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Comparative Study of SWCNT Reinforced E-Glass/Epoxy Composite with Bidirectional E-Glass/Epoxy Composite Plate

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Abstract:- The main aim of this project is to compare the composite material using carbon nanotubes. In current sensation composite materials are very important in aerospace automotive structural applications. Carbon nanotube gives an additional strength to the material which is going too compared with the composite material made up of resin and fibres E-glass fibres reinforced composite plates are fabricated using hand layup method. These plates are tested under low velocity impact in drop weight at three distinct impact energies, followed by in plane compression The values are examined and the methods to enhance the strength of the composite plate will be discussed, this research experimental and numerical test result will be analyzed to determine the damage occurred in the material and the strength to withstand the weight applied in the material.

Keywords:- *Fabrication-Glass Fibers, Hand Layup Method, Reinforcement.*

I. INTRODUCTON

Hybrid composites consist of two or more types of reinforcements or matrices or both. Normally, one of the fibers in a hybrid composite is a high modulus, high strength and high cost fiber such as graphite/carbon, and the second fiber usually is a low modulus fiber like Kevlar, E-glass or S-glass. [1]

The aim of the present work is to simulate two sequential and standardized tests, the drop-weight impact and the compression after impact (CAI) tests, on specimens manufactured using polymer-based composite materials. Drop-weight impact is categorized as a low-velocity and large mass impact test. Under drop-weight impact, delamination is the major damage mechanism as it reduces considerably the compressive strength of the structure. [2]

The compression after impact (CAI) test was developed to determine the damage tolerance of composite materials based on the fact that the composite compressive strength reduces substantially after impact. Several CAI testing methods have been developed by various research centers and private companies including NASA, SACMA, AIRBUS, BAE System, and BOEING. These are being used by aerospace/space and industrial manufacturers. [3]

In this present work the investigation of damage tolerance in composite plates under Compression after impact is studied. The effect of impact resistance on the composite plate under low velocity impact is analyzed in this project.

The Methodology of study includes;

- To carry out the analysis of composite plate in finite element analysis explicit ABACUS method.
- To test the composite plate under low velocityimpact.
- Free fall drop experimental test results are compared with the ABACUS numerical simulation results.

II. MATERIALS

This chapter introduces basic concepts of stiffness and strength underlying the mechanics of fibre-reinforced advanced composite materials. This aspect of composite materials technology is sometimes termed micromechanics, because it deals with the relations between macroscopic engineering properties and the microscopic distribution of the material's constituents, namely the volume fraction of fibre. This chapter deals primarily with unidirectional-reinforced continuous-fibre composites and with properties measured along and transverse to the fibre direction.

A **Lamina is** a ply or layer of Composite Laminate. A **Laminate** is a plate Consisting of number of Uni- directional or Multi – directional layer **(MDL)** of one or more Composites Material.

A **Matrix** is the material that binds the filaments or Fabric to form a composite material. The main function of the Matrix material in Fiber Re-inforced Composite is to act as medium to transfer the load. It also protects the fibers from Mechanical and Environmental De-gradation.

The Composite Material has a long history of usage. Concrete is the most common artificial composite material of all and consists of loose stones **(Aggregate)** held with the matrix of cement. Composites can also use Metal Fibers

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reinforcing other metals .Wood is also a naturally occurring composite comprising of Cellulose Fibers in a **Lignin** and **Hemi-Cellulose** Matrix **(HCM).**

Composites are made up of individual (**Constituent**) materials. The Constituent Materials are of two categories namely **Matrix (binder)** and **Re-inforcement** or **Re-inforcing** Material. The Matrix phase materials are generally continuous.

The Re-enforcing material may be in the form of Fibres, Particles or Flakes.

There are three main classifications of Composite Materials namely

- Particle reinforced
- Fiber reinforced
- Structural Composites

The Composite Material such as **Glass**, **Carbon and** Kevlar based Pre-prags and hand lay-up Components are used in light weight Aircrafts.

A. Introduction To Glass Fibers

Fibers are the principal constituents in Fiber re – inforced Composite material and thus occupy the largest Volume Fraction. The Weft Direction in a dry Fabric or Pre – prag refers to the perpendicular direction with respect to the longitudinal direction of the fibers i.e., across the length of the roll. The Warp Direction in a dry fabric (or) Pre – prag refers to the longitudinal direction (ie). Along the length of the roll.

