Numerical and Experimental Ballistic Performance of Aluminum and Polycarbonate Sandwich Plates

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Abstract

The response of a sandwich target consisting of Aluminum and Polycarbonate to normal impact by cylindro conical projectile was investigated. Both numerical and experimental methods were used to compare the ballistic resistance of monolithic aluminum, monolithic polycarbonate and sandwich plates. Johnson Cook plasticity and damage models were incorporated for the numerical work. To validate the numerical observations, experiments were conducted in the sub ordnance velocity regime at 375 m/s. Aluminum Polycarbonate sandwich plate showed higher ballistic resistance when compared with monolithic targets. The experimental deformation modes of the targets are found to be in good agreement with the numerical observation.

1. Introduction

The demand for lightweight impact resistant shielding equipment is rising rapidly. A number of studies are available on the ballistic performance of homogenous targets whereas only few are available on layered ones. [1, 2] showed multilayered targets using Aluminum have more ballistic resistance than individual monolithic ones of the same thickness, a conclusion verified in the present study, but contradicted by [3, 4] when steel is used. In the present work, response of sandwich plate consisting of adjacent layers of Aluminum and Polycarbonate to normal impact by cylindro - conical projectile is studied.

2. Experimental work

The sandwich plate of dimensions 120 mm by 120 mm was formed by stacking alternate layers of Aluminum and Polycarbonate, each of thickness 1 mm, bonded together with epoxy resin. The outer layers are Aluminum. This sandwich target of thickness 5 mm, along with monolithic Al - 1100 and Polycarbonate targets of the same thickness and dimensions were impacted at the center by a cylindro conical bullet at 375 m/s. The projectile used was 9 by 19 mm made of 4340 steel. Figures 1, 2 and 3 show Al -1100, Polycarbonate and the sandwich targets respectively.

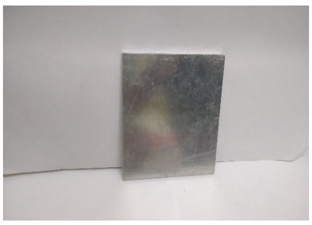

Fig. 1 - Al-1100

Fig.2 - Polycarbonate

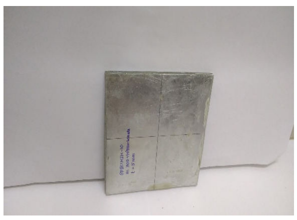

Fig.3 - Sandwich

3. Numerical simulation

3.1 Geometry

The target is partitioned in the impact zone to give a refined mesh. The effect of epoxy resin is neglected in the
analysis. Figures 4 a and 4 b show the model with mesh and boundary conditions respectively.

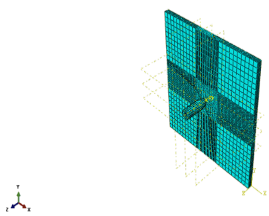

Figure 4.a.- Meshed model

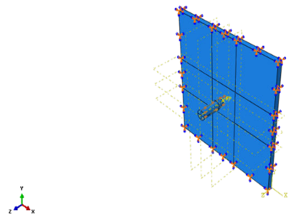

Figure 4.b - Model with boundary conditions

3.2 Material and failure models

The elastic and physical properties of projectile and target and given in Table 1.

Material / Parameters	Density (kg/m^3)	Young's Modulus (GPa)	Poisson's ratio
Al -1100	2700	70	0.3
Polycarbonate	1200	2.2	0.37
Steel - 4340	7850	210	0.33

Table 1 - Mechanical properties of projectile and target

The material behaviour of Al - 1100 target and 4340 steel projectile was modelled using Johnson - Cook elasto - viscoplastic model [10] which takes into account linear thermo - elasticity, yielding, plastic flow, strain hardening, strain rate effect and thermal softening due to adiabatic heating. The equivalent von Mises stress of this model is expressed as

$$\sigma(\varepsilon^{pl}, \acute{\varepsilon}^{pl}, T) = [A + B(\varepsilon^{pl})^n][1 + C\ln(\acute{\varepsilon}^{pl}/\acute{\varepsilon}_0)][1 - (T^*)^m]$$

where ε^{pl}, $\acute{\varepsilon}^{pl}$ and $\acute{\varepsilon}_0$ are equivalent plastic strain, equivalent plastic strain rate and reference strain rate respectively. A, B, C, n and m are material constants. T^* is the homologous temperature given by,

$$T^* = (T - T_0)/(T_{melt} - T_0)$$

where T is the current temperature, T_{melt} is the melting temperature and T_0 is the reference temperature. Johnson Cook damage model was used for Al - 1100 and 4340 Steel while the Ductile Failure criterion was used for Polycarbonate. The fracture model proposed by Johnson and Cook [9] takes into account the effect of stress triaxiality, strain rate and temperature on the equivalent fracture strain. The equivalent fracture strain is expressed as,

$$\varepsilon^{pl}_f(\eta, \dot{\varepsilon}^{pl}, T^*) = [D_1 + D_2 \exp(D_3 \eta)] [1 + D_4 \ln(\dot{\varepsilon}^{pl}/\dot{\varepsilon}_0)] [1 + D_5 T^*]$$

where η is the stress triaxiality - ratio of hydrostatic stress to Mises stress (σ_H/σ). The ductile failure predicts the onset of damage due to nucleation, coalescence and growth of voids. According to this model, the equivalent plastic strain at the onset of damage, ε_D is a function of stress triaxiality and equivalent plastic strain rate. The damage variable, D = Σ ($\Delta\varepsilon^{pl}/\varepsilon^{pl}_f$) increases monotonically at each increment of plastic deformation. Damage initiates when D = 1. The Johnson Cook parameters for the target and projectile are given in Table 2

