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Ballistic Analysis of Composite Materials

P. Sugandhan[1], S.Thirumavalavan[2]
[1]Graduate Student, [2]Assistant Professor
Department of Mechanical Engineering, Bharath University, Chennai – 600 073, India
Corresponding Author: P. Sugandhan

ABSTRACT
Laminated ballistic composite may be used in protective helmets or with ceramics and other materials like fiber reinforced polymers (FRP) for protective body amour. It is used in several industries such as Aviation sector, defense and general purpose Helmet making industries. It requires several high cost equipment for the testing and analyzing of the material. While the use of computer simulation software like ANSYS help researchers to analyze these type of problems very easily. The failure of an alloy of Structural Steel, Carbon composite and E-Glass are analyzed under high-velocity impact of round tool of different materials using the FEM software, ANSYS Workbench 15. Impact velocity of 300 m/s was analyzed by FEM simulation. In this analysis the thickness of the plate was kept constant but the layer of the plate was changed.

Keywords: *Ballistic Analysis, Composite, Finite Element Method*

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I. INTRODUCTION

Composite materials that are fiber-reinforced are used in several demanding fields that requires ballistic protection. This is due to their outstanding mechanical properties, flexibility in design capabilities, ease of fabrication and good corrosion, wear and impact resistant [6].

When a handgun bullet strikes body armor, it is caught in a "web" of very strong fibers. These fibers absorb and disperse the impact energy that is transmitted to the vest from the bullet, causing the bullet to deform or "mushroom." Additional energy is absorbed by each successive layer of material in the vest, until such time as the bullet has been stopped. Because the fibers work together both in the individual layer and with other layers of material in the vest, a large area of the garment with composite technology becomes involved in preventing the bullet from penetrating. This also helps in dissipating the forces which can cause no penetrating injuries (what is commonly referred to as "blunt trauma") to internal organs. Unfortunately, at this time no material exists that would allow a vest to be constructed from a single ply of material. People have always attempted to protect themselves against their enemies and the weapons being used, but this has always been balanced by their need to be mobile. The earliest form of armor was not intended to protect any form of transportation but to protect the person. When the scale of attack was dramatically increased with the advent of fire arms, any form of protection was easily overmatched and it was soon abandoned in favor of the greater mobility given to the individual. When the need for fighting vehicles was arisen, the importance of achieving lightweight protection has also been recognized. The design of composite armor is a very complex task as compared to conventional single-layer metallic armor, due to the exhibition of coupling among membrane, torsion and bending strains, weak transverse shear strength and discontinuity of the mechanical properties along the thickness of the composite laminates. This has drawn attention of several researchers to study the penetration phenomenon in composite amours. The impact resistance and subsequent load-bearing capacity of composite depend on many factors such as fibre and matrix properties, fibre-matrix lay-up, number of layers or ply, thickness, and impact velocity [7].

This paper explains about failure of an alloy of Structural Steel, Carbon composite and E-Glass are analyzed under high-velocity impact of round tool of different materials using the FEM software, ANSYS Workbench 15. The impact velocity of 300 m/s is analyzed by FEM simulation. In this analysis plate thickness was kept constant but combination of plate layer was changed.

1.1 Objective

The main focus of this research work is to study the response of plate made of different composite materials when impacted at high velocity of 300m/s by using finite element analysis. Some of the objectives are to determine the effect of high velocity impacts on plates made of different composite materials, to analyze the deformation as well as residual velocity distribution of the plates made up of composite materials, when struck by a bullet at velocity of 300 m/s to evaluate the deformation occurred on plates after the impact at particular velocity.

II. MATERIAL SELECTION

At present Kevlar composites are very promising material due to unique mechanical properties mostly used in aerospace and army utilities, where impact energy absorption and high strength to weight ratio material required. Only DuPont have the patent rights for Kevlar 29 and Kevlar 49. So cost of material is high as compared to other materials. We need a replacement for Kevlar fiber in industries like Aviation sector, War and general purpose Helmet making industries, War equipment industries use high velocity impact analysis for design purposes. This paper explains about ballistic impact on composites such as Carbon/Epoxy Composite, E-Glass Composite, SS304.