B. Types of Fibers

- Glass Fibers
- Carbon Fibers
- Kevlar Fibers

C. Fiber Densities

FIBER MATERIALS	DENSITY	TYPICAL DIA OF THE FIBER IN MICRONS
E- Glass	2.54	10
S-Glass	2.49	10
Carbon	1.45	12

Table 1:- Fiber Densities for Various Fiber Materials

Glass fiber is a material consisting of numerous extremely fine fiber of glass. The Glass Fibers can also naturally as Pele’s Hair. The “GLASS WOOL” is one of the product of fiber glass. Thus the Glass Fiber has roughly Comparable.

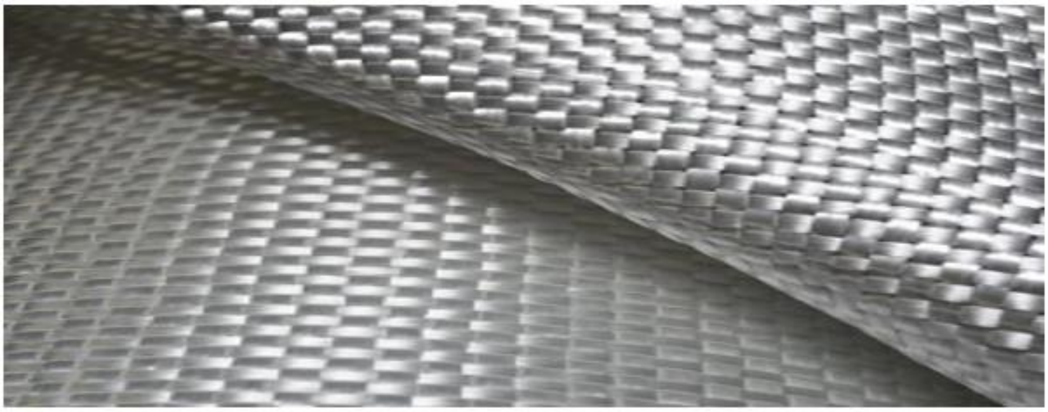

Fig 1:- Glass Fiber

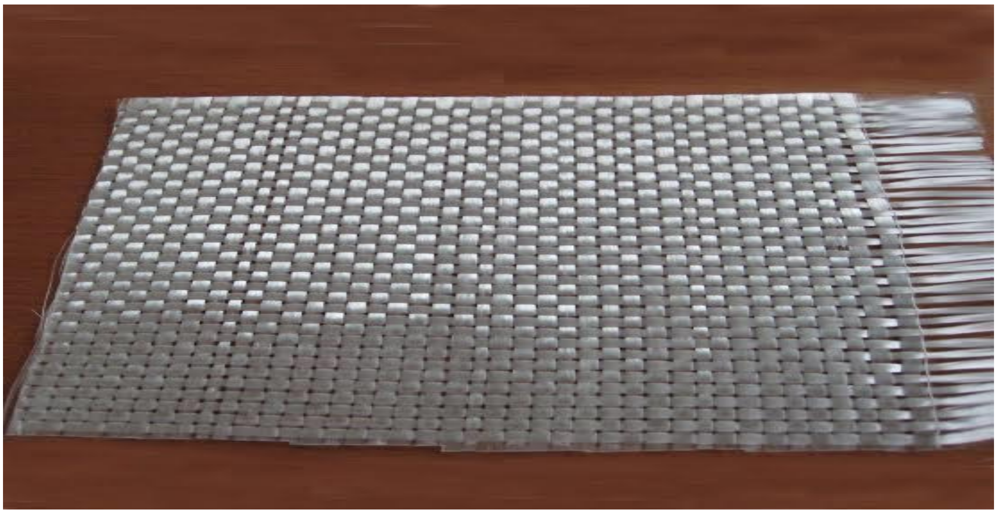

Fig 2:- E – Glass used in Composite Technology

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Electrical / Chemical resistance; alumino – lime silicate with less than 1% w /w alkali oxides with high acid resistance. It is the most commonly used Organic Glass fiber in Composite Technology because if its Lower Manufacturing Cost as Compared to S- Glass. It is used specifically for Electrical applications. It has high resistance to current flow. E- Glass is made from Boro – silicate glass.

