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EXPERIMENTAL AND NUMERICAL SIMULATION OF BALLISTIC IMPACT ON GLASS FIBRE REINFORCED PLASTIC COMPOSITE PANELS

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Abstract

Ballistics is defined as the science dealing with a great variety of phenomena that occur during the impact of a projectile on a target. Demand for light weight armors, made composites more familiar in the field of armor system for personal protection. The study of ballistic impact by conducting experimental test is expensive and time consuming. Due to the complexity and costs related to ballistic experiments it is not optimal to base all impact related studies on laboratory tests alone. Therefore, a general solution technique is needed as a supplement to high-precision testing in order to reduce the experimental needs and costs to a minimum. Numerical simulation of ballistic impact of a steel projectile on glass fibre reinforced plastic composite Panel is investigated to get the knowledge in numerical simulation using 3-D nonlinear dynamic explicit finite element code. The plastic kinematic hardening material model is used. Finite element simulations are carried out with semi spherical nose bullet. Knowledge gained in this analysis is extended to understand the material behavior under impact of glass-epoxy laminate using ANSYS/AUTODYN a general purpose non-linear dynamicmodeling and simulation software. Trial simulations are conducted and results are discussed.

Keywords: Finite element Simulation, ballistic Impact, composite panel, Ballistic limit, Experimental results.

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INTRODUCTION

Fibre Reinforced Polymer matrix composites have been considered for armour applications in automobile field, where velocity is in the range of 30-100 m/s. Glass fibre being more popular than other types of fibre because of their cost advantage. In this article, medium velocity impact on Glass/epoxy laminates consists of two sets of composite plates (5 layers of WRM/epoxy and 8 layers of WRM/epoxy laminates with different fibre orientation) was studied. A mild steel cylindro-conical projectile with a mass of 554.0 gm was used in the experiment. A piston type gas gun set up was employed to impact the composite panels. Tests were conducted with 54 m/s projectile velocity. From the experimental results, residual velocity and the energy absorption were observed. During experiments, the bullet strikes the target with some inclination. Consequently, the exit velocity was also reduced. The damage and delamination were more at the rear face of the target. Cracks formed around the damage portion are in the direction of fibre orientation. Numerical simulation of bullet impact was conducted.

Preparation of Specimen

Two sets (5 layers of WRM/epoxy and 8 layers of WRM/epoxy laminates with different fibre orientation) of composite panels were prepared by hand lay-up technique. LY556 Araldite was used as the epoxy matrix and HY951 as the corresponding hardner. WRM mats with an aerial density of 610 gsm were used. Proper care was taken during manufacturing to ensure uniform and even thickness. A volume fraction of 50% was maintained for all the laminates. The laminates were cured in room temperature and left in the mold for three days for complete curing. The panels were cut to a size of 290×260 mm by a band saw cutter and the edges were trimmed. For conducting the quasi-static tests two panels (having 00 and 450 fibre orientation to the loading direction) were prepared by hand lay-up technique. The same materials and proportions of materials are taken to prepare the panels. By using the band saw cutter, specimens were cut to the required size. Edge tapes were prepared for the specimens by hand lay-up process for better gripping. Three strain gauges were pasted in length, width, thickness directions respectively to measure the strains in all directions.

Experimental Tests

Quasi-Static Test

Uni-axial tensile tests were performed on the specimens using Universal Testing Machine. The strain gauges were pasted in all the three perpendicular directions to determine the mechanical properties as shown in Figure 1. Table 1 shows the mechanical properties of Glass/epoxy composite.

Table 1. Mechanical properties of Glass/epoxy composite

Material Property	Value
Young's Modulus E11,E22	220.43 MPa
Young's Modulus E33	8.56 MPa
Poisson's Ratio ν12, ν31	0.13
Poisson's Ratio ν23	0.84
Shear Modulus, G12	38 MPa
Bulk Modulus	178 MPa
Failure Stress σ11,fail, σ22,fail	45 MPa
Failure Stress σ12,fail	19 MPa

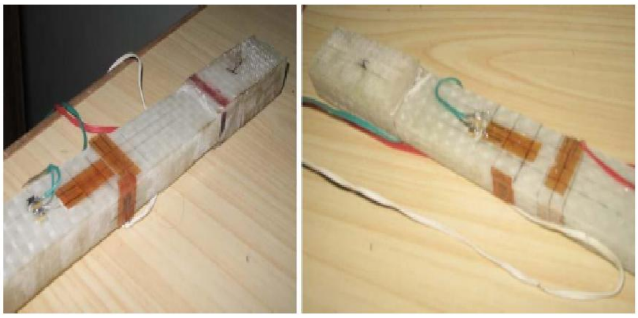

Figure 1. Uni-axial tension test specimens having fibre orientation 0^0 and 45^0

Impact Test

A series of medium velocity impact tests were performed on the composite panel using a piston type gas gun setup. The outline diagram of experimental setup is shown in Figure 2 and actual setup in Figure.3. The gun consists of a charging chamber having inlet for charging and outlet for releasing at one end, and a provision to fit 3.5m long barrel at other end. A 2.5 m nozzle made of FRP was attached to the other end of the barrel in to which the projectile was placed. A stopper was attached to the FRP nozzle to prevent the projectile from getting into the steel barrel. A Projectile of mass 554 gm made of mild steel was used in the experiment shown in figure 4. The details of the projectile are given in Table 2.

