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Compression After Impact on GFRP & CFRP Sandwich Composites

Sunith Babu L
Department of Mechanical Engineering
M.S. Ramaiah Institute of Technology
Bangalore, India

H. K. Shivanand
Department of Mechanical Engineering
University Visvesvaraya College of Engineering
Bangalore, India

Abstract **Impact can degrade the strength of a sandwich panel and can lead to catastrophic failure. In this study, two types of sandwich panels with FRP facings made of Glass/Epoxy and Carbon/Epoxy skins with PU foam core of density 100kg/m^3 was subjected to low velocity impact test using a hemispherical indentor of diameter 12.7mm using a drop weight testing machine. It was found that three different types of failure were obtained namely facesheet indentation, core crushing and rear face debonding. It is further essential to assess the post impact damage strength and hence residual properties becomes an important part of the study. Compression After Impact (CAI) is one such method to determine the residual strength of the impacted sandwich panel. The impacted panels were tested and compared with undamaged panels to assess the loss in residual compressive strength.**

Keywords—impact damage, compression after impact, drop test, residual strength, PU foam

I. Introduction

Sandwich composites are highly preferred materials in aerospace, automotive and few consumer applications, due to their high strength to weight ratio and also high stiffness & strength at low weights as compared to any other materials available in the industry. These materials are highly preferred over conventional materials, since they can customized based on the needs of a specific industry and this calls for material characterization. There are a number of standards available to characterize sandwich composites such as flatwise compression, edgewise compression and flexural tests being the widely used methods to determine the properties of a sandwich composites. These test methods only help to characterize a particular composite and cannot be regarded as a standard test results for that material, since issues arising from process parameter, material parameter and test parameter may require repeated tests for each manufacturing process. However, one major issue that the composites are susceptible are loss of strength due to impact damage [1-5]. There are several test parameters which are a function of impact damage, which includes dimensional, properties of skin and core interface, mass of impactor, velocity of fall and shape of impactor [6,7]. Further, the low velocity impact damage can significantly reduce the structural strength of composites by 50% [8]. Hence the need for post impact analysis plays a major role. Due to impact, different damages may rise such as indentation, facesheet and core crushing followed by rear face delamination [9]. Damage analysis of such impacted panels is a simple process which involves visual inspection incase it's a VID – visible impact damage. In situations such as BVID – barely visible impact damage, need for C – Scan techniques are essential. In all probable situations, the strength degrades leading to catastrophic failure of the panels.

The compressive, shear and bending strength have found to be reduced due to impact loading in transverse direction. Among all these the compressive residual strength have found to be the most venerable. Hence need for CAI analysis is found to be the crucial parameter in impact characterization [10- 13]. Compression can be applied in three different ways namely column type [10], in-plane [14] and four point type [15]. In this work, column type compression tests have been adopted to check the residual compressive strength of CFRP and GFRP sandwich panels and compared with undamaged sandwich panels.

II. Experimental

A. Fabrication of Impact Specimen

The facings of the sandwich panels were prepared with GFRP & CFRP bi-woven cloth material with same warp & weft sequence. The matrix material used in the preparation of sandwich panels were epoxy resin LY556 & HY951 hardener in the ratio 10:1. The core density of 100 kg/m^3 was chosen with a constant core thickness of 14mm while top and bottom facing thickness were kept constant at 1mm for both GFRP & CFRP making the total thickness of sandwich panels at 16mm. The panels were fabricated using Vacuum Bagging Technique and were post cured at 60^{o}C for 24 hours to ensure perfect bonding of facings with the core material. The final sandwich panel was cut into a square plate of 150X150mm with thickness 16mm as shown in *fig.1*.

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B. Impact Testing

A total of 6 specimens were impacted at three different Impact energies - 4.9J, 14.71J & 24.52J on both CFRP & GFRP sandwich panels. Three trails were carried and the results were averaged and tabulated as shown in *table 1*. An impact mass of 5kg and free fall impact was chosen, with a hemispherical impactor of diameter 12.7mm. Three different height of fall was chosen to determine the damage mechanism.

