Quasi Static Flexural Characteristics of Laminated Composites with Different Length to Width Ratio

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Abstract - This paper presents an experimental investigation on the Quasi Static Indentation behaviour of laminated composites with different length to width ratios. The materials used for the tests are Glass Fibre Reinforced Polymer (GFRP) and Carbon Fibre Reinforce Polymer (CFRP), both with unidirectional layers and with bi-woven layers stacking sequence of thicknesses 1mm and 2mm. All the material fabrication and basic tests were done from National Aerospace Laboratories, Bangalore. Specimens used for the test were of dimensions 150×150mm, 150×100mm and 150×50mm. All the tests were conducted in Digital Flexural Test System with a hemispherical indenter of diameter 12.6mm made of mild steel at a speed of 25mm/min. All the results were studied thoroughly to understand the type of damage, maximum energy absorbed, damage area, maximum deflection and the results were used to improvise the quality of the material from every corner. Discussions were made on the validation of experimental results and analytical results.

Key Words: Glass Fibre Reinforced Polymer, Carbon Fibre Reinforced Polymer, Hybrid Composite Laminates, Basic Tests, Quasi Static Indentation and Aspect Ratio.

1. INTRODUCTION

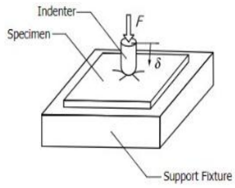
In today's world, many Mechanical systems involve a complex interaction of different types of loads, geometry, environmental conditions, manufacturing processes and type of material. Composite material is defined as the arrangement of two or more materials that results in good physical properties than those of the individual components alone. Generally, composite materials consists of two constituents, one is called as reinforcement which consists of fibers, particles or flakes of and the other is called as matrix which are normally continuous fibers. Examples of composite system include concrete reinforced with steel, epoxy reinforced with graphite fibres etc. Composite materials can be utilized as a part of place of steel; it might be light auxiliary steel. Its uses and properties are in standard with the steel with favourable position of being light in weight. One of its real uses is in building chassis of automobiles, aeroplanes, space, transportation, sports, medical, military etc.

1.1. Importance of GFRP and CFRP

Both GFRP and CFRP materials have a very significant role in replacing many materials because of its big impact in providing maximum material stiffness, lower material and maintenance cost, convenient to installation, resists to a board range of chemicals, greater flexural strength, maximum weight reduction, good insulator with lower thermal conductivity, non-conductive and has a high dielectric capability, corrosion resistance etc.

1.2. QSI or Flexural Significations

Quasi Static Indentation test has a significant role in quantifying the different flexural strength and damage of different materials, especially due to the concentrated forces on targeted regions in many composite structures. It is essentially carried out to study the relationship of Force vs Displacement for different masses from smaller regions.



An estimate of the energy required to impact damage to the structure is also calculated. In this paper, following the ASTM D 6264 standard all the tests are conducted.

A quasi-static indentation (QSI) test is used to bag quantitative measurements of the damage resistance of a continuous-fiber-reinforced composite material to a concentrated indentation force. The failure modes will help us to understand the composites deeper.

1.3. Aspect Ratio

The main aim of this experimentation work is to study and analyse flexural properties when subjected under quasi static loading. The effect of change in length to width ratio help in deep understanding of the composite laminates and the results proved that composites behaviour different for aspect ratio.

