Experimental Investigation of CNT Infused GFRP Hollow Box Beams

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Abstract - *Fabrication and Experimental Investigation of Glass fiber reinforced epoxy hollow square box beam. The Multiwalled Carbon Nanotubes (MWCNT) are used as nano fillers. In this present work, Glass fiber/Epoxy composite box beam is developed by Ultra-Sonication, Hand Lay-Up method followed by Vacuum Bagging. Three different pairs of specimens are made with varying MWCNT weight percentage by 0%, 0.5%, 1%. The Three-point bending and Edgewise compressions tests are carried out for all the specimens and the results are compared to determine the influence of carbon nano tubes on Glass Fibre Reinforced Polymer (GFRP) hollow box beams. The study evaluates that the bending stress is high at 1 wt.% infusion of MWCNT. The results conclude that the bending stress of GFRP/epoxy, GFRP/epoxy + MWCNT 0.5%, GFRP/epoxy + 1% are in a range of 52.5574 MPa, 65.6814 MPa, 81.10 Mpa respectively. The stress developed during compression is high in 0.5 wt.% infusion of MWCNT. The results conclude that the maximum stress developed during compression of GFRP/epoxy, GFRP/epoxy + 0.5% MWCNT, GFRP/epoxy + 1% MWCNT composites are in a range of 64.471 MPa, 85.371 MPa, 70.281 Mpa respectively. An increment of MWCNT further decreased the properties. It is determined that CNT added GFRP hollow box beams show higher mechanical properties compared to virgin GFRP hollow box beams.*

***Key Words*: Fabrication, Glass Fiber, Epoxy, MWCNT, Ultra-Sonication, Hand Lay-up, Vacuum Bagging.**

1. INTRODUCTION

Over the past few years, the composites are playing a vital role in many industries and also in the development of new components. The use of composites has spread among many sectors such as the aeronautical, aerospace etc. In the aeronautical industries, the composites are used in the manufacturing of aircraft's structural parts, machinery, primary and secondary skin surface, landing pads, landing gear supports etc. In the aerospace industries, the composites are used in the manufacture of rocket chambers, fuel tanks and other small components.

The main reason for the use of composites in above-mentioned industries is that composites offer reasonable strength at a very less weight compared to conventionally used metals. The composites have more tensile and compressive strength properties than many other metals.

The glass fiber reinforced polymeric (GFRP) composites are very popular for their aircraft engineering applications such as elevators, rudders, fuselage and landing gear doors due to their light weight and high fatigue resistance.

The carbon nanotubes (CNTs) are cylindrical hollow fibres which consist of single or multi layers of pure graphite. They are very light and offer more surface contact than any other nano materials. The nano tubes also consist of multiple walls of carbon rings which gives additional strength to the structure.

The hollow box beams help to reduce the self-weight of the beam. They have higher resistance to the torsional buckling and offer less resistance to air flow. They have uniform geometry along two or more cross sectional axes and thus uniform strength characteristics, this make them good choice for columns.

2. LITERATURE SURVEY

1. **Ming-Chuen Yip et al** [1], The paper reports on fabrication of carbon nano tube infused GFRP composite laminates using ultra sonication and hand lay-up method. The study was to investigate inter laminar shear strength and flexural strength of composites consisting of different weight present of CNTs. When CNT weight percent was 0.5 mechanical properties were best shown. ILSS was significantly improved by 15.7% and flexural strength was improved by 9.2%. Dynamic Mechanical Analysis was employed to measure storage modulus of composite laminates. Fracture surface was observed by scanning electron microscopy, the significant weakening of fiber matrix interface and matrix softening were major factors effecting strength and modulus at high temperatures. Only when CNTs were firmly adhered to epoxy matrix, load transfer from epoxy resin to CNTs was freely possible.