2.1 Carbon/Epoxy Composite

Carbon fibre reinforced composites have exceptional mechanical properties. These strong, stiff and lightweight materials are an ideal choice for applications where lightweight & superior performance are important, such as components for aircraft, automotive, rail and high quality consumer products. Composite materials are produced by combining a reinforcing fibre with a resin matrix system such as epoxy. This combination of fibre and resin provides characteristics superior to either of the materials alone and are increasingly being used as replacements for relatively heavy metallic materials. In a composite material, the fibre carries the majority of the load and is the major contributor to the composite material properties. The resin helps to transfer load between fibres, prevents them from buckling and binds the materials together. Carbon fibres are produced from polymer fibres such as polyacrylonitrile and from pitch. The initial fibre material is drawn under tension whilst it is heated to around 1000°C causing 2 dimensional carbon-carbon crystals (graphite) to be formed when hydrogen is driven out. The carbon-carbon chain has extremely strong molecular bonds and this is what gives the fibres their high strength.

2.2 E-Glass Composite

E-Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fibre forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fiberglass.

2.3 SS304 Composite

Stainless steel 304 is considered to be one of the versatile and durable stainless steel among the other steels. Stainless steel 304 is the most versatile and the most widely used of all stainless steel. Its chemical composition, mechanical properties, weld ability and corrosion/ oxidation, resistance provide the best all round performance stainless steel at relatively low cost. It also has excellent low temperature properties and response well to hardening by cold working. If inter granular corrosion in the heat affected zone may occur, it is suggested that SS304L be used. And for industrial grade equipment, SS304HQ or SS304H can be used is wider range.

2.4 Material Dimensions

The Carbon/Epoxy composite, E-Glass composite, SS304 composite Plate of 300 mm x 300 mm x 3 mm size have been used for the analysis.

III. DESIGN

Designing has been done in CATIA V5. In the design, we used square plate which has dimension of 300 X 300 X 3 mm. Carbon/Epoxy composite, E-Glass composite and SS304 were modelled under the same specifications. Modeling of the composite plates are shown in fig 3.1 and the projectile is having cylindrical body with sharp shape. The diameter of the projectile is 7.62mm and the shank length is 13.81mm and the target is square plate with 3 mm thickness. For both projectile and target, full geometry is used for the simulation since both material and deformation pattern are axisymmetric in nature. The projectile shape is shown in fig. 3.2

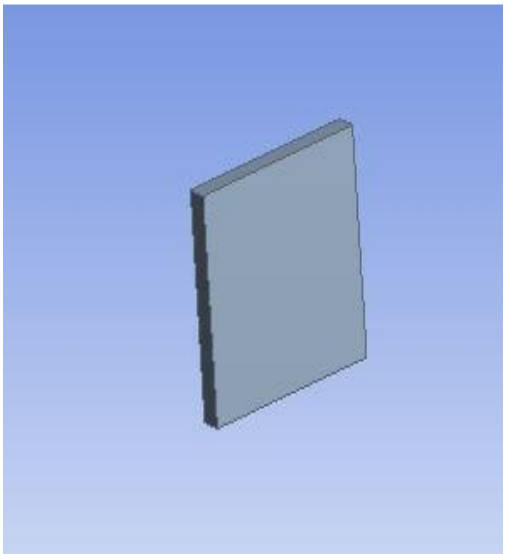

Fig.3.1 Design of the composite plate

Fig 3.2 Predicted vs. Actual plot for surface roughness

IV. FEA ANALYSIS

FEM techniques are useful to get solution of differential and integral equations having complex geometries of real world. With the help of this technique real complex problems are now solvable without any experimental work. The method essentially consists of assuming the piecewise continuous functions for the problem solution and obtaining the final parameters of the functions in a manner that reduces the error in the analytical solution. Although this method has become a popular trend in characterizing composite materials, it must be used with a precaution and be always validated by experimental work. It is also doubtful that experimental testing can be replaced totally by finite element analysis; rather it is probably a compliment to each other. Meshing is important parameter in finite element analysis. Based on meshing we will have better results. TETRA elements are used for meshing. No of elements created in meshing is 424. Meshed models are shown in fig 3.3 and fig 3.4.