The Constituents of E – Glass are as follows,

E-GLASS CONSTITUENTS	CONSTITUENTS VALUES
Sio2	54.5
Al2o3	14.5
Cao	17
MgO	4.5
B2O3	8.5
Na2O	0.5

Table 2:- Constituents of E – Glass.

E – Glass is the most commonly used glass fiber since it has

- Good strength
- Stiffness
- Electrical properties
- Weathering properties

Property	Minimum Value (S.I.)	Maximum Value (S.I.)	Units (S.I.)	Minimum Value (Imp.)	Maximum Value (Imp.)	Units (Imp.)
Atomic Volume (average)	0.0088	0.009	m^3/kmol	537.009	549.213	in^3/kmol
Density	2.55	2.6	Mg/m^3	159.191	162.313	lb/ft^3
Energy Content	100	120	MJ/kg	10833.9	13000.6	kcal/lb
Bulk Modulus	43	50	GPa	6.23662	7.25188	10^6 psi
Compressive Strength	4000	5000	MPa	580.151	725.189	ksi
Ductility	0.026	0.028		0.026	0.028	NULL
Elastic Limit	2750	2875	MPa	398.854	416.984	ksi
Endurance Limit	2970	3110	MPa	430.762	451.067	ksi
Fracture	0.5	1	$MPa.m^{1/2}$	0.455023	0.910047	$ksi.in^{1/2}$
Hardness	3000	6000	MPa	435.113	870.227	ksi
Loss Coefficient	1e-005	0.0001		1e-005	0.0001	NULL
Modulus of Rupture	3300	3450	MPa	478.625	500.38	ksi
Poisson's Ratio	0.21	0.23	Mpa	0.21	0.23	NULL
Shear Modulus	30	36	GPa	4.35113	5.22136	10^6 psi
Tensile Strength	1950	2050	MPa	282.824	297.327	ksi
Young's Modulus	72	85	GPa	10.4427	12.3282	10^6 psi
Specific Heat	800	805	J/kg.K	0.619087	0.622956	BTU/lb. F
Thermal Conductivity	1.2	1.35	W/m.K	2.24644	2.52725	BTU.ft/h $.ft^2$.F

Table 3:- Properties of E – Glass Fiber

III. FABRICATION OF COMPOSITE PLATE

A. Hand LAY UP:

Hand Land Up is the process of Fabrication of Composite Components in Fibers, Bi-directional E Glass fibers, single walled carbon nanotubes(SWNT) are wetted with the matrix materials in requires proportion to obtain the shape and Dimensions.

The Resin system used for Hand Lay Up is Epoxy Resin system consisting of Araldite LY 556, and Hardener HY 951 is also used during Hand layup Process.

The Epoxy resin system is used due to the following reasons,

- Low Viscosity (1500 – 3000 CP) resin system which helps during the Lamination.
- Room Temperature curing system.
- Application of Positive pressure not required.
- Low density (1.10 – 1.15 g/ cu.m).
- Good Mechanical Properties.

B. Tool PREPARATION

- Tool Cleaning
- Lay out for identification of layup area.
- Wax Simulation.
- Identification of Scribe lines.
- Masking
- Application of Release Agent.

C. Tool Cleaning Steps

- Cleaning of the tool surface for resin flashes or wax simulation using plastic or wooden scrapers.
- Removal of dust particles with vacuum cleaner.
- Use dry cloth for removal of fine dust particles and check visually the cloth and repeat the process.

D. Tool Fabrication

- Study of drawing and lay up schemes.
- Identify the template corresponding to each layer.
- Weigh the fabric layers individually.
- Calculate the resin and hardener weight.
- Arrange the necessary tools and other lay-up aids.
- Mix the resin and hardener.
- Place the fabric on the tool.
- Jab and roll the fabric using brush and proper size roller and ensure that fabric id fully wetted with resin.
- Repeat the above procedure for all the layers.