1.4. Literature Review

From the literature survey it acknowledges that, many research works have been experimented based on type of material, varying loads, velocity, indentation, varying thickness, length to thickness ratio, stacking sequence, type of fibers, fiber to resin weightage, modes of failure (crack initiation & perforation), type of experimentation etc. In this paper, an attempt has made to understand the composite material under quasi static indentation by varying different aspect ratios. [1]S. Chahardoli (2017) et al. worked on, a new form of energy absorbing structures, where energy absorbsion is occurred during a combined process, the parametric study were simulated using finite element code LS-Dyna [3]Omer Faruk Erkendirci (2016) studied on the quasi-static penetration resistance behaviour of unidirectional carbon fiber fabric/High Density Polyethylene (HDPE) composite, a flat punch has been used and QS-PST experiments are carried out for varying support span to punch diameter ratios. [4]L.S. Sutherland (2016) et al. Experimented on Quasi-static indentation behaviour of a pultruded GFRP multicellular deck panel used in footbridges by using two indenters - Hemispherical and Flat. [5]Mehmet Bulut (2016) et al. Quasi static penetration tests (QSPT) with a circular and cylindrical punch on Woven Carbon, Kevlar and S-glass fiber laminates were conducted. Compression-shear and tension-shear based failure modes were characterized [7] J. Sirichantra (2012) et al. worked on development of the flaps (petals) has been monitored on CFRP laminates under quasi-static loading and concluded that although similar flaps have also been observed, the toughness value derived in the indentation tests is not a pure mode. [8] Hongkarnjanakul (2013) et al. worked on low-velocity impact Finite Element (FE) modelling by switching ply location layup $[0_2, 45_2, 90_2, -45_2]_s$ laminated plates [12] ZS. RÁCZ and L. M. VAS worked on the study and analyze of the flexural properties of unidirectional reinforced carbon fiber/epoxy (UD) specimens with different span-to-thickness ratio (L/h) and width-to-thickness ratio (b/h).

2. Materials and Experimentation

2.1. Preparation of Material

The materials used for the experimentation are Glass Fibre Reinforced Polymer (GFRP) and Carbon Fibre Reinforced Polymer (CFRP) with thicknesses of 1mm and 2mm. The laminated materials are prepared by simple hand layup process followed by vacuum bagging process with a matte finish on eider side of the surfaces. A lengthy sheets were prepared with the layup scheme $[0^0/90^0]_4$ for 1mm thickness and $[0^0/90^0]_8$ for 2mm thickness laminates for both GFRP and CFRP laminates using epoxy resin and the volume fraction of fibers in both GFRP and CFRP laminates are 0.43 and 0.52 respectively and the thickness of single composite layer was 0.2mm. Eventually the prepared lengthy sheets are left for curing for two days at room temperature and are fabricated into 150×150mm, as required for experiments, using diamond cutter machine and are ready for testing.

2.2. Experimentation

Except QSI test all other basic tests like Density Test, Constituent Content Test, Tensile Test, Flexural Test and Inter Laminar Shear Stress were conducted at NAL (National Aerospace Laboratories, Bangalore) and their results are shown below:

	GFRP	CFRP
Density of Resin Kg/m³	1.15×10^3	1.15×10^3
Density of Fibre Kg/m³	2.54×10^3	1.6×10^3
Density of the material	1.70×10^3	1.57×10^3
Volume Fraction of Resin (V_m)	0.57	0.47
Volume Fraction of Fibres (V_f)	0.43	0.53
Weight Fraction of Resin (W_m)	0.38	0.38
Weight Fraction of Fibres (W_f)	0.62	0.62
Young's Modulus, E (GPa)	11.0	12.6
Tensile Strength, σ_{TS} (MPa)	222	366
Flexural Modulus, E_B (GPa)	16.4	35.23
Flexural Strength, σ_{FS} (MPa)	345	599
ILSS, τ_{max} (MPa)	34	54

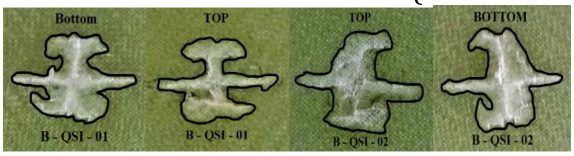
All the tests were conducted in custom built Digital Flexural Test System with a maximum loading capacity of 10kN using the hardened hemispherical indenter of diameter 12.6mm made of mild steel. A load cell of capacity of 45kN was used in the equipment and is controlled by using Micro Controlling System software using an indenter with a diameter of 12.6mm of hemispherical tip made of mild steel was used for the experimentations.