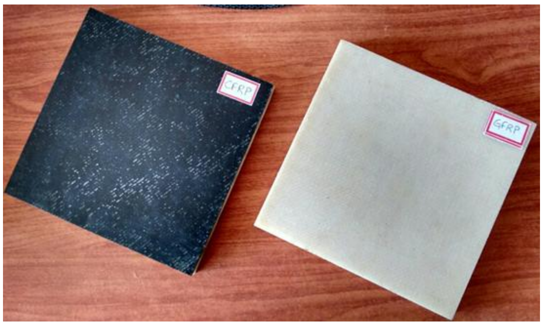

Fig 1: CFRP & GFRP sandwich panels

Lower height of fall was chosen for (BVID) – Barely Visible Impact Damage and higher height of fall for reviewing (VID) Visible Impact Damage. It was found that GFRP sandwich panels made of glass/epoxy showed better energy absorption capacity as compared to carbon based sandwich panels as listed in *Table I.*

TABLE I. LOW VELOCITY IMPACT TEST RESULTS – 100kg/m^3

Specimen Code	Mass of Panel [kg]	Impact Energy	Max Load [N]	Energy at Max Load [J]	Damage Mechanism
G100-0.1	0.220	4.90	1255	4.65	Top Face
G100-0.3	0.220	14.72	1325	14.42	Top Face + Core Crushing
G100-0.5	0.220	24.52	1390	22.27	Both Facings + Core Crushing
C100-0.1	0.226	4.90	869	3.72	Top Face
C100-0.3	0.226	14.72	895	11.4	Top Face + Core Crushing + Bottom Face
C100-0.5	0.226	24.52	930	17.7	Complete Perforation

It is evident from the above results that CFRP sandwich panels absorbed lesser energy due to impact as compared to GFRP sandwich panels. The energy – time histories are plotted as shown in *fig 2* & *fig 3*