E. Types of Layup Aids

- Component drawing-Rollers
- Scale -Red Ink Pen
- Templates -Brushes
- Scissors -Knife
- Cotton Gloves-Process sheet
- Surgical Gloves-Sketch pens
- Spatulas -Dust bin
- Face mask

F. Layup Fabrication

- Tool Preparation
- Surface area calculation
- Cutting of fabric
- Weighing of the each fabric layer
- Calculating the resin and hardener requirement
- Mixing of Resin and Hardener
- Application of mixed resin on the surface with the help of brushes and rollers
- Layup of the fabric over the spread resin
- Jabbing and rolling over the cloth for proper wetting with resin
- Repitition of resin and fabric layers alternatively to achieve the desired thickness
- Application of dry peel ply
- Application of Vacuum if necessary
- Cleaning of the hand tools and aids
- Allow for the curing at room temperature.

G. Calculation

Consider a composite material that consists of fibers and matrix material. The volume of the composite material is equal to the sum of the volume of the fibers and the volume of the matrix. Therefore,

$V_c = V_f + V_m$

Where, V_c- Volume of composite material

V_f - Volume of fiber V_m - Volume of matrix

Composite = Reinforcement + Matrix $V_c = V_f + V_m$

$V_c = l \times b \times$ total number of layer

$V_c = 150 \times 100 \times 6$

$V_c = 90{,}000$ mm³

$V_f = l \times b \times$ thickness × total number of layers $V_f = 150 \times 100 \times 0.305 \times 6$

$V_f = 27{,}450$ mm³ $V_c = V_f + V_m$

$V_m = 62{,}550$ mm³

1mm³ = 0.001 ml

= 62,550 × 0.001

= 62.550 ml

Resin: Hardener - 10:1 Ratio

= 62.550 ÷ 11

= 5.6863

Resin = 5.6863 × 10

Resin = 56.863 ml Hardener = 5.6863 × 1

Hardener = 5.686 ml

IV. EXPERIMENTAL TEST

The experimental tests were performed on E-Glass epoxy composite and single walled carbon nanotubes (SWCNT) produced by vacuum assisted resin infusion, as commonly used in wind turbines, ships and offshore applications. The chosen reinforcement was a Bi-directional mat made from E-glass fiber with an average thickness of 3mm. Epoxy resin LY-556 with Hardener HY951 curing agent was used as resin. A mix ratio of 10:1 was selected with a curing time of 24h at room temperature.

As initial part of the work, the materials properties were fully characterized. Three Bi-directional mat type laminates were tested. All laminates had a 6 layers per specimen and thickness of 0.305 mm. The impact tests were performed according to the standard test method ASTM D695.

➢ *Drop Weight Testing*

For the low-velocity impact, a vertical drop-weight testing machine was developed. For the low-velocity impact, a vertical drop-weight testing machine was developed. Low-velocity impact (LVI) is the source of various types of damage such as matrix cracking, delamination, fiber breakage and even the perforation of the fiber– matrix surface in laminated polymer matrix composites Drop-weight impact testing was performed to investigate the behaviour of the hybrid bio-composites. An instrumented drop weight test apparatus were used in this study for conducting impact tests. Impact parameters such as deceleration/acceleration, contact force, plate velocity and plate displacement were measured during impact testing. The recording of parameters was performed using the instruments: piezoelectric accelerometer, spherical impactor, linear velocity transducer (LVT) and linear variable differential transformer (LVDT). The instrument was equipped with data acquisition system connected to a standard computer to analyse the captured data.

➢ *Compression After Impact Testing (CAI Testing)*

Once the simulation of the impact test is finished, the CAI test is subsequently carried out. Therefore, the post-impact structure state should be imported and the new boundary conditions which reproduce the CAI test should be defined. Post impact compression testing of impacted specimens was carried out using compression after impact (CAI) test fixture. The specimens were clamped along the top and bottom edges during CAI tests. Anti-buckling guides were used to provide simple support along the lateral edges to prevent overall buckling of the specimen. The side supports were snug fit so that the transverse deformation due to Poisson's effect was not constrained. The CAI testing was carried out by loading the specimen on a universal testing machine with a maximum capacity if 200 KN with the laminate axis.

➢ *Testing Method*

The Test Method used in this experimental analysis was ASTM D695. ASTM D695 is a method used to determine the compressive properties of un-inforced and reinforced plastics. Using compression plates to apply a force, the properties obtained are compressive strength, compressive yield point, and modulus. The standard specimen for strength determination is a right cylinder or prism whose length is twice its principal width or diameter. If the specimen is too thin, an anti- buckling support jig should be used to prevent the specimen from buckling.