2. **Moneeb Genedy et al** [2], It was demonstrated that with addition of multi walled carbon nano tubes (MWCNT) fatigue life of GFRP has been significantly improved compared to neat GFRP. The GFRP composites were fabricated and tested under static tension and cyclic tension with mean fatigue stress equal to 40% of the GFRP tensile strength. The micro structural investigations using scanning electron microscopy were used for further investigation of MWCNTs on GFRP composites. The results of experiment for 0.5 wt.%, 1

wt.% were able to increase the fatigue properties of glass fiber reinforced polymer by 1143% and 986% compared with the neat GFRPs. The tensile strength also improved by 28% on addition of 0.5 wt.% and 2% on addition of 1 wt.% MWCNT. The non-significant effect of 1 wt.% on tensile strength of GFRP compared with 0.5 wt.% MWCNTs is attributed to the fact that tensile strength of GFRP is governed by adhesion of epoxy and glass fibers.

3. **Chavan, Gaikwad** [3], The study was an overview of the work done in the area of characterization of glass fiber epoxy composite material. Different manufacturing processes are used for manufacturing the glass fiber epoxy composites. It was observed that work has been done related to manufacturing and mechanical characterization of glass/epoxy materials. A study on analysis of tensile, shear and flexural strength by varying volume fractions of glass fiber and epoxy materials has been carried out. The various preparation technologies that were used for preparing the GFRP composites has been discussed. The behavior of the glass fiber composite under tensile, shear and flexural loading with different manufacturing processes were studied. The ultimate tensile strength and flexural strength of the fiber glass composite increased with the increase in the fiber volume fraction.

4. **Rupesh Khare et al** [4], In the paper, the recent research on the carbon nano tubes has been reviewed. The interfacial bonding properties, the mechanical performance, electrical percolation of nanotube/polymer was also reviewed. This states that several experiments have confirmed the theoretically predicted mechanical properties of carbon nanotubes (CNT). The addition of CNT can improve the composite microstructure, change the nature of the matrix. The CNTs can remain undamaged up to 1500-degree temperature. The CNT can resist extreme shear stresses.

5. **Akash Deep et al** [5], In the paper, the design of glass fiber composites with epoxy matrices modified with multi-walled carbon nano tubes (MWCNT) and short carbon fiber fillers was carried out. The manufacturing has been done using the hand lay-up technique assisted by press moulding machine. The flexural three-point bending test was performed on multiwalled carbon nano tube reinforced GFRP and hybrid GFFRPs (MWCNTs and SCFFs) using Hounsfield H50KS universal testing machine at a strain rate of 1 mm/min. The results showed that the addition of nano and micro fillers improved the flexural strength of GFRP laminate. The MWCNTs alone and MWCNTs & SCFFs both improved the flexural strength of the composite laminate when compared to the new GFRP. The increment was more evident in the case of composite filled with 0.5 wt.% MWCNTs and 0.5 wt.% SCFFs both.

6. **Smrutisikha Bal** [6], In the paper, multi-walled carbon nano tubes (MWCNTs)/epoxy resin composites are fabricated by dispersing MWCNTs in epoxy matrix. The dispersion of CNTs was analyzed using an optical microscope. Ductile nano composites are prepared by setting samples at low temperature. With a little wt.% of CNTs, composite samples yield higher mechanical and electrical properties than pure resin samples. Improvement in flexural modulus and electrical conductivity were observed in the composites containing well dispersed CNTs than the ones with poorly dispersed CNTs. Lower values were due to in-homogeneous dispersion of nanotubes in polymer matrix. The ductile samples having better dispersion state exhibit significant improvement in the mechanical and electrical properties.

7. **Omer Yavuz Bozkurt et al** [7], In the paper, the effect of nano-silica inclusion on tensile and flexural characteristics of glass fiber epoxy composite laminates. The fabrication has been carried using the hand lay-up technique. Four different weight percentages of nano particles of 1%, 1.5%, 2%, 3% were used for the fabrication of composite laminates. The tensile and the flexural tests has been carried for the specimens. The results obtained from the specimens having nano-silica particles showed improvement on tensile strength, flexural modulus and flexural strength.