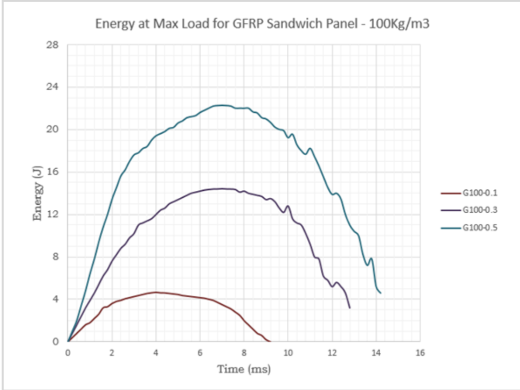

Fig 2. Energy – Time histories for GFRP Sandwich Panel

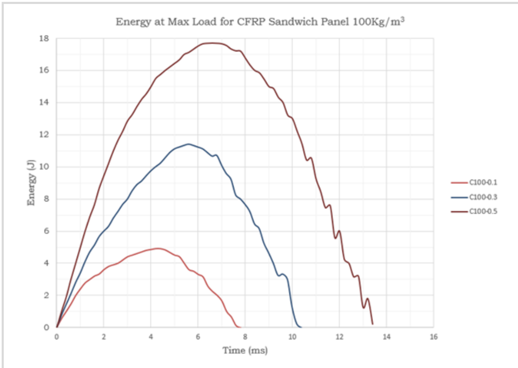

Fig 3. Energy – Time histories for GFRP Sandwich Panel

The energy – time plot for GFRP sandwich panels clearly indicates that as the height of fall increases, the frictional forces between the impactor and sandwich panel increases thereby displaying several peaks in the plot. The absorbed energy reached a max of 22.27J for an input energy of 24.52 indicating that with increase in height of fall, the energy absorption capacity increases. However in case of CFRP sandwich panels, the energy absorption capacity was only 17.7J. However, the sandwich panel completely perforated in CFRP as compared GFRP sandwich panel of same combination. This was due to the fact that carbon displayed weaker performance in impact loading as compared to GFRP sandwich panels. This is one main reason why carbon is not ideally preferred in impact associated applications and in aerospace applications even though they have high compression and tensile strength. Although both material showed linearity in the initial phase of the impact testing, the effect of indentor on the panel is shown the second half of the graph, where in the energy absorption capacity was tending to zero in CFRP sandwich panels as compared with GFRP panels which stopped at 4.76J. Since the loading was higher at 5kg, the impact damage were localized as shown in *fig 4* & *fig 5*.

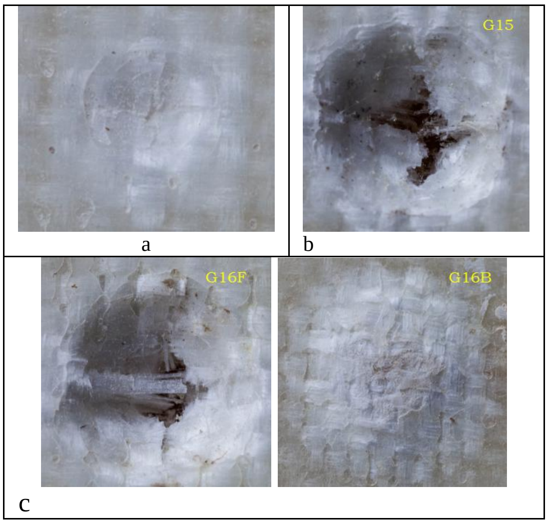

Fig 4. Impacted GFRP sandwich panels a) 0.1m b) 0.3m c) 0.5m

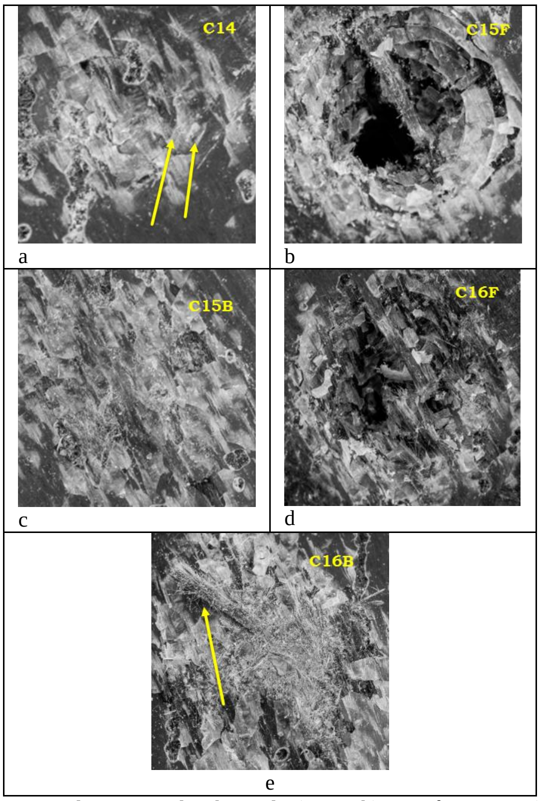

Fig 5. Impacted GFRP sandwich panels a) 0.1m b) 0.3m front view c) 0.3m rear view d) 0.5m front view e) 0.5m rear view

The CFRP sandwich panel had an interlaminar fracture resulting in multiple layer debonding from the matrix. The impact resulted in fragmented failure of the sandwich panel as compared to GFRP sandwich panels as shown in Fig 4c. The CFRP sandwich panels had fiber pullout and face-core debonding instances as shown in *Fig 5b* & Fig 5d. The extent of damage caused at the rear face with a 0.5m height of fall was higher in CFRP sandwich panel as compared to GFRP where-in a dent was created due to greater energy absorption process.