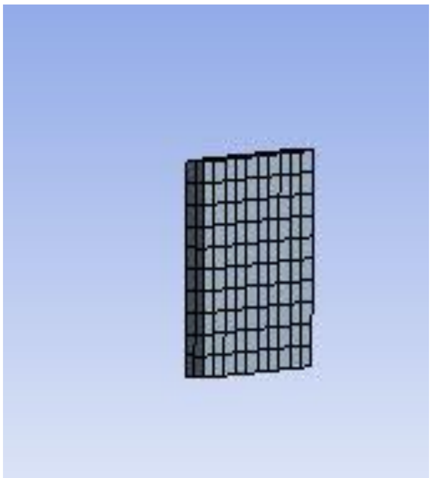

Fig.3.3 Meshing of the composite plate

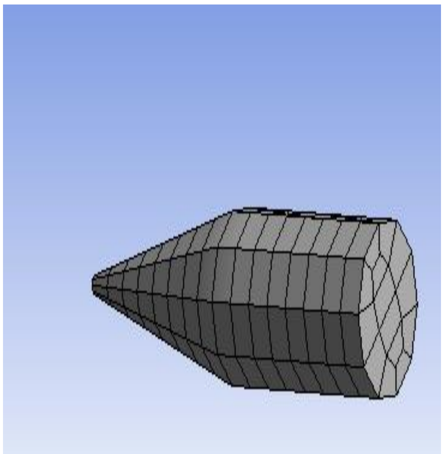

Fig 3.4 Meshing of the projectile

V. RESULTS AND DISCUSSION

The analysis is carried out using ANSYS Workbench 15. The results of the composites are listed and by which the material Carbon/Epoxy composite and E-Glass composite are subjected to directional deformation and SS304 with directional deformation and directional velocity.

5.1. Carbon/Epoxy composite

Plate - The material of the plate is considered here to be Carbon/Epoxy Composite.
Projectile- The material of the conical bullet used is Steel 4340 which is default for the handgun.

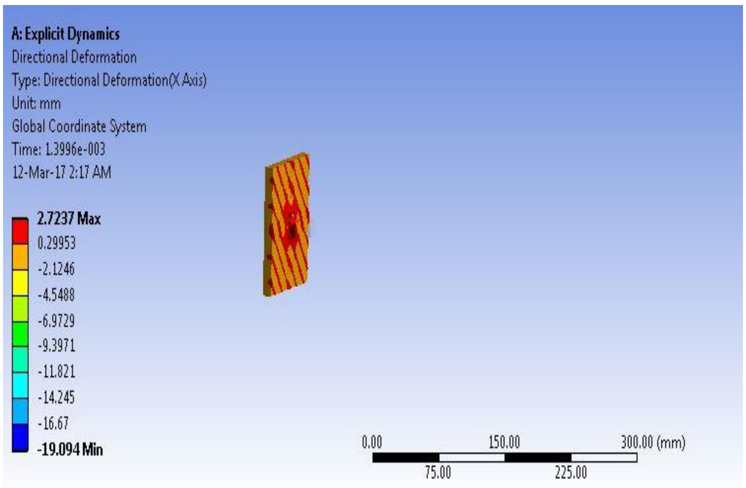

Fig.5.1 Analysis of the Carbon/Epoxy composite plate

5.2. E-Glass Composite

Plate - The material of the plate is considered here to be E Glass Composite.
Projectile- The material of the conical bullet used is Steel 4340 which is default for the handgun.

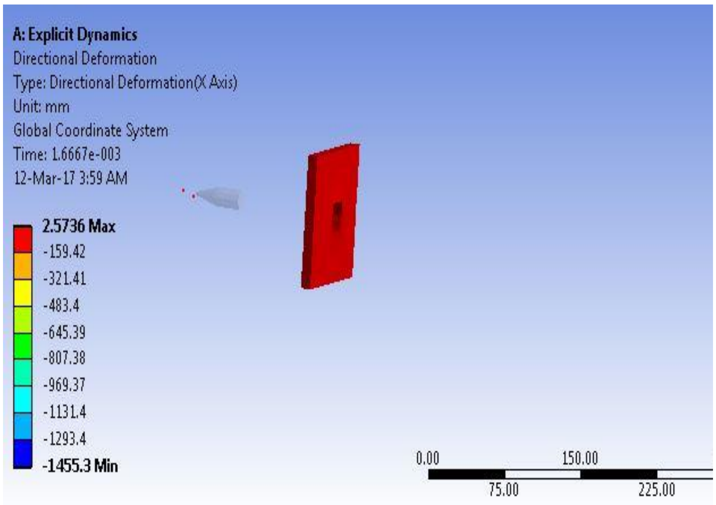

Fig.5.2 Analysis of the E-Glass composite plate

5.2. SS304 Composite

Plate - The material of the plate is considered here to be SS304.
Projectile - The material of the conical bullet used is Steel 4340 which is default for the handgun.