3. MATERIAL SELECTION

Epoxy Resin is considered as the matrix material since it can meet high strength and stiffness requirements. It is compatible with most composite manufacturing processes, particularly hand lay-up and vacuum bagging techniques.

Table 1: Properties of Epoxy Resin

Type of Epoxy, Hardner	LY556, HY951
Modulus of Elasticity	2.9 – 3.4 Mpa
Deformation	5 – 7 %
Tensile Strength	68 – 80 Mpa
Bending Strength	110 – 130 Mpa
Specific Wt. at 25 ˚ C	1.20 g/cm

The S-glass fiber is considered as reinforcement material since it has high structural and thermal properties.

Table 2: Specification of Glass Fiber

Type of Fiber	S – glass fiber
Thickness	0.3 mm
Direction	Bi – Directional
Weave Type	Plain Weave

Table 3: Properties of S-glass fiber

Density	300 GSM
Modulus of Elasticity	78 Gpa
Elongation to break	5.3 %
Tensile Strength	575 – 3970 Mpa

The Carbon Nano Tubes are been selected as the nano filler materials. They have high aspect ratio, large interacting volume compared to other nanofillers enabling them to provide higher mechanical properties.

Table 4: Properties of CNT

Type of CNT	Multi-Walled CNT
Purity	>99%
Average Length	~5 µm
Average Diameter	10 – 15 nm

4. FABRICATION

4.1 HAND LAY-UP PROCESS

A wooden mold is made according to the required dimensions of the specimen (300mm x 30mm x 2.6mm). Then the releasing agent is been applied to the mould. The mold is then wrapped around with mylar sheet for easy releasing of the composite after curing. The glass fiber sheet is cut into layers according to the surface area of the mould, the number of layers of glass fiber depends on the thickness that is to be achieved. Eight layers of glass fiber is been used to achieve an estimated 2.8 mm thickness. The resin LY556 and hardner HY951 are mixed in the ratio of 1:10. To fabricate a composite beam infused with multi-walled CNTs, the CNT and resin are mixed for 2-3 hours using ultrasonication process.

Fig 1: Fabrication of GFRP Box Beams using Hand lay-up

Fig 2: Ultrasonication of Resin CNT mixture

The CNTs are infused in the composite by different weight percentages 0%, 0.5%, 1%. Resin and fiber are maintained at a weight ratio of 1:1. Glass fiber sheets are wounded around the mold and resin mixture is simultaneously applied to glass fiber layers. Glass fiber is wounded in such a way that the closing ends meet at opposite each time, covering all four sides. Roller is used to press and roll along the composite to avoid any air bubbles. The presence of air bubbles in the composite can lead to weak fiber binding and also void formations which results in failure of the composite therefore, care is taken to avoid formation of air bubbles in and on the surface of composite.

4.2 VACUUM BAGGING PROCESS

After the hand lay-up process, the wet composite beam is wounded with the peel ply, breather fabric and release film. The vacuum bagging setup is prepared, and the wet composite beam is placed inside the vacuum bag, the bag is enclosed using sealant tape without leaving any gaps to prevent air leakage. The material is left in the bag connected to the vacuum pump for curing for 3-4 hours. The obtained composite beam is released from the mold and cut into the required length using the composite cutting saw machine and any sharp edges are softened using the zero-emery paper.

Fig 3: Vacuum Bagging of GFRP Box Beams

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The final specimens obtained:

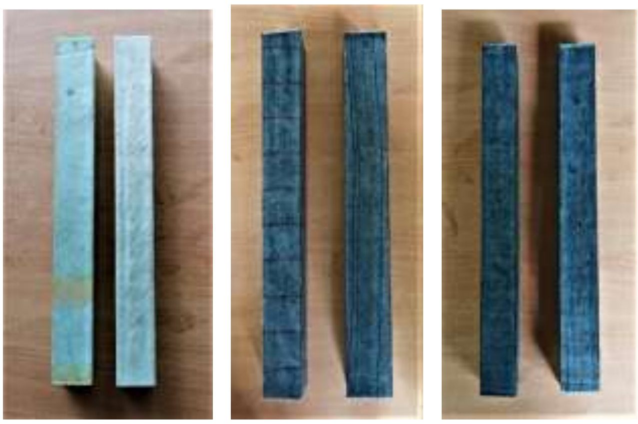

Fig 4: 0%, 0.5%, 1% CNT Infused Specimen in Sequence

5. RESULT AND DISCUSSION

5.1 THREE POINT BENDING TEST

The GFRP beams are subjected to three-point bending test using the Universal testing machine (UTM). It has a crosshead testing device with a maximum load cell capacity of 100 ton. The testing is displacement controlled.

The specimen is placed on the two knife edges leaving a gauge length of 200mm for loading, 50mm on both the ends as tab length. The indentor is brought in close contact with the specimen. The inputs are given as test length 50mm, the speed of loading at a rate of 2mm/min. The gauge thickness is 2.65 mm. Three specimens are tested from each category. The load and displacement values are noted as the testing results.

