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Medium Velocity Impact on Sandwich Beams

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Abstract— Sandwich structures are now extensively used everywhere due to their high strength and less weight. In this paper the impact tests on adhesively bonded sandwich beams are carried out. Sandwich beams with GFRP as a core material having aluminium facesheets are transversely impacted by a rigid projectile at various impact velocities of the projectile with the help of pneumatic gun. Various failure modes exhibited by the sandwich beams are encountered which involves large inelastic deformation, core shearing and delamination etc.

Keywords— Sandwich beam; GFRP; projectile; Impact; delamination

I. INTRODUCTION

At various occasions we come across impact phenomenon, fractures, and perforation in every field, whether it is a space vehicle or stone hitting by the mob, or any structural damage in a building or even a road accident.

In engineering applications impact phenomenon has a wide meaning which describes energy absorption, resistance to damage etc. which had given rise to sandwich structures. Nowadays many applications are evolving prior to the use of sandwich structures that are related to energy absorption, design against impact or blast-resistance. This includes blast protection structures, satellites, automobiles, aircraft, ships, railways, automobiles, wind power systems etc. Trend of using sandwich structures gaining a faster pace and many companies are looking forward to replace traditional metallic parts by composite materials like Fibre metal laminates (FML).

For high strength and low weight FMLs are widely used for making aircraft fuselage, wings etc. as in Airbus A380. Another material named glass fibre reinforced plastic (GFRP) is also proving good for such applications. It consists of fibre glass with epoxy resin. GFRP having low weight, greater stiffness and strength together with high impact resistance finds its place in space applications. GFRP together with aluminium facesheets make a better composite.

A typical sandwich structure consists of two surface plates or face sheets connected by a lightweight core material. These components of the sandwich material are bonded together using either adhesives or mechanical fasteners. In a typical sandwich structure, there are two facesheets which are generally made from the same material and usually in the same thickness. Sandwich structures are now a major concern in almost every field and most structures in engineering are constituted of beams, so an understanding of the impact response of these structural elements is essential for the development of such functional materials.

II. REVIEW

Chiras et al. [1] in their experiments and numerical analysis used tetragonal lattice and deduced fracture failure in tension and buckling in compression. Feng Zhu [2] established a theoretical solution for blast loading of clamped sandwich panels with honeycomb or aluminium foam core. Radford et al. in [3] predicted performance of metallic honeycomb core for sandwich beams and in [4] metal foam projectiles were used at high speed on sandwich panels of Steel and square honeycomb core. The study was quasi-static. Rathbun et al conducted high pressure experiments on steel – honeycomb sandwich and monolithic beam [5]. They concluded smaller displacements in sandwich beams having same weight. Tagarielli et al. [6] used metal foam projectiles on glass fibre-vinylester beams and monolithic beams. Experiments concluded that sandwich beams gave better performance. Vaziri et al. [7] did study on sandwich plates with honeycomb core; he established that necking, delamination and tearing are the failure modes in his experiments. Liu et al [8] proposed an analytical model of clamped sandwich beams with different core strengths.

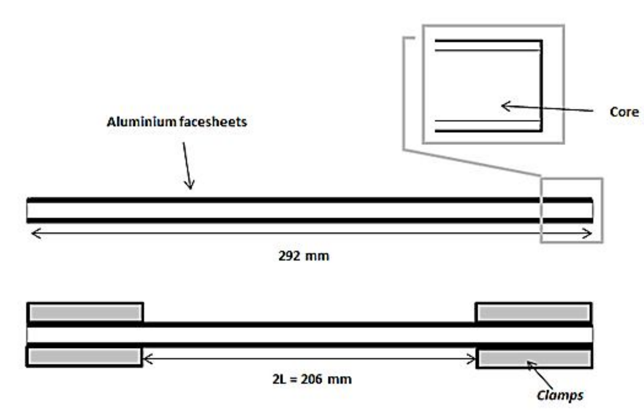

Fig. 1 Line diagram of the clamped sandwich beam.