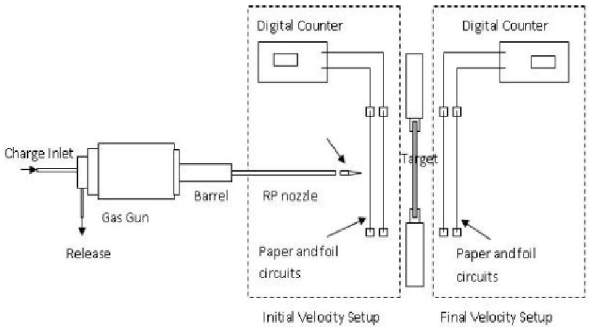

Figure 2. Outline Diagram of Experimental setup

Figure 3. Experimental Setup

Figure 4. Cylindro-Conical projectile

Table 2. Projectile Characteristics

Characteristics	Projectile
Length of the Projectile (Lp)	99.5 mm
Shank Length (Ls)	46.0 mm
Nose Length (Ln)	53.5 mm
Projectile Radius (Rp)	19.63 mm
Mass (M)	554.0 gm
Cone angle (θ)	35.5^0

The specimen was mounted in a holder fixture and clamped on all sides. The fixture along with the target was placed perpendicular to the direction of projectile, at a distance equal to 1.0 m the end of the nozzle. The gap between the target fixture and the end of the nozzle was used to fit the setup for measuring the initial velocity of the projectile. The projectile was placed inside the nozzle and accelerated by opening the release valve (after charging the charging chamber of the gas gun setup with compressed air up to the required pressure). The variation between the projectile velocity and the charging pressure was linear and shown in Figure 5. The initial velocity and residual velocity of the projectile were determined by a simple set up. It consists of two papers of 500 mm × 500 mm on to which continuous strips of aluminium foil were pasted in a zigzag fashion to form an opened circuit. The two ends of the circuit were connected to a battery source. The papers were separated by a distance and connected to an electronic counter to form a closed circuit. The distance between the papers was noted. Once the projectile penetrated the target, it pierced the paper and opened the circuit, there by triggering the counter. During medium velocity impact, the possibility of the formation of debris cloud was less and hence this setup could produce a reliable result. From the counter, the time taken by the projectile to travel between the papers was noted. The initial, final velocities and the corresponding kinetic energies of the projectile were calculated from the counter value and thus the energy absorption. After performing the impact test, the surface and internal damages in the target were thoroughly analyzed. The delamination area was also visualized. It was repeated for all the specimens.

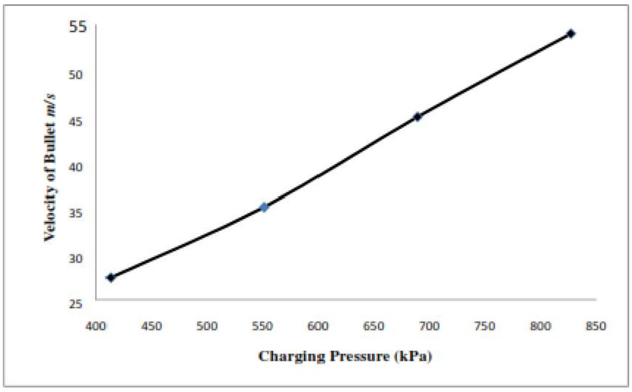

Figure 5. Variation of charging pressure with velocity of bullet.

RESULTS AND DISCUSSION

All the composites sets were tested with cylindro-conical projectile at a velocity of 54 m/s. During experiments, the bullet strikes at normal for few target panels only, and for remaining it is striking with some inclination to the normal. Because of this inclination, the impacted area was increased and residual velocity was reduced. The observed results are tabulated as follows in table 3.

Table 3. Target panel details and experimental results

Laminate	Laminate orientation code	Thicknes s (mm)	Impact velocity (m/s)	Residual Velocity (m/s)	Energy absorption
1-1	[05]	4.03	54	1.08	807.41 Nm
1-2	[05]	4.03	54	2.67	805.76 Nm
2-1	[0/453/0]	4.2	54	0.94	807.49 Nm
2-2	[0/453/0]	4.18	54	3.28	804.75 Nm
4-1	[0/456/0]	6.22	54	50.57	99.46 Nm
4-2	[0/456/0]	6.02	54	20.48	691.55 Nm

From the experimental results, it was observed that 5 ayered laminate was absorbing more energy because of inclination of bullet while striking. It is observed that for a laminate 4-1. The bullet strike normally, results in more residual velocity. Figure 6 shows the damage of panel 4-1 under bullet impact.