➢ *The Challenges of Testing to This Standard Are:*

- Compressive strain measurement
- Reporting calculations in compliance with the standard

V. RESULTS AND DISCUSSIONS

➢ *Low Velocity Impact Using Drop Weight Testing (LVIDW)*

- Three different heights of drop test were conducted to E-Glass fiber/ epoxy composite and SWCNT reinforced Glass fiber /epoxy composite. heights(50cm,100cm and 150cm)
- First we discuss about the low velocity impact test in E-Glass fiber/epoxy composite plate (100cm) of thickness 4mm.
- After the test no cracks with slight bulging was observed at the weight of 1kg fall from 50cm height.
- At the height of 100cm the weight of 1kg the plate experience no cracks and bulge formation.
- At the height of 150cm the weight of 1kg, crack is observed.

- Where as in SWCNT reinforced E-glass fiber epoxy composite plate whose dimensions were same as E-glass fiber/ epoxy composite plate.
- The difference of two composite plates are tabulated below,

- The impact test result is conducted in OMEGA inspection and analytical laboratory in Chennai
- Three separate plates were used for both the composite plates to test the different heights of low velocity impact test and CAI test. **Dimensions (10×10×0.4cm).**

S.no	Material used	Height of 50cm	Height of 100cm	Height of 150cm
1.	SWCNT reinforced E-glass fiber/ epoxy composite plate	No cracks and Bulge formation	No crack and Bulge formation	No crack with slight bulge
2.	E-glass fiber/ epoxy composite plate	No crack with slight bulge	No crack with strong bulge	Crack initiated

Table 4:- (comparison of plates at different heights)

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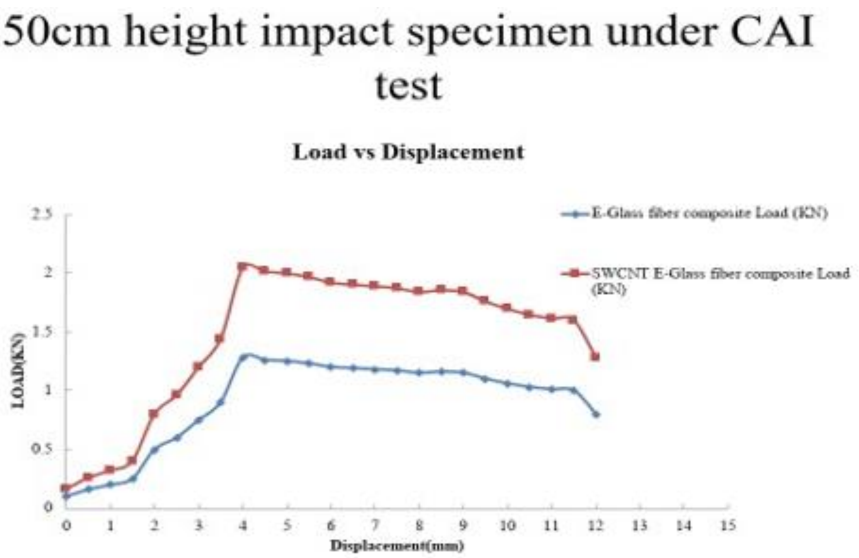
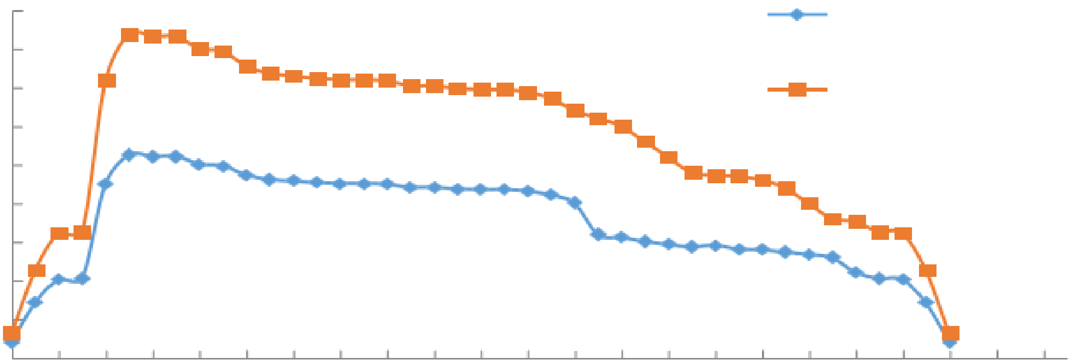
- *CAI Test results*