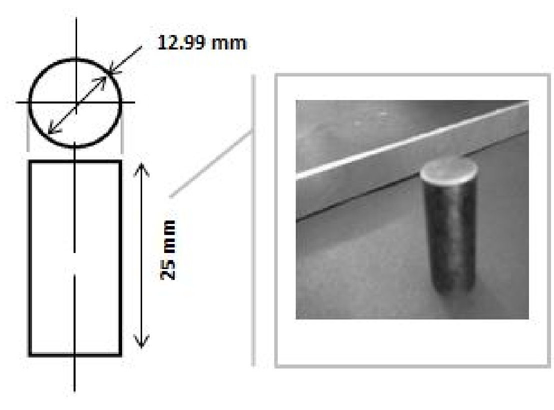

Fig. 2 Geometric layout and camera view of the blunt cylindrical projectile

In this paper, investigation of the impact response and performance of sandwich beam having GFRP core and aluminium facesheets is done experimentally. Identical sandwich beams are transversely impacted by a rigid projectile (bullet) in sub-ordnance range. The recorded data is then used for calculating different entities like impact energy, energy absorbed, velocity drop etc. The data available is encoded into MATLAB code and the plots are made defining different effects. The failure modes which are encountered during experiments are discussed.

III. MATERIALS FOR TEST SPECIMEN

Sandwich beams were fabricated by using GFRP (0/90) layup as core material and aluminium as facesheet material bonded together by ARALDITE having excellent adhesion, strength, and toughness properties. The thickness of the GFRP core is 2 mm and the thickness of aluminium facesheets is 0.875 mm. The adhesive thickness is kept constant being 0.2 mm. The line diagram of the sandwich beam is shown in Fig 1 with aluminium facesheets and GFRP core. Table I gives sandwich configuration of the beams.

A Blunt-cylindrical projectile of steel (EN 24) is employed for impact testing and it is regarded as undeformable element as there is no visible deformation occurred in the tests. The projectile is shown in Fig 2 having the following attributes:

- Length of projectile = 25 mm
- Diameter of projectile = 12.99 mm
- Mass of projectile = 25.78 gm.

The aluminium and GFRP sheets are commercially procured and are sheared in required thickness and length. The GFRP core is sandwiched and adhesively bonded between two aluminium facesheets. The core and the two facesheets of aluminium are pressed together for 24 hours at room temperature to dry up together firmly before impact testing.

TABLE I: SANDWICH BEAM CONFIGURATION

Thickness of the beam (mm)	Face sheet thickness [Aluminium] (mm)	Core Thickness [GFRP] (mm)	Adhesive Thickness (mm)	Mass per unit length (gm./mm)
3.84	0.875	2	0.2	0.112

IV. EXPERIMENTAL SET UP

The fabricated Sandwich beams are transversely impacted by the projectile using the Pneumatic Gun Apparatus kept at Impact Mechanics lab, Department of Mechanical Engineering at Aligarh Muslim University, Aligarh. Fig 3 shows the front view of the experimental set up. Fig 4 shows the line diagram of the set up.

The velocity of projectile hitting the beams is in medium velocity range (25-500 m/s). The pneumatic gun is capable of firing projectiles with velocities up to 115 m/sec. The projectile is placed in a loading barrel connected to the pressure chamber. The projectile accelerates in the barrel, when the pressure is released from the pressure chamber with help of pressure release valve.

Different velocities of the projectile are obtained by varying the pressure in the pressure chamber. Two photo diodes installed at the muzzle of the barrel which are used to trigger the timing device. Impact velocity of the projectile is measured with the help of a photo gate type arrangement comprising infrared light emitting diodes and photo sensing diodes. Residual velocity of the projectile is measured with the help of aluminium foil screens. The impact tests are done on the sandwich beams at increasing velocities of the bullet.