Fig. Quasi Static Indentation Setup

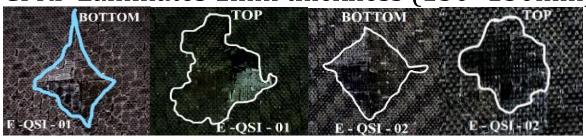
Fig. Force vs Displacement Graphs (Left), Manual Controls to operating the QSI equipment (Middle) and Force and Displacement readings in Micro Control Systems Instrument (Right).

The test specimens are clamped on the opposite sides in the square fixture. Once the setup is made ready for testing the specimen details are fed in the MCS software, once the test is begin the indenter starts moving down with a speed of 25mm/min. and stops automatically when the specimen is damaged and the results are shown in the computer. The tests were conducted for, 150×150mm, 150×100mm and 150×50mm of 1mm and 2mm thicknesses, for both GFRP and CFRP laminates.

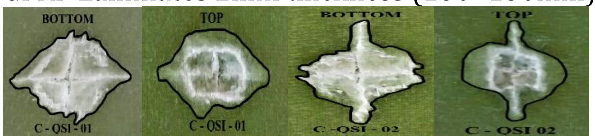
GFRP Laminates 1mm thickness (150×150mm)



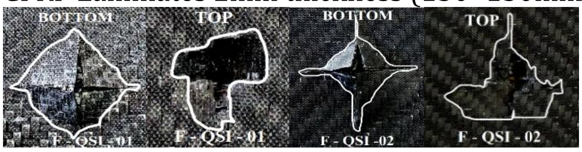
CFRP Laminates 1mm thickness (150×150mm)



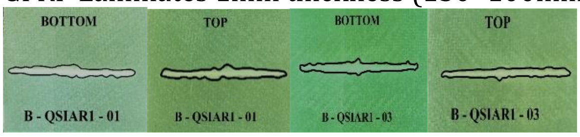
GFRP Laminates 2mm thickness (150×150mm)



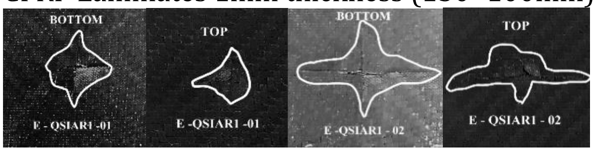
CFRP Laminates 2mm thickness (150×150mm)



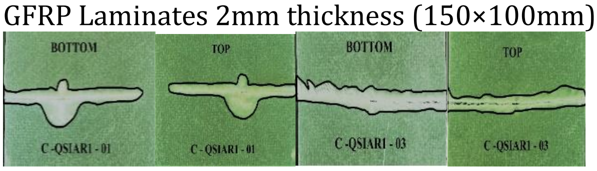
GFRP Laminates 1mm thickness (150×100mm)



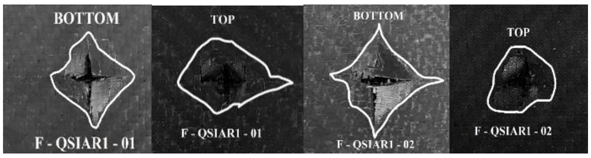
CFRP Laminates 1mm thickness (150×100mm)



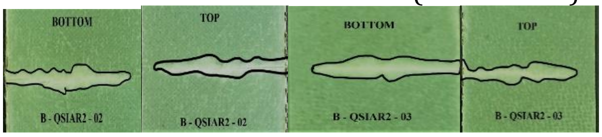
GFRP Laminates 2mm thickness (150×100mm)



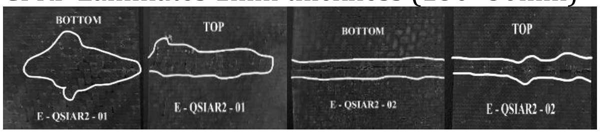
CFRP Laminates 2mm thickness (150×100mm)



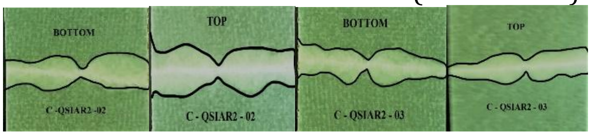
GFRP Laminates 1mm thickness (150×50mm)



