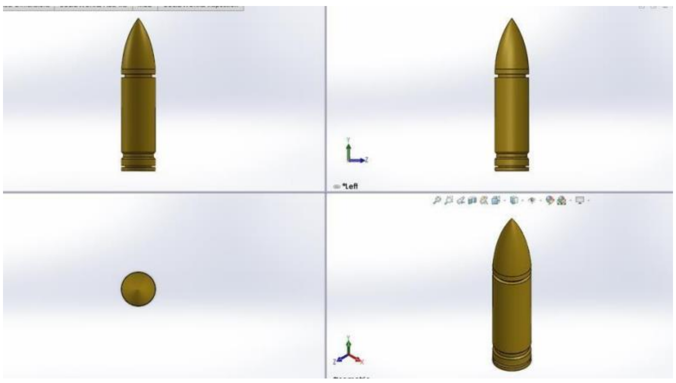
The first step in the analysis is to create models for the Bulletproof vest and the bullet using SolidWorks 3D modeling software package. So to create a ballistic setup, we need to first create the sketches, parts and then assemble its parts i.e. vest and bullet

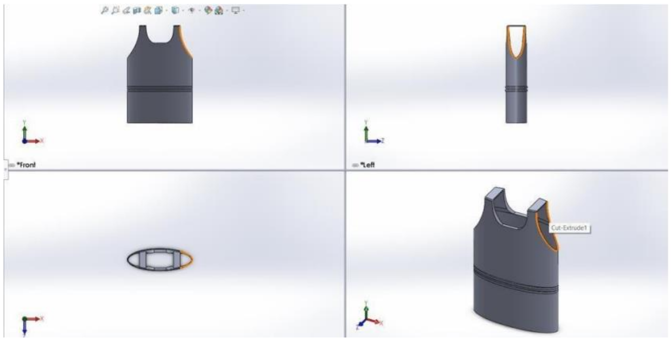
Table 3: Dimensions of Bullets and Bullet Proof-Vest

Threat Levels	Bullet Dimensions	Bullet Weight	Vest Thickness	Distance of Impact
Threat Level 1	9 x 19 mm	7.88 gm	10 mm	5m

Dimensions and weight of bullets are in accordance with the armor classification of **IS17051:2018** given by the Bureau of Indian Standards.

Solidwork Model





3.3 Importing Setup to Ansys

To import the SolidWorks assembly into Ansys software for the analysis, we need to first save the SolidWorks assembly(which is currently in .SLDASM format) to .IGS format, so that it could be easily imported geometry during the explicit dynamics analysis.

These are the steps to do the setup in Ansys :
Step 1: First we need to create a new project in Ansys by opening Ansys Workbench.

Step 2: Now we need to select the analysis system we want to use, here we have used Explicit Dynamics

Step 3: Now the next step is to import the geometry into the Ansys software for FEA analysis

Step 4 : We need to go to the Ansys Mechanical software by right-clicking on the Model Option and then by selecting the Edit option, this will take us to where we will doing the actual analysis part.

Table 4: Meshing in different threat levels

Properties	Threat Level 1	Threat Level 2
Element Size	0.01m	0.03m
Max Size	1.2	1.2
Curvature Min Size	0.005m	0.015m
Element Order	Linear	Linear

Table 5: Boundary conditions on Models at different threat levels

Properties	Threat level 1	Threat Level 2
Speed	500 m/s	710 m/s
Distance of impact	5m	10m
End time	0.012s	0.014s
Result Number of points	20	20
Fixed Support	Both sides & bottom of the vest design	Both sides & bottom of the vest design

3.4 Specifying Post-Processing Desired Results

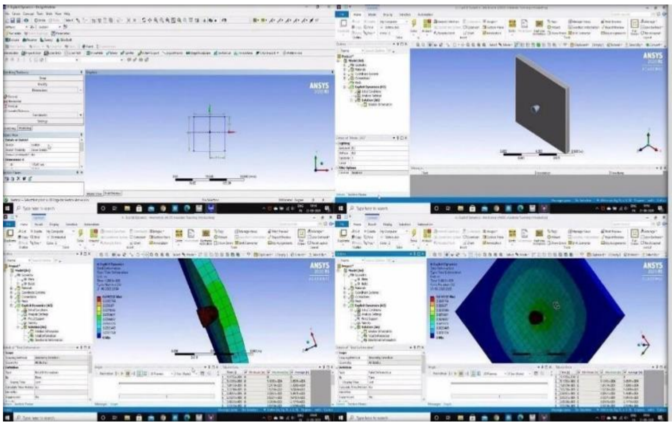
Now, in the final phase, we delineate the specific outcomes sought post-simulation. The ensuing values represent the key parameters obtained upon the completion of the simulation.