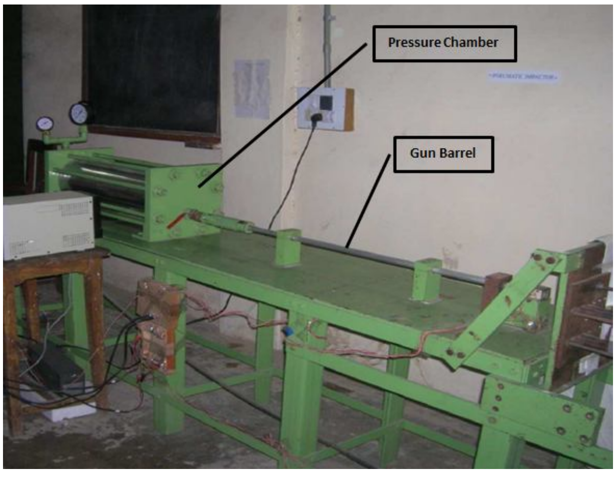

Fig. 3 Pneumatic Gun Apparatus at Aligarh (Front view)

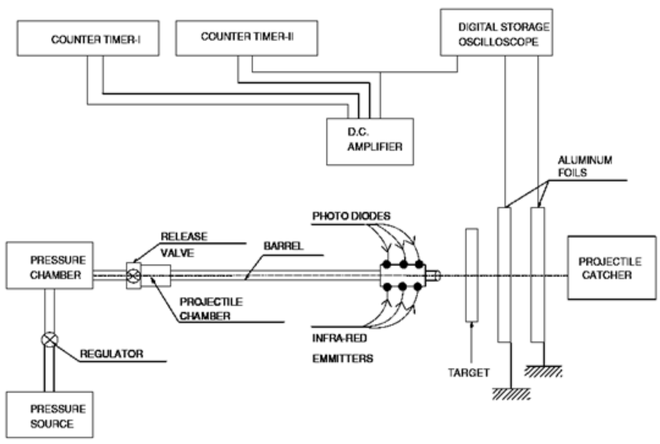

Fig. 4 Schematic of experimental set up

TABLE II : EXPERIMENTAL DATA OBTAINED FROM IMPACT TEST

Specimen no.	Velocity			Energy			Maximum Deflection (mm)	Failure	Remarks
	V_i (m/s)	V_r (m/s)	V_d (m/s)	E_i (joules)	E_r (joules)	E_{ab} (joules)			
1	35.75	-	-	16.47	-	16.47	13	Not Fractured	The beam remains unfractured, Debonding occurred at the middle back face. Front face experienced debonding near the clamps.
2	46.29	-	-	27.62	-	27.62	17	Not Fractured	Tearing of the back face along with core had occurred at the left clamp. Debonding is experienced at the right clamp.
3	50.10	-	-	25.68	-	25.68	20	Not Fractured	Tearing of the of the back face along with core from the left clamp followed by full debonding from the front face and turned to an angle of 150^0. But the beam is not fractured by the projectile.
4	53.60	07.25	46.35	37.03	0.677	36.35	-	Fractured	Debonding occurred at the front face and the right back face had been debonded from the core to 95^0. The beam is fully fractured.
5	59.52	40.32	19.20	45.66	20.95	24.71	-	Fractured	Core had been teared off at both the ends. Back face teared at left side and turned to 170^0. Debonding between back face and core had appeared near the middle portion.
6	75.75	62.50	13.25	73.96	50.35	23.61	-	Fractured	Debonding had occurred at both sides and at both faces. Back face at left side had turned to 220^0.
7	86.20	67.72	18.48	95.77	59.10	46.67	-	Fractured	Core had been teared off from the middle as well as at both ends followed by debonding. Maximum Back Face turning of about 300^0.
8	100	70.42	29.58	128.9	63.92	64.98	-	Fractured	Core had been teared off from the middle and at right end. Maximum Back Face turning about 300^0.