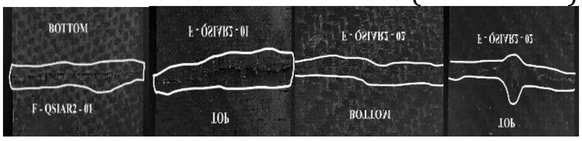
CFRP Laminates 1mm thickness (150×50mm)



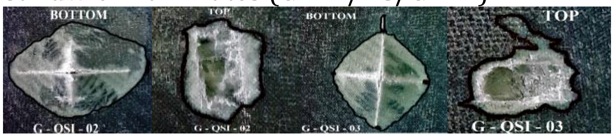
GFRP Laminates 2mm thickness (150×50mm)



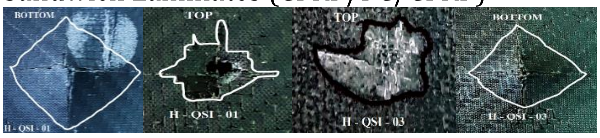
CFRP Laminates 2mm thickness (150×50mm)



Sandwich Laminates (GFRP/PC/GFRP)



Sandwich Laminates (CFRP/PC/CFRP)



Sandwich Laminates:

Sandwich panels are composites which consist of two thin laminate outer skins and lightweight (e.g., honeycomb) thick core structure. Owing to the core structure, such composites are distinguished by stiffness. In spite of the core thickness, they are light in weight and have relatively high flexural strength. Various fields where the Sandwich materials are used in civil engineering, Ships, aeronautics, bridges and road vehicles. The mechanical properties of each composites are unique from one another depending on the method of manufacturing and with the properties of sandwich components.

The sandwiches described in this report were made by two different combinations: 1. GFRP/PC/GFRP 2. CFRP/PC/CFRP. The GFRP (1mm), CFRP (1mm) and Polycarbonate (2mm) specimens (PC) are cut into 150x150mm, using Araldite AV 138 resin and Hardener HV 998 of standard ratio 10:4, the combinations are bonded together with a bonding strength of 2.59kN. Below are the sandwich materials prepared

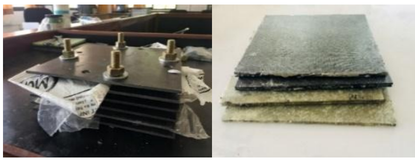


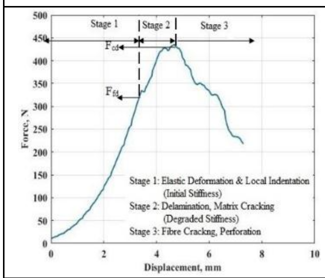
Fig. Sandwich Materials clampped in between plates (left), After removing from the clamps (right).

3. Results and Discussions:

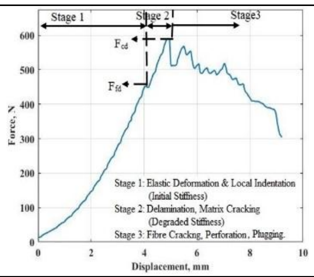
B– GFRP 1mm thickness; C – GFRP 2mm thickness; E – CFRP 1mm thickness; F – CFRP 2mm thickness;
G – GFRP 1mm/PC 2mm/ GFRP 1mm;
H – CFRP 1mm/PC 2mm/ CFRP 1mm;
QSI - Quasi Static Indention

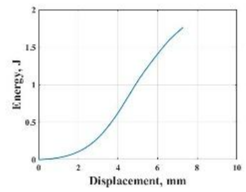
Serial No.	Disp. At Ultimate Load (mm)	Maximum Displacement (mm)	Ultimate Load (kN)
B-QSI	5.090	8.34	0.421
E-QSI	4.880	9.25	0.652
C-QSI	7.240	10.06	1.293
F-QSI	7.780	11.57	1.450
AR1 - Aspect Ratio of 150×100mm			
B-QSIAR1	5.460	7.58	0.538
E-QSIAR1	7.930	11.39	0.686
C-QSIAR1	6.410	12.49	1.108
F-QSIAR1	5.710	11.57	1.529
AR2 - Aspect Ratio of 150×50mm			
B-QSIAR2	5.600	6.83	0.426
E-QSIAR2	7.780	9.49	0.578
C-QSIAR2	5.860	7.81	0.936
F- QSIAR2	5.880	12.19	1.259
Sandwich Materials (150×150mm)			
G-QSI	7.440	9.50	2.970
H-QSI	7.120	11.26	3.08