A typical Load – Time plot is shown in *fig 6* for CFRP sandwich panel C100-0.5 which clearly explains the level of load increase and decrease.

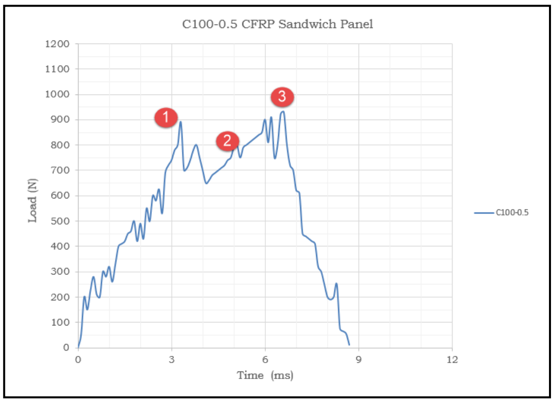

Fig 6. Load – Time Plot for C100-0.5 CFRP Sandwich Panel.

It is clear from the graph that at point 1 the impact damage is higher due to indentation caused by the impactor on the top face, now the sandwich panel absorbs certain amount of energy making a dip in the curve. With further penetration, the dart requires additional force to pierce through the core followed by bottom facing damage and this peak is seen at point 3 as shown in *fig 6*.

III. Compression After Impact Test

The compression after impact test was carried out at room temperature, using a universal testing machine with a loading capacity of 150kN. The specimen was loaded at a constant rate of 5mm/min. Although there are several methods available for compression test methods as listed by [10] [14] &15]. A simple column based compression testing method was used. All the six specimen were compression tested to check for its residual compressive strength and decide on the energy absorption capacity during compression test. Two unimpacted specimen each from GFRP & CFRP sandwich panels were compression tested to check for the difference in load capacity. As the specimen was loaded, the Force –

Displacement curve was recorded and in turn. From the curve the *failure load* was found and compared with undamaged specimen. The difference in load capacity is shown in *Table II*

TABLE II. CAI Results for GFRP & CFRP Sandwich Panels

Specimen Code	Impact Energy [J]	CBI Failure Load [kN]	CAI Failure Load [kN]	CAI Strength [N/mm^2]	Percentage loss in strength [%]
G100-0.1	4.90		27.550	15.31	18.1
G100-0.3	14.72	33.635	26.230	14.57	22
G100-0.5	24.52		24.550	13.64	27
C100-0.1	4.90		31.336	17.41	31.45
C100-0.3	14.72	45.714	29.659	16.48	35.12
C100-0.5	24.52		27.830	15.46	39.1

The CBI results were obtained from each of the sandwich panel made of GFRP & CFRP facings, without impact damage. The results obtained from this test is plotted in *Table II*. Further all the six impacted specimen were subjected to compression test to find the percentage loss in residual strength and the load displacement curves are plotted for both CFRP & GFRP sandwich panels as shown in *fig 7 & fig 8*. It is found that as the energy absorption capacity increases, the failure load increases and in turn the percentage loss in failure load also increases. For GFRP sandwich panels as the trend moves from BVID to VID the load fell down by 24.550 kN as compared to the undamaged sandwich panel of 33.635kN. A loss in residual strength load of 27% was noticed. However with the same configuration in carbon, the trend was different wherein the loss in residual strength load increased to 39.1%. This was due to the fact that carbon exhibit poor impact resistance characteristics and hence the energy absorption capacity was lesser than glass.