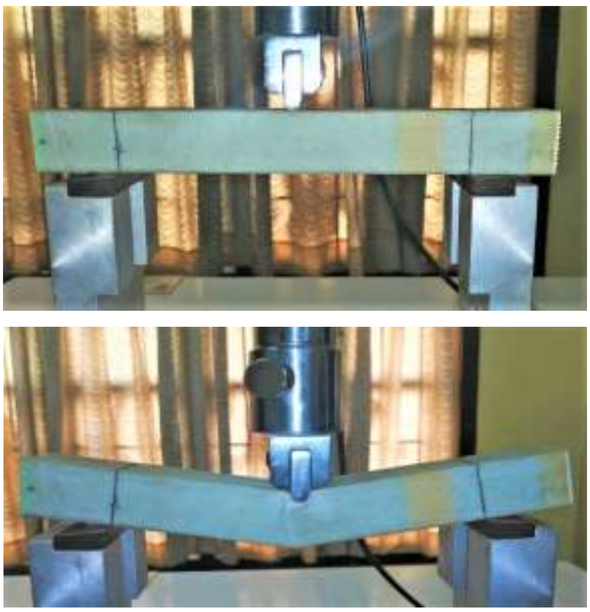

Fig 5: Bending Test for Plain GFRP Beam

Table 5: Bending test result for Plain GFRP

Peak Load	4.277 KN
Deflection at Peak Load	4.912 mm
Bending Stress	52.5574 Mpa

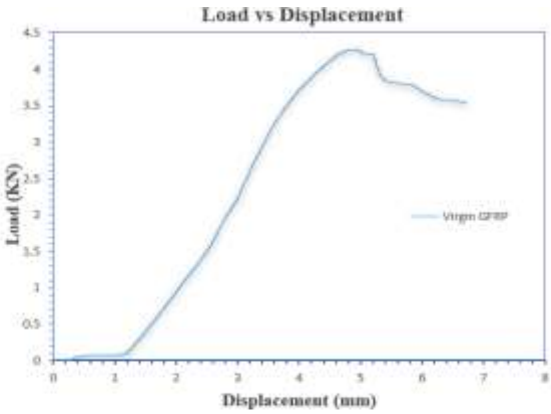

Fig 6: Load vs Displacement graph for plain GFRP Beam

Fig 7: Bending Test for 0.5% CNT Infused GFRP Beam

Table 6: Bending test result for 0.5% CNT infused GFRP

Peak Load	5.345 KN
Deflection at Peak Load	5.336 mm
Bending Stress	65.6814 Mpa

Fig 8: Load vs Displacement graph - 0.5% CNT infused GFRP

Fig 9: Bending Test for 1% CNT Infused GFRP Beam

Table 7: Bending test result for 1% CNT infused GFRP

Peak Load	6.591 KN
Deflection at Peak Load	4.735 mm
Bending Stress	81.10 Mpa

Fig 10: Load vs Displacement graph - 1% CNT infused GFRP

The hardness of the indentor (Stainless steel) is higher than the GFRP. Therefore, the beams initially underwent deflection even at lower loads until a certain point. Then they started to resist the load, the 0%, 0.5% CNT infused GFRP showed constant stiffness for up to loads of 3.5 KN, 4.4 KN respectively. In case of the 1% CNT GFRP the beam showed constant stiffness until it reached its peak load. On further increasing the loads the stiffness of the beams reduced as the composite underwent an increased rate of deformation. After reaching the peak loads of 4.27 KN, 5.34 KN, 6.59 KN respectively, the plain GFRP composite exhibited a little ductility as the fiber started weakening. But the 0.5% and 1% CNT GFRP composites did not exhibit any ductility even when the fiber started to weaken as the addition of CNT increased the stiffness of the beam. Later the curves started to drop as the materials underwent failure.

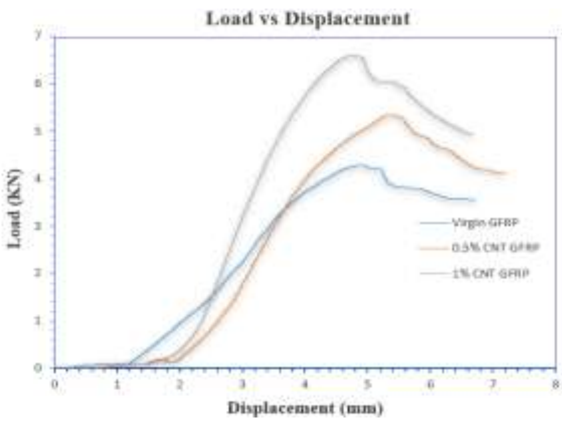

Fig 11: Comparison of Bending Test results of 0%, 0.5%, 1% CNT infused GFRP beams

Fig 11 shows that 1% CNT infused glass fiber composite box beam showed the higher bending strength of 81.10 Mpa followed by the 0.5% CNT infused glass fiber composite beam with 65.68 Mpa strength compared to the virgin glass fiber composite beam with 52.22 Mpa.

5.1.1 FAILURE INVESTIGATION

In all the specimens, during the bending test the upper flange on which the load is applied underwent compression and the lower flange underwent tension.

In case of plain GFRP beam, after reaching the peak load the upper flange started undergoing local buckling. Due to local bucking upper flange underwent matrix breakage and webs supporting the beam started cracking. On the lower surface, the weakening of fibers under loading started due to tension. The crack initiation started at the top surface and propagated to lower surface through the webs.

Fig 12: Plain GFRP box beams after failure

In the 0.5% CNT infused GFRP, after reaching the peak load the crack initiation started at the top surface and propagated to the webs. But before crack completely propagating through the lower surface, due to high brittleness the beam underwent failure without any further deformation unlike the virgin glass fiber beam.

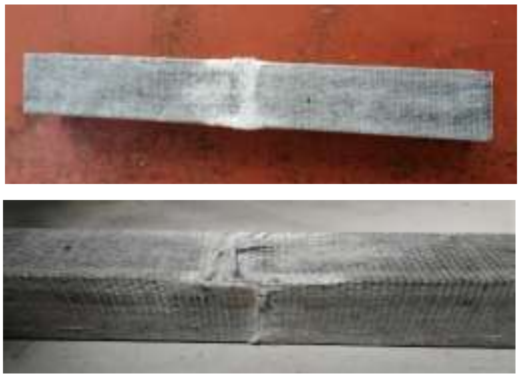

Fig 13: 0.5% CNT infused GFRP box beams after failure

The failure of 1% CNT infused GFRP is also similar to that of 0.5% CNT infused GFRP but in this case the process was little faster than 0.5% GFRP due to higher brittleness of the specimen. After reaching the peak load, the crack initiated at the top and propagated to the webs and before completely reaching the lower surface the beam underwent failure.