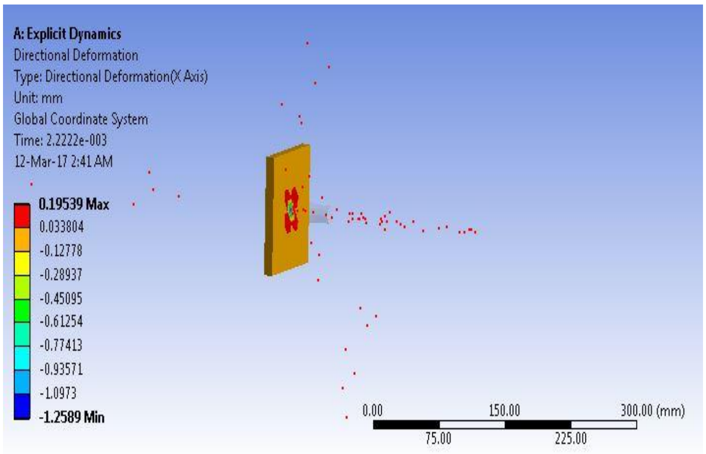

Fig.5.3 Directional deformation of SS304 composite plate

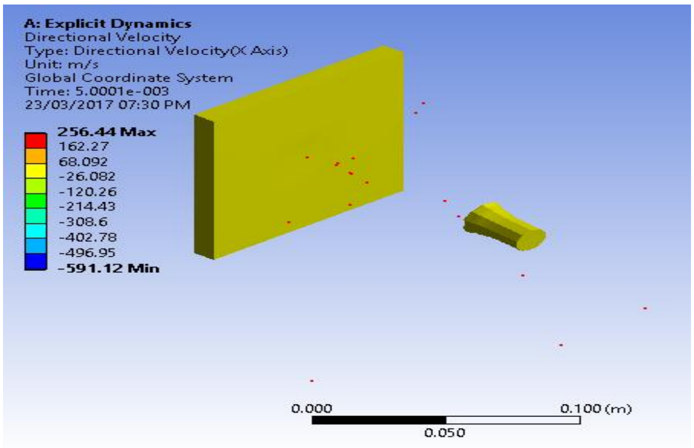

Fig.5.4 Directional Velocity of SS304 composite plate

From fig 5.1 analysis of Carbon/Epoxy composite is done by which the directional deformation states the maximum index of 2.7237mm and minimum of -19.094mm deformation. Which reflects the inability of its usage in the field of defense. Fig 5.2 is the directional deformation analysis of E-Glass composite which results in the maximum deformation of 2.5736mm and minimum of -1455.3mm. Finally, from the fig. 5.3 and fig. 5.4 the directional deformation of SS304 and directional velocity of SS304 respectively results in the maximum deformation of 0.19539mm and minimum deformation of -1.2589mm that states the capacity to withhold high tension of projectiles and fast moving bodies in defense and aviation field. The deformation is listed in the table 5.1

Table.5.1 Deformation of the composite materials

Case	Material	Deformation (mm)	
		Maximum	Minimum
1	Carbon/Epoxy composite	2.7237	-19.094
2	E-Glass composite	2.5736	-1455.3
3	SS304	0.19539	-1.2589

VI. CONCLUSION

The design and analysis of the composite materials are subject to identify the deformation and its state to utilize in the field of defense and other important sectors. The result and deformation of the materials are found to be

- Carbon/Epoxy composite which does not withstand the projectile force of 300m/s and deformed at the maximum rate of 2.7237mm.
- The E-Glass also analysed under the same projectile force which resulted in failure like the Carbon/Epoxy composite. The E-Glass resulted in maximum deformation of 2.5736mm.
- The SS304 composite is the stronger among the other two materials. The result is tabulated from its directional deformation and velocity under the constant projectile force of 300m/s. The SS304 resulted in the maximum deformation of 0.19539mm and it states that the capability of its usage under heavy load conditions.

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