B-QSI



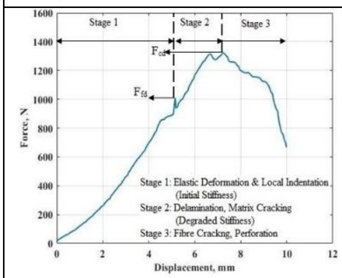
E-QSI

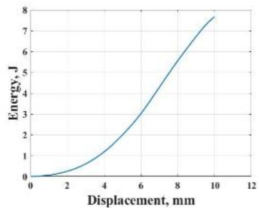




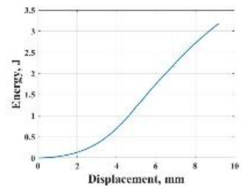
Force at first damage, F_{fd} = 330 N
Force at Complete damage, F_{cd} = 435N
Displacement at F_{cd} = 4.7 mm
Maximum Energy = 1.8 J

C-QSI-01



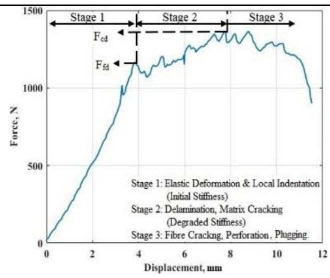


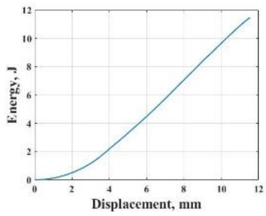
Force at first damage, Ffd = 1020
Force at Complete damage, Fcd = 1320 N
Displacement at Fcd = 7mm
Maximum Energy = 7.6J



Force at first damage, F_{fd} = 450 N
Force at Complete damage, F_{cd} = 590 N
Displacement at F_{cd} = 4.8 mm
Maximum Energy = 3.2 J

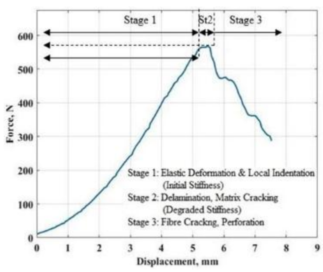
F-QSI-01



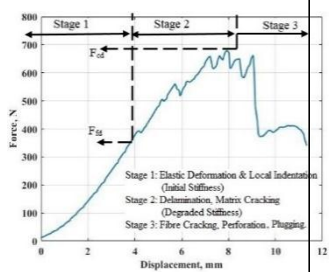


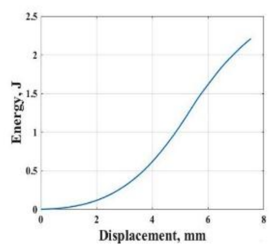
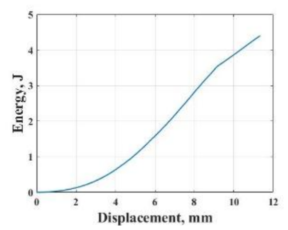
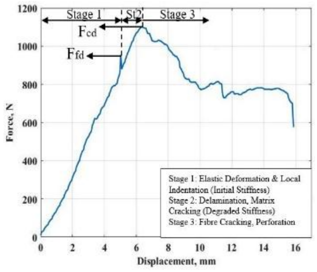
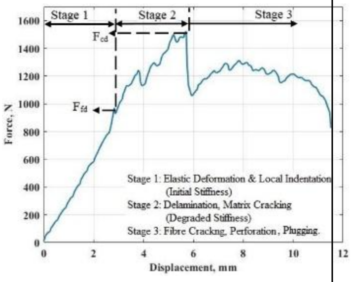
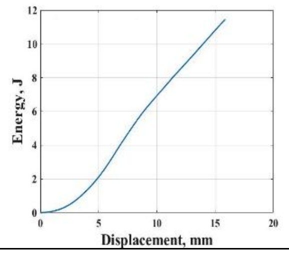
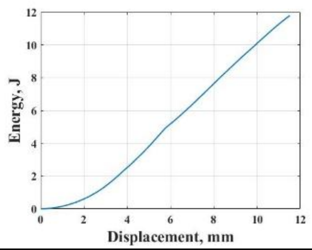
Force at first damage, Ffd = 1165 N
Force at Complete damage, Fcd = 1368 N
Displacement at Fcd = 7.8 mm
Maximum Energy = 11.5 J