V_i = Impact velocity of projectile (m/s)
V_r = Residual velocity of projectile (m/s)
V_d = Velocity drop, $V_i - V_r$ (m/s)
E_i = Impact energy (joules)
E_r = Residual energy (joules)
E_{ab} = Energy absorbed, $E_i - E_r$ (joules)

The fractured beams are analyzed and the observations are recorded as in Table II. Fig 5 shows the fractured beams at different velocities of the projectile.

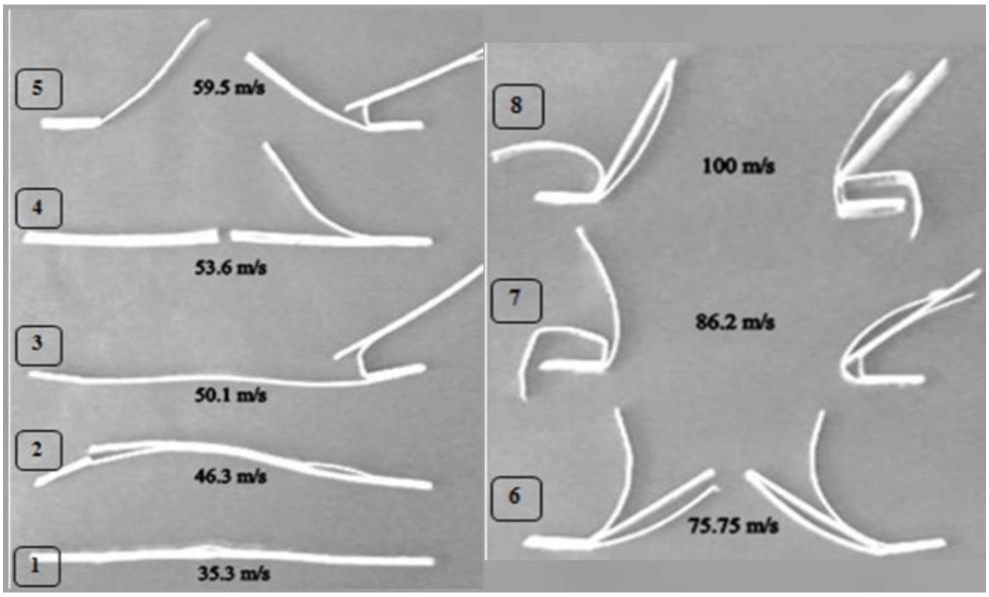

Fig. 5 Photograph showing the Sandwich beams impacted at different projectile velocity. The number written below at each beam is the impact velocity of the projectile.

V. RESULTS

1) Mid-span Deflection of sandwich beams

In order to identify the deflection of impacted sandwich beams, deflection curves of the mid-point of back face are shown in Fig 6, the maximum deflection of the sandwich beams is plotted. Graph show that the deflection in sandwich beam increases with increase in projectile velocity.

2) Variation of Residual velocity with Impact velocity of projectile

The projectile ejecting after breaking the beam has some residual velocity. Fig 7 shows the plot shows the variation of the residual velocity with impact velocity. It is observed that the residual velocity remains zero up to a certain value of the initial velocity and then increases with the initial velocity. The velocity at which the residual velocity just shoots up may be treated as the ballistic limit. The impact energy of the projectile is completely absorbed by the target until it reaches the ballistic limit, up to ballistic limit there is a straight horizontal line and then increases for certain value of impact energy and again when the impact velocity increases further the residual velocity decreases, as more energy is absorbed at higher velocities than at intermediate velocities. The ballistic limit for the sandwich beams attained is about V_{bl} = 50 m/s.