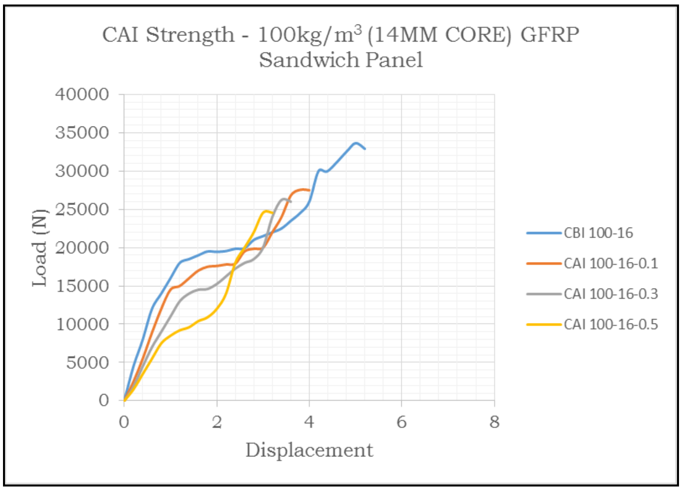

Fig 7. CAI Strength for GFRP Sandwich panels

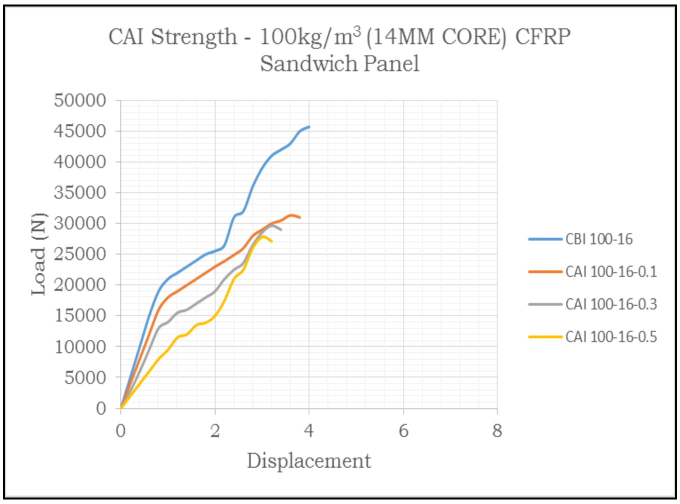

Fig 8. CAI Strength for CFRP Sandwich panels

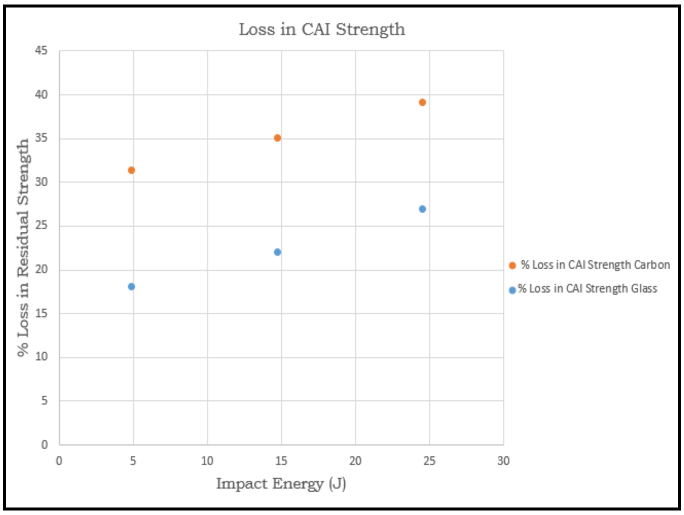

Fig 9. Percentage loss - Residual Strength of GFRP & CFRP sandwich panels.

The compression after impact strength (residual strength) was determined using the eq 1

$$\sigma = F/bd \qquad (1)$$

Where in F is the load at failure, b is the specimen width and d is the specimen thickness.

It is found that with increase in height of fall, the loss in residual strength increases. Since the local damage is higher, the effect of compression on these sandwich panels results in quick degradation of strength due to interlaminar failure of the laminates and in turn this effect propagates within the foam core making it venurable to further failure. When the bottom facings debonded the compression strenght further increased and the crack propagated further. The same is shown in *fig 7 & fig 8* which shows a down fall in load curve when the peak load is attained. All the load – displacement curves follow a similar trend, ensuring material linearity during the test.