B-QSIAR1

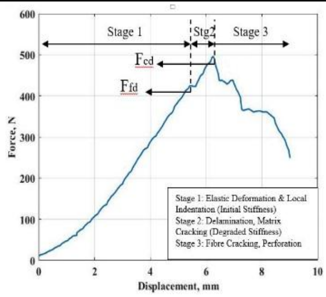
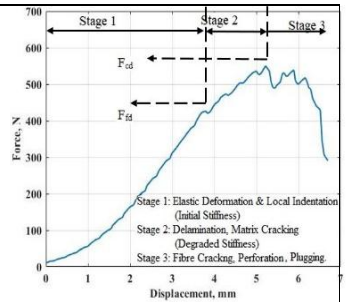
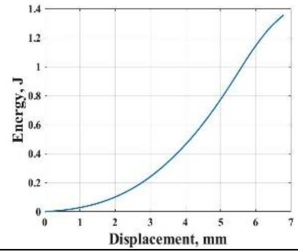
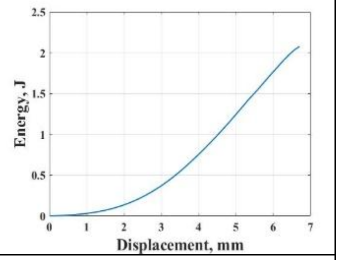


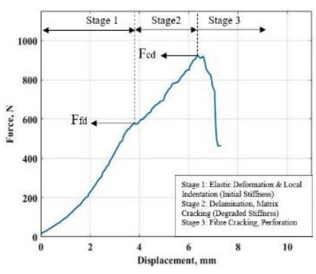
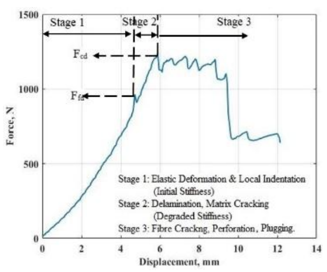
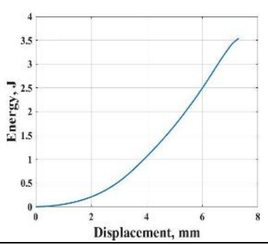
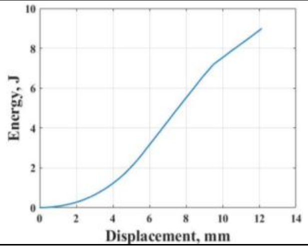
E–QSIAR1

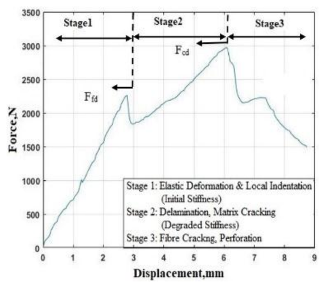
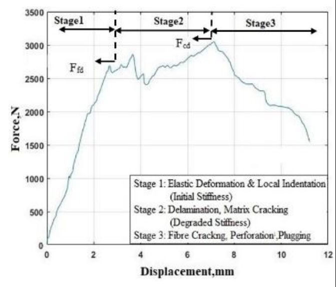
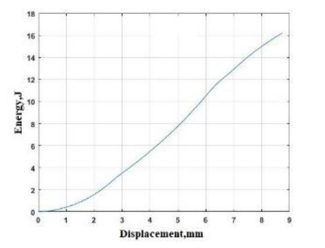
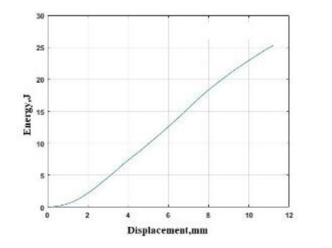