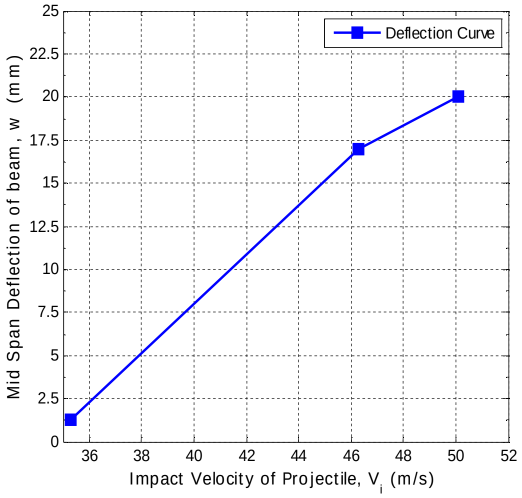

Fig. 6 Mid span deflection (w) versus impact velocity, (V_i)

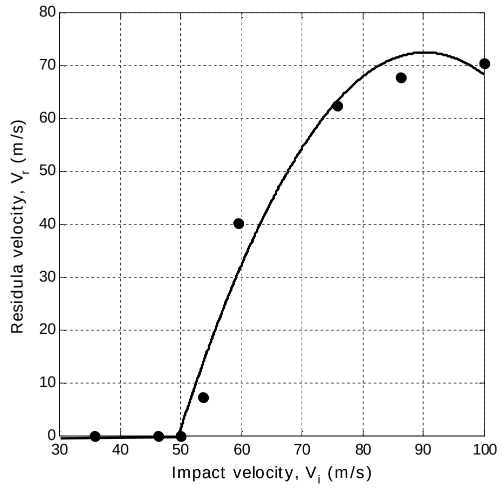

Fig. 7 Impact velocity (V_i) versus Residual Velocity (V_r)

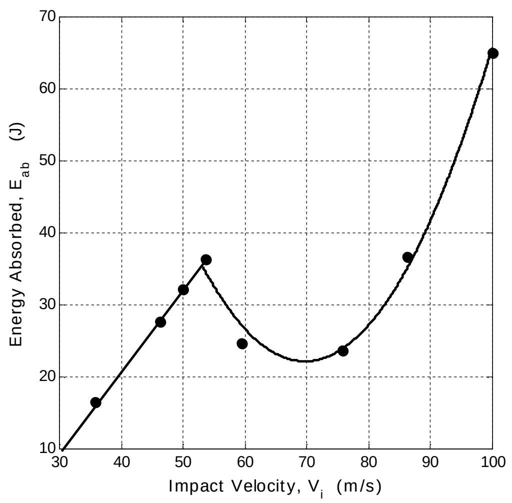

Fig. 8 Energy absorbed, (E_{ab}) versus Impact velocity (V_i)

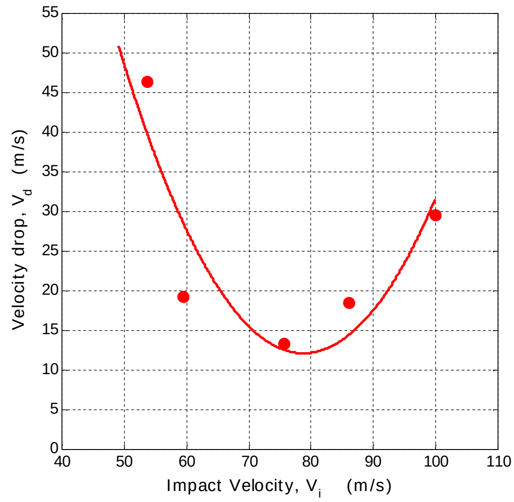

Fig. 9 Impact velocity (Vi) versus Velocity drop (V_d)

3) Energy absorbing capacity

The plot between initial velocity of the projectile and energy absorbed by each target beam specimen is shown in Fig 8. The Plot shows the effect of energy absorbing capacity of the beam at different impact velocity.