Figure 6. Damage pattern of laminate 4-1 under bullet impact

From the Figure 6, it is observed that failure occurs due to the combination of punching shear and intra-lamina shear. It occurs at the rear face of the panel, unlike metals where composites fail at non-impact zone. The punching is high compared to delamination, which occurred around the plug and due to impact radial cracks were formed. From the Figure, it is observed that the major crack is in the direction of fibre orientation because of normal impact. Figure 7 shows the damage pattern of laminate 1-2 under bullet impact and it is observed that failure was due to punching and delamination. The delamination was high, compared to punching doe to inclination of impact. The plug was in the form of elliptical rather than circular resulted in more absorption of energy.

Figure 7. Damage pattern of laminate 1-2 under bullet impact

From the above Figure, it is observed that delamination occurred in both front and rear surfaces (unlike the failure in laminate 4-1). This laminate showed the petal formation after impact and the major cracks are in the direction of fibre orientation.

Numerical Simulation

Geometric modeling

The projectile and target plate used for impact test are shown in Fig 8. The characteristics of projectile are presented in Table 2. The dimension of target panel is 290mm×260mm. A potential impact region of 120mm×120mm is considered to conduct the numerical simulation. The initial thickness of target is considered as 6.2 mm. The projectile and target are discretised by mapped meshing. The finite element model is shown in Fig 9.The initial velocity for projectile is 54 m/s and boundary condition for target plate is fixed. Here, translational degrees of freedom of each node were constrained. At the impacted region the finer mesh is considered for better results.

Fig 8. Projectile and Target plate used in impact test

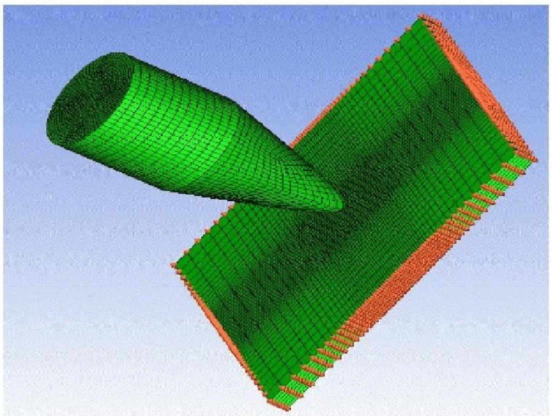

Fig 9. Finite element model of projectile impact on composite target

Material Properties

The projectile is made up of mild steel and Plastic kinematic hardening material model is considered. The target material is made up of Glass/epoxy composite. The material properties are described below.

Table 4. Material Properties of Mild Steel

Reference Density, □	7850kg/m3
Equation of State	Linear
Bulk Modulus, K	175GPa
Strength: Cowper Symonds	
Shear Modulus, N	80.77 GPa
Yield Stress, □y	250MPa
Tangent Modulus,B	21GPa
Hardening exponent, n	1
Strain rate parameter, D	40 (Cowper-Simonds)
Strain rate parameter, q	5 (Cowper-Simonds)

From experiments, it is observed that the material is not eroding. So, failure and erosion models are not considered for the projectile.

Table 5. Material properties of GLASS/EPOXY COMPOSITE

Reference Density, □	1870kg/m3
Equation of State	orthotropic polynomial
Young's Modulus, E33	8.56MPa
Young's Modulus, E11	220.43MPa
Young's Modulus, E22	220.43MPa
Poisson's ratio, ν12	0.13
Poisson's ratio, ν23	0.13
Poisson's ratio, ν31	0.54
Shear Modulus, G23	38MPa
Bulk modulus, A1	120.5MPa
Parameter A2	1200Mpa
Strength Model	Elastic
Shear modulus, G23	38Mpa
Failure Model	Material Stress/Strain
Tensile failure stress, σfail,22	45MPa
Tensile failure stress, σfail,33	45MPa
Tensile failure strain, □f11	0.01
Tensile failure strain, □f22	0.27
Tensile failure strain, □f33	0.27
Erosion Model	Geometric Strain
Erosion Strain	0.4

Numerical Simulation

Numerical simulation is conducted using ANSYS/AUTODYN for 150µs in P4-Dell PC with 3.0 GHz processor. The time step for the numerical simulation is 2.67×10-4 µs. The computational time is around 26 hrs.