	
Force at first damage, F_{fd} = 545N Force at Complete damage, F_{cd} = 560N Displacement at F_{cd} = 5.4 mm Maximum Energy = 2.3 J	Force at first damage, F_{fd} = 390 N Force at Complete damage, F_{cd} = 680 N Displacement at F_{cd} = 8 mm Maximum Energy = 4.4 J
C-QSIAR1	F–QSIAR1
	
	
Force at first damage, F_{fd} = 960N Force at Complete damage, F_{cd} = 1100N Displacement at F_{cd} = 6.6mm Maximum Energy = 11.4J	Force at first damage, F_{fd} = 990 N Force at Complete damage, F_{cd} = 1500 N Displacement at F_{cd} = 5.7 mm Maximum Energy = 12 J

B-QSIAR2	E–QSIAR2

	
	
Force at first damage, F_{fd} =355 N Force at Complete damage, F_{cd} = 385N Displacement at F_{cd} = 5.8 mm Maximum Energy = 1.38 J	Force at first damage, F_{fd} = 430 N Force at Complete damage, F_{cd} = 550 N Displacement at F_{cd} = 5.3 mm Maximum Energy = 2.1 J

C-QSIAR2	F–QSIAR2
	
	
Force at first damage, F_{fd} = 590N Force at Complete damage, F_{cd} = 920N Displacement at F_{cd} = 6.75 mm Maximum Energy = 3.5J	Force at first damage, F_{fd} = 980 N Force at Complete damage, F_{cd} = 1250 N Displacement at F_{cd} = 5.9 mm Maximum Energy = 9 J

G-QSI	H-QSI
	
	
Force at first damage, F_{fd} = 2300 N Force at Complete damage, F_{cd} = 2990 N Displacement at F_{cd} = 6.1mm Maximum Energy = 16.2J	Force at first damage, F_{fd} =2600 N Force at Complete damage, F_{cd} = 3100 N Displacement at F_{cd} = 7mm Maximum Energy = 25.5 J

4. CONCLUSION:

In this paper, a substantial experimental investigation has been conducted on GFRP, CFRP and Hybrid composite laminates under quasi static indentation for different aspect ratios. The results shows the gradual decrease in the energy absorption as the length to width ratio increases for all the materials experimented. The maximum load taken by the GFRP(1mm), CFRP(1mm), GFRP(2mm) and CFRP(2mm) are 0.421kN, 0.652kN, 1.293kN and 1.450 respectively, for the thickness 2mm of both GFRP and CFRP is 1.293kN and 1.450kN respectively. In the same way the maximum load taken by the laminates for the aspect ratio of 150×100mm for GFRP(1mm), CFRP(1mm), GFRP(2mm) and CFRP(2mm) are 0.538kN, 0.686kN, 1.108kN and 1.529kN respectively. And for the aspect ratio of 150×50mm the maximum load taken by the laminates are 0.426kN, 0.578kN, 0.936kN and 1.259kN for GFRP(1mm), CFRP(1mm), GFRP(2mm) and CFRP(2mm). For the Hybrid Composite Laminates the maximum load taken are 2.970kN for GFRP/PC/GFRP and 3.08kN for CFRP/PC/CFRP. From the all above results it can be concluded that both CFRP and Hybrid CFRP laminates are pretty more stronger that GFRP and Hybrid GFRP Laminates but as there is no much variation in the load taken it can be the reasons like process of manufacturing, quality of the fibres used, way of experimentation etc. However the damages are observed carefully and concluded that more inspection and investigation is needed to improvise the quality of the material

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