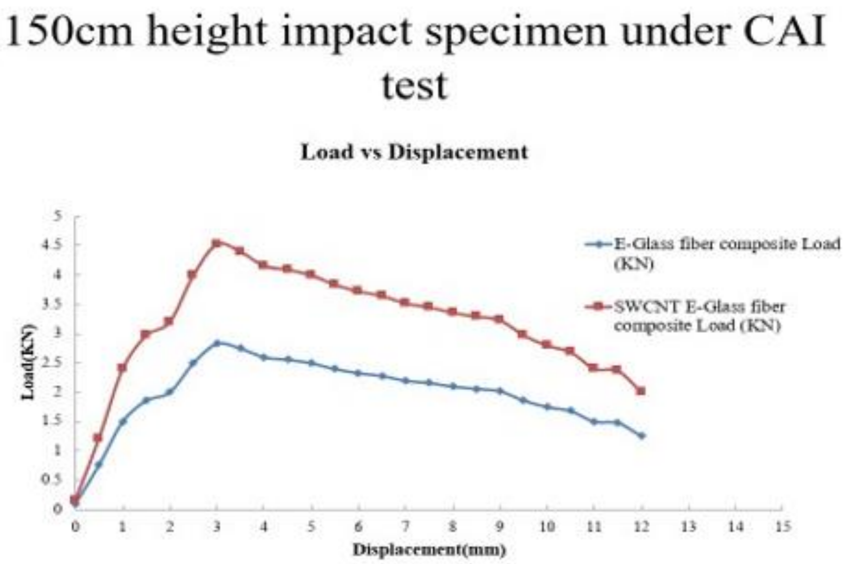
- After the impact test, to measure the impact of the impactor size (damage Zone) in the plate by using co-ordinate measuring machine.
- Then the plate subjected to the CAI test in Universal testing machine. By using CAI test fixture the specimen is placed.

The graph was plotted Load (KN) vs Displacement (mm).





Graph 1:-100cm height impact specimen under CAI)



Graph 2:- at height 150cm

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- ➢ *E-glass fiber/ epoxy composite plate:*
- Compression after impact test results of 50cm height impacted E-glass fiber /epoxy composite plate withstand the maximum of **2.83KN** compressive force.
- Compression after impact test results of 100cm height impacted E-glass fiber /epoxy composite plate withstand **2.62KN** compressive force.
- Compression after impact test results of 150cm height impacted E-glass fiber /epoxy composite plate withstand **1.28KN** compressive force.

- ➢ *SWCNT E-glass fiber/ epoxy composite plate:*
- Compression after impact test results of 50cm height impacted SWCNT reinforced E-glass fiber /epoxy composite plate withstand **4.53KN** compressive force.
- Compression after impact test results of 100cm height impacted SWCNT reinforced E-glass fiber /epoxy composite plate withstand **4.192KN** compressive force.
- Compression after impact test results of 150cm height impacted SWCNT reinforced E-glass fiber /epoxy composite plate withstand **2.05KN** compressive force.
- For easy understanding the tabulation is shown below the value of residual strength in compression after impact of the two composite plates impacted by different heights.

S.no	Materials used	Height 50cm maximum load (KN)	Height 100cm maximum load (KN)	Height 150cm maximum load (KN)
1.	SWCNT reinforced E-glass fiber/ epoxy composite plate	**4.53**	**4.192**	**2.05**
2.	E-glass fiber/ epoxy composite plate	**2.83**	**2.62**	**1.28**

Table 5:- SWCNT E-glass fiber/ epoxy composite plate

VI. CONCLUSION

CAI or edgewise compression strengths are relative to the peak load that is obtained in the force–displacement curve during tests. If the entire force displacement curve is considered, some additional information can be retrieved. The residual compressive strength after impact damage (CAI strength) has been noted from the plot. The SWCNT E-glass fiber /epoxy composite plate maximum residual compressive strength is sixty percent (60%) more than the E-glass fiber/epoxy composite plate. From the results, the long height impact (150cm) created the structural damage to the plate behave of that it took low residual compressive strength in both cases of SWCNT E-glass fiber /epoxy composite plate and bidirectional E-glass fiber /epoxy composite plate.

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