Results of Numerical Simulation

The results of finite element simulation for the bullet striking velocities of 54 m/s is given below. The elements located at the middle portion of the target plate starts failing when stress/strain level exceeds the failure stresses/strain limit set by the constitutive model due to the impact. They are eliminated from the computational domain gradually after the penetration of the bullet through the plate. The bullet during penetration induces large strain in the target which is responsible for the plug formation. Figure 10 shows the material status of target plate due to impact.

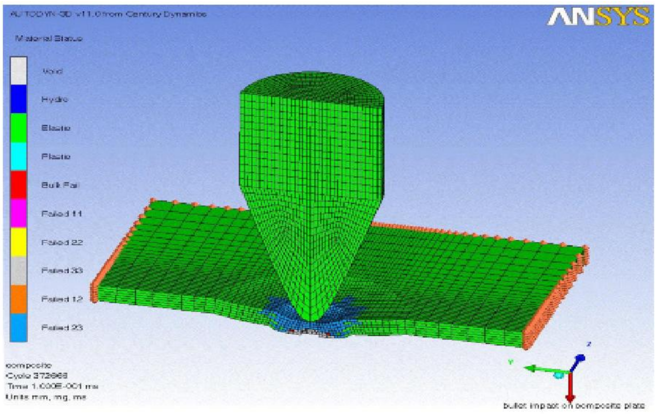

Fig 10 Material status of Glass/Epoxy composite target due to impact at 0.1ms

Figure 11 shows the variatation of displacement and velocity of projectile with time during penetration of target. The kinetic enegry loss in the bullet is responsible for the reduction in velocity. This reduction in kinetic energy of bullet is responsible for the damage of target plate.

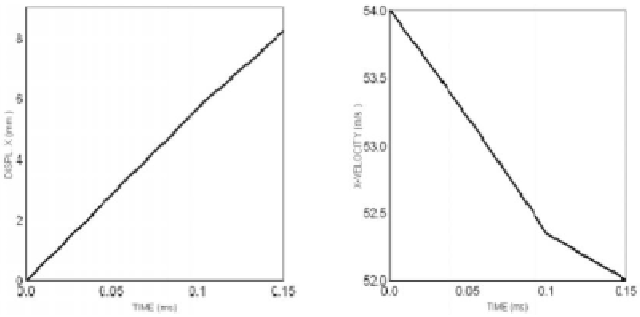

Fig 11. Variation of Displacement and velocity of projectile with time.

Figaure 12 shows the energy plots with time for projectile and Target. As time increases total energy is reduced because of energy dissipation due to impact. This energy reduciton is responsible for making the plug in target plate. Due to the impact, some of the kinetic energy is converted into internal energy. As kinetic energy reduces the internal energy increases and thus making the total enegy constant. In case of target plate due to the impact total, kinetic, internal energies increases. Due to the formation of cracks and erosion in the target plate, the bilinear effect of total energy is observed.

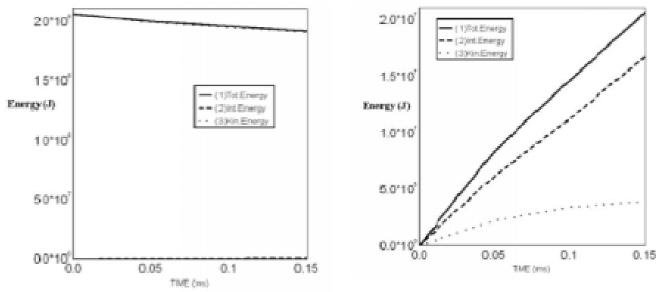

Fig 12. Variation of Energies with time for Projectile and Target.

Summary

Medium velocity impact was performed on two sets of WRM/epoxy composites laminates using cylindro-conical projectile. Residual velocities and energy absorptions were obtained. It was found that the failure was due to punching shear and intra-lamina shear. When bullet strikes normally the energy absorption is more if it makes inclination to the normal of target plate energy absorption is more. Cracks are forming on the rear side and are in radial direction. The major cracks are orienting in fibre orientation directions. When the bullet strikes with inclination the formation of plug is in the form of ellipse rather than circular. Petailing failure was also observed in some impact tests. Numerical simulation of projectile impact on composite plate was conducted and results are discussed.

Conclusion

In this paper, an attempt is made to use rate dependent, simplistic, material model of plasticity coupled with a failure criteria and conducted numerical simulation of ballistic impact of a steel projectile of an armour steel plate using 3-D nonlinear explicit finite element formulation available in ANSYS/AUTO-DYNA. Understanding of the material model, failure criteria and the mechanism of ballistic impact is deepened in the penetration simulations Impact tests were performed on Glass/epoxy laminates and showed a variation of results because of inclined impact rather than normal impact. Energy absorption is less if the bullet strikes normal to the laminate. Plug formation and petal formation depends on the type of impact. From the experiments it was observed that crack propagation in the direction of fibre orientation direction and spall off material and delaminaiton observed in the rear face of laminate.

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