1. Total Deformation

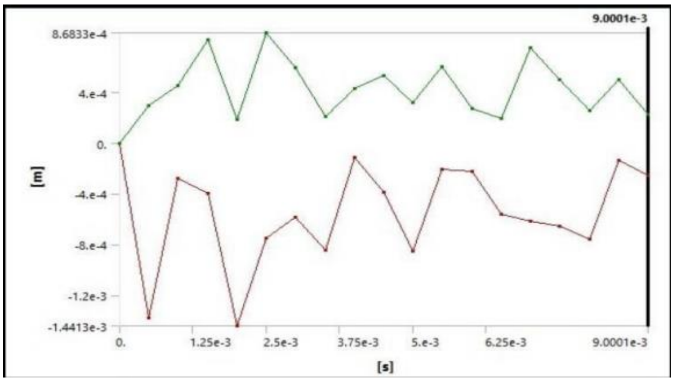
2. Equivalent Stress

3. Equivalent Elastic Strain

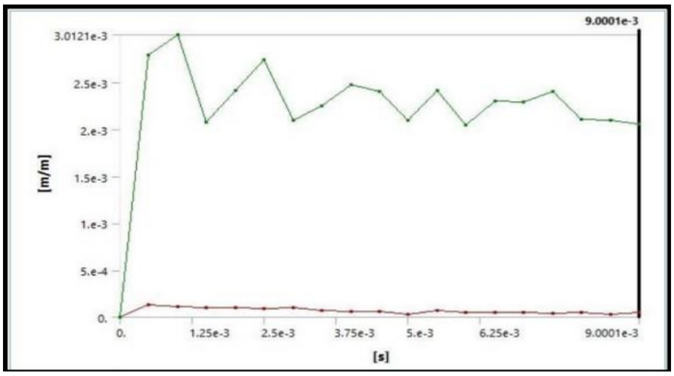
Aramid Bullet Proof Results



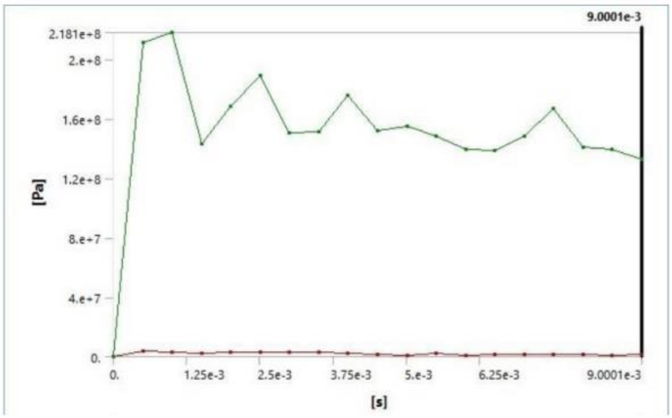
Directional Deformation (X-axis)



Equivalent Elastic Strain



Equivalent Stress



3. CONCLUSIONS

• Conducted impact analysis on bulletproof vests' composite materials (Aramid, UHMWPE) using FEM in SolidWorks and Ansys 2023 R1 software.

• Simlated bullet impact per Bureau of Indian Stanards (IS17051: 2018), assessing deformation, strain, stress, and velocities.

• Identified UHMWPE's better impact distribution while noting Aramid's superior energy absorption and reduced penetration in handgun bullet tests

Vest Fiber	Equivalent Elastic Strain	Equivalent (von - Mises) Stress	Total Deformation	Directional Deformation(X-Axis)
Aramid	2.0552e-003m/m	1.3258e+008 Pa	2.5934e-004 m	2.2066e-004 m
UHMWPE	2.0552e-003m/m	1.3258e+008 Pa	1.974e-004 m	2.0089e-004 m
Ceramic	2.0552e-003m/m	1.3258e+008 Pa	2.774e-004 m	2.5043e-004 m

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