Further, the displacement histories enables a user to know more about the type of failure and from which location it originated. Much of the failures have originated from damaged skins and in turn propogated further. When matrix crack occurred, the strength degradation was faster as compared to core damage or facesheet indentation as shown in *fig 4 & fig 5*

It is worth noting that the effect of CAI strength is lower in carbon as compared to glass and the percentage loss in CAI residual strength is higher in carbon as compared to glass/epoxy sandwich panel as shown in *fig 9*

IV. CONCLUSION

A total of six sandwich panels were tested for low velocity impact for constant thickness, facings and core density with variation in height of fall. All CFRP sandwich panels tested for impact showed lower energy absorption capacity as compared to GFRP sandwich panels. The CFRP sandwich panels displayed higher loss in residual strength as compared to GFRP sandwich panels. The loss in residual strength in CFRP was around 39% for an impact energy of 24.52J as compared to GFRP which was only around 27%. Hence GFRP sandwich panels displayed better impact and compression after impact properties as compared to CFRP sandwich panels.

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REFERENCES

[1] Ferri R, Sankar BV. Static Indentation and low velocity impact test on sandwich plates. In: Proceedings of the ASME Aerospace Division, Vol 55, 1997, 485-90

[2] Carlsson LA, Sendlein LS, Merry SL. Characteriation of face sheet/core shear fracture of composite sandwich beams. J Comps Mater 1991;25:101-16

[3] Hoo Fatt M, Park K.Dynamic models for low-velocity impact damage of composite sandwich panels – Part A: deformation. Compos Struct 2001; 52:235-51

[4] Daniel IM, Jandro LA. Fabrication, testing and analysis of scomposite sandwich beams. Copos Sci Technol 2000;60: 2455-63

[5] Zee R, Hsich C. Energy absroption process in fiberous composites Mater Sci Eng A 1998; 246: 161-8

[6] Abrate S Localised impact on sandwich structures with laminated facings. App Mech Rev 1997;50(2):69-82

[7] Tomblin J Lacy T, Smith B, Ilooper S, Vizzini A, Lee S. Review of damage tolerance for composite sandwich airframe structure. DOT/FAA/AR-99/49, USA, Federal Aviation Authority; 1999.

[8] Aminanda Y, Castanie B, Barrau JJ, Thevenet P. Experimental analysis and modeling of the crushing of honeycomb cores. Appl Compos Mater 2005;12:213-27

[9] Patrick M. Schubel, Jyi-Jiin Luo, Isaac M. Daniel, Impact and post impact behaviour of composite sandwich panels, Com Part A: applied science and manufacturing, 38 - 2007 1051-1057

[10] Edgren F, Asp LE, Bull PH. Compressive failure of impacted NCF composites sandwich panels – charaxterisation of the failure process. J Compos Mater 2004;38(6):495-514

[11] Davies Gao, Hitchings D, Besant T, Clarke A, Morgan C. Compression after impact strength of composite sandwich panels. Compos Struct 2004;63:1-9

[12] Hawyes VJ, Curtis PT, Soutis C. Effect of impact damage on the compressive response of composite laminates. Compos Pt A 2001; 32(9):1263-70

[13] Hoog PJ. Bibo GA, Impact and damage tolerance. In: Hodgkinson JM, editor, Mechanical testing of advanced fiber composites. CRC Press; 2000. P. 211-47

[14] Bull P, Edgren F. Compressive strength after imapct of CFRP – foam core sandwich panels in marine applications. Compos pt B 2004; 35(6-8):535-41

[15] Shipsha A, Hallstrom S, Zenkaert D. Failure mechanis, and modelling of impact damage in sandwich beams – A 2D approach: Part I – Experimental Investigation. J Sand Struct Mater 2003;5(I): 7-31