At impact velocities just above the ballistic limit i.e. 50 m/s, the energy absorbed increases to a certain degree because there is enough time for the sandwich beam to undergo deflection, which is the major energy absorbing process and correspondingly the failure of beam specimen in this range is taking place mainly because of tensile tearing. But at relatively higher velocities, the response time for the target is less and so the deflection of the target is less in comparison with the previous cases and corresponding energy absorption decreases and the specimens exhibits the failure due to shearing at the clamped ends.

4) Velocity drop after fracture

Velocity drop is the difference of impact velocity and the residual velocity. Fig 9 shows the plot between the impact velocity and the velocity drop for sandwich beams. Velocity drop decreases with increase in projectile velocity. At low impact velocity the drop is more as most of the energy is absorbed by the beam. As the impact velocity is increased the drop velocity is decreased up to a certain limit, this is due to the fact that now the failure occurs because of the shearing at the clamped ends and the projectile is ejected with much amount of residual velocity. After this phenomenon the graph goes up corresponding to lesser residual velocity and beams exhibited fracture at the mid at this higher velocity range.

VI. FAILURE MECHANISMS

Large inelastic deformation is the dominating failure mode for the sandwich beams. As shown in Fig 10 beam is deflected severely at the mid-point and the load carrying capacity of the beam will be lost due to this kind of failure.

Another mode of failure is the interfacial failure known as delamination. Delamination is one of the most significant failure modes in sandwich structures. It is found that nearly all the specimens exhibits interfacial failure i.e. debonding at the interface. The reason can be explained reasonably that the strength of adhesive layer is lower than core shear strength of sandwich structure.

Delamination refers to situation in which failure occurs on a plane between adjacent layers in a composite. This type of failure is dominated by the properties of the adhesive and since adhesive strength is low, the composite is prone to develop delamination. In many types of composite structure (e.g. aircraft, marine) delamination is the most common form of defect/damage. It was found that some of the specimens had shown total debonding of the facesheet at the interface. The Fig 10 shows a debonded area in the sandwich beam, after impact at about 46 m/s.

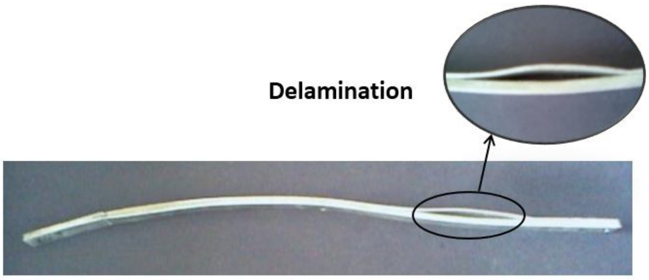

Fig. 10 Showing Delaminated area after impact

The Tensile tearing of the facesheet is encountered in some of the specimens. The backface is teared up at the right end clamp and deflected. Some specimens are followed by tearing of backface at both the clamps and thrown away by the projectile. Moreover in some specimens due to the high velocity of the projectile, after the fracture at the mid, the two sides of the beam are turned on either sides towards the clamps. The degree of turning is proportional to the impact velocity of the projectile.

VII. CONCLUSION

The impact tests with Blunt - cylindrical projectile were carried out on the sandwich beams having 0.875 mm aluminium facesheet and 2 mm GFRP as a light weight core bonded by Araldite adhesive. Experimental results show that the deflection of all sandwich beam specimen increases with increase in projectile velocity up to ballistic limit. After the ballistic limit is crossed turning of the fractured parts towards the clamps in beam specimen took place, and the turning is larger at larger impact velocities. Some of the specimens namely 7 and 8 experienced about 270^0 turning of the back facesheet. Several failure modes in the specimens are encountered during as a result of impact. These are large inelastic deformation, core shear, delamination, tearing of face sheets. Face sheet debonding from the core largely impairs the load bearing capacity of sandwich beams, and hence the property of the adhesive becomes the important parameter for designing sandwich structures.

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