Material	A (MPa)	B (MPa)	n	m	T_{melt} (K)	T_o (K)	$\dot{\varepsilon}_o$	C	D_1	D_2	D_3	D_4	D_5
Al-1100	148.361	345.513	0.183	0.859	893	293	1	0.001	0.071	1.248	-1.142	0.0097	0
Steel 4340	1430	2545	0.7	1.03	1793	293.2	15	0.014	0.05	3.44	2.12	0.002	0.61

Table 2 - Johnson Cook parameters for Al - 1100 and 4340 Steel [5,6]

The values for plastic strain and plastic stress and the damage initiation values for polycarbonate are summarized in Table 3 and Table 4 respectively.

Yield Stress (MPa)	Plastic Strain
80.6	0
88	0.1
142.5	0.5
168	0.6
187	0.7

Table 3. Yield Stress vs Plastic strain for Polycarbonate [7]

Strain Rate (s^{-1})	Polycarbonate
Quasi - static	1
4900	0.85
8000	0.85
80000	0.6

Table 4. Damage initiation values of polycarbonate [8]

3.3 FE Mesh

Mesh convergence study was done to determine the optimum mesh size for the problem. Around 38,440 C3D8R hexahedral elements were used for the sandwich plate, 36000 elements for Al-1100 and Polycarbonate plates and 720 hexahedral C3D8 elements for the projectile. 10 elements were employed along the targets' thickness. The optimum mesh size to be used in the impact zone was found to be 0.5 mm by 0.5 mm. Figure 5 shows the mesh convergence graphs of the three targets for an impact velocity of 375 m/s.

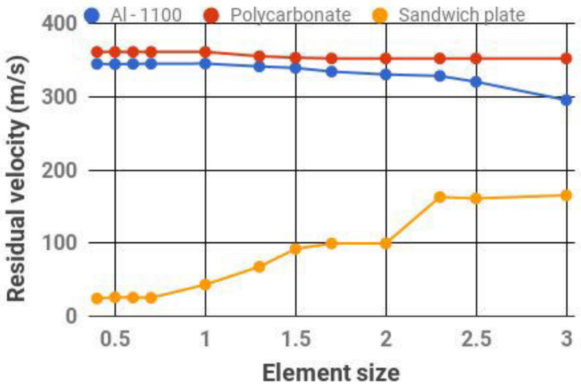

Fig. 5 - Mesh convergence graph

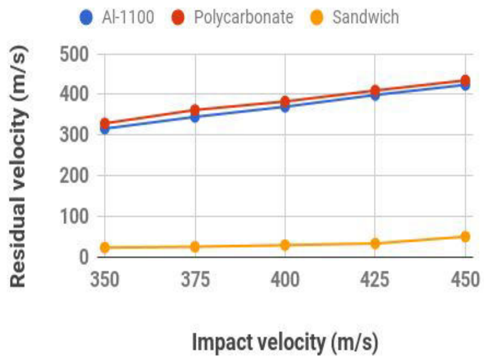

Fig. 6 - Impact vs Residual velocity

4. Results and Discussion

Figure 6 shows the graph between impact velocity and residual velocity of the projectile. The bullet impact was simulated for five different impact velocities as summarized in Table 5. The experimental deformation pattern and the numerical deformation pattern of the three targets were in good agreement as shown in Figures 6, 7, and 8 for an impact velocity of 375 m/s. Four petals were formed rearward in monolithic polycarbonate plate. For monolithic Al - 1100, the metal in the impact zone was thrown rearward and no distinct petaling was observed. For the sandwich target, rearward petaling was observed. The ballistic limit velocity, V_{50} of a target is defined as the least velocity at which the projectile would completely pass through the target. Technically, it is the average of two striking velocities : the maximum velocity at which partial perforation occurs and the least velocity at which penetration occurs. The ballistic limit velocities of the three targets evaluated numerically by trial and error are shown in Table 6.

		V_{impact} = 350m/s	V_{impact} = 375m/s	V_{impact} = 400m/s	V_{impact} = 425m/s	V_{impact} = 450m/s
Residual velocity (m/s)	Al - 1100	316	345	370	399	424
	Polycarbonate	329	362	383	410	435
	Sandwich	23	25	29	33	50

Table 5 - Residual velocities of the three targets for five impact velocities

Target	Al - 1100	Polycarbonate	Sandwich
Ballistic limit, V_{50} (m/s)	153	137	315

Table 6 - Ballistic limit velocities of the three targets

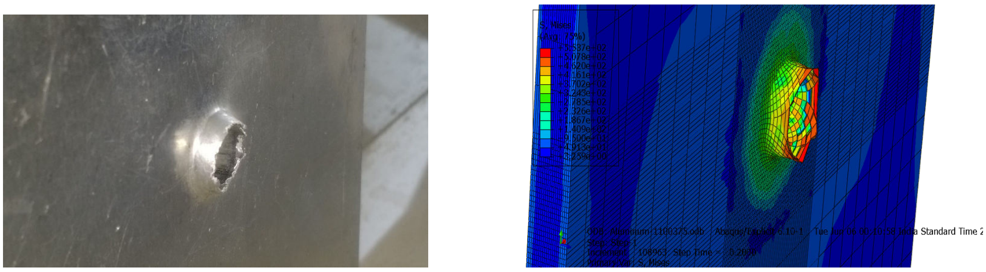

Fig 7 - Al - 1100

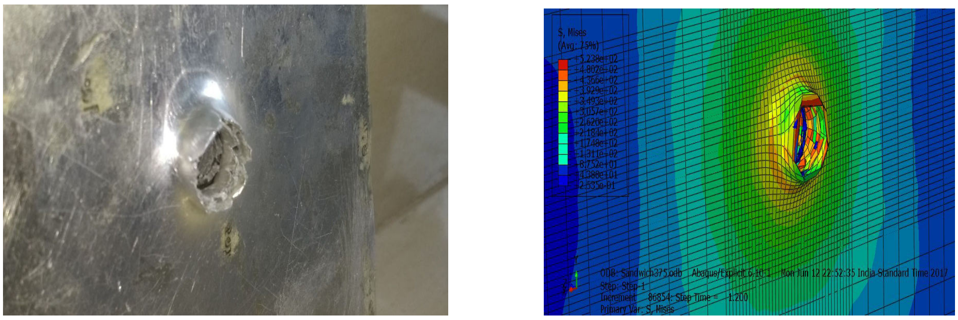

Fig 8 - Sandwich

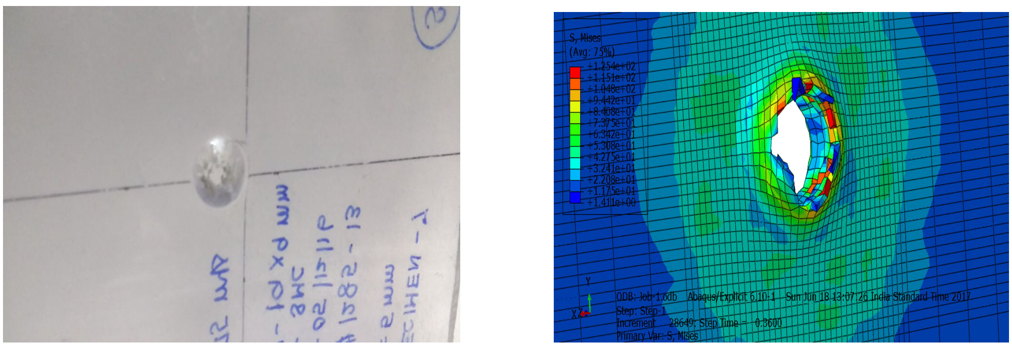

Fig 9 - Polycarbonate

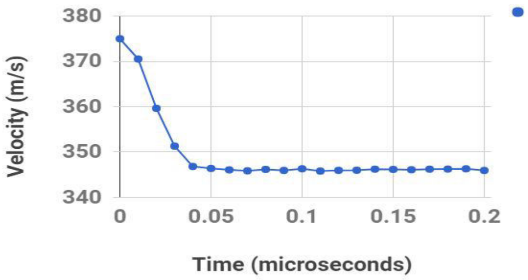

Fig 10 - Al - 1100

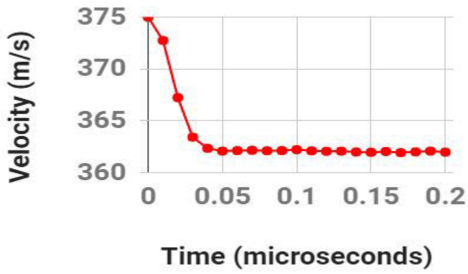

Fig 11 - Polycarbonate

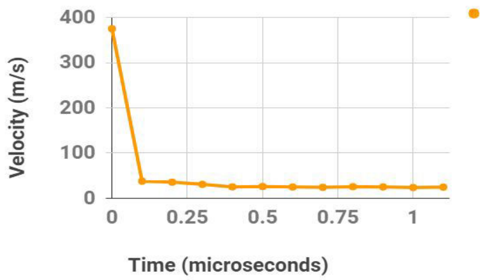

Fig 12 - Sandwich

5. Conclusion

Figures 10, 11 and 12 show the velocity vs time plot for an impact velocity of 375 m/s for the three targets. It is seen from the graphs and tables that the sandwich target considerably reduces the projectile's velocity post impact and hence its kinetic energy. It also possesses the highest ballistic limit velocity of the three targets. Thus, the sandwich target absorbs more energy and offers good resistance to the normal impact of the projectile.

6. References

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