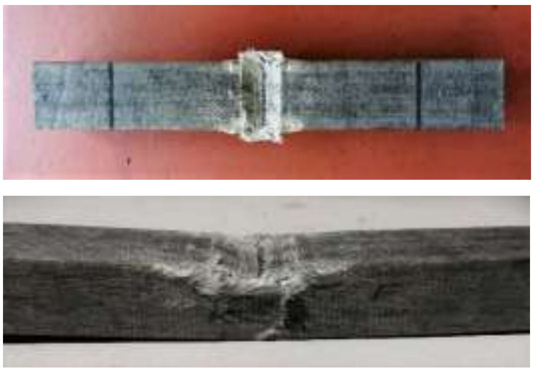

Fig 14: 1% CNT infused GFRP box beams after failure

5.2 EDGEWISE COMPRESSION TEST

The GFRP beams are subjected to edgewise compression using the Universal testing machine (UTM). It has a crosshead testing device with a maximum load cell capacity of 100 ton. The testing is displacement controlled.

The specimen was filed to achieve flat edges on both sides of the specimens. Then the specimen is placed in between the jaws of the universal testing machine, the loading jaw in brought in close contact to the specimen. The inputs are given as test length 50 mm, the speed of loading at a rate of 2 mm/min. Three specimens are tested from each category. The specimens were not crushed completely during the test since the maximum stress developed during compression can be determined without completely damaging the specimen. The load and deflection values are noted as the testing results.

Fig 15: Compression test on plain GFRP Beam

Table 8: Compression test result for plain GFRP

Load at Max. Compression	23.737 KN
CHT at Peak Load	3.261 mm
Stress at Max. Compression	64.471 Mpa

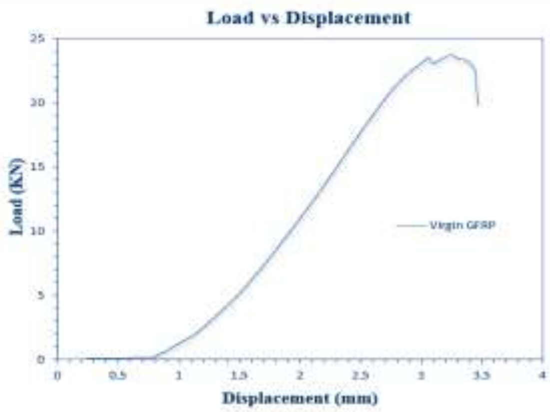

Fig 16: Load vs Displacement graph for plain GFRP beam

Fig 17: Compression test on 0.5% CNT infused GFRP Beam

Table 9: Compression test result for 0.5% CNT infused GFRP box beam

Load at Max. Compression	31.432 KN
CHT at Peak Load	5.331 mm
Stress at Max. Compression	85.371 Mpa

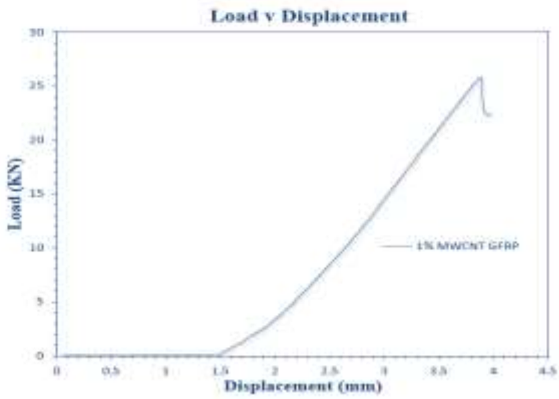

Fig 18: Load vs Displacement graph for plain GFRP Beam

Fig 19: Compression testing of 1% CNT infused GFRP Beam

Table 10: Compression test result for 0.5% CNT infused GFRP box beam

Load at Max. Compression	25.872 KN
CHT at Peak Load	3.888 mm
Stress at Max. Compression	70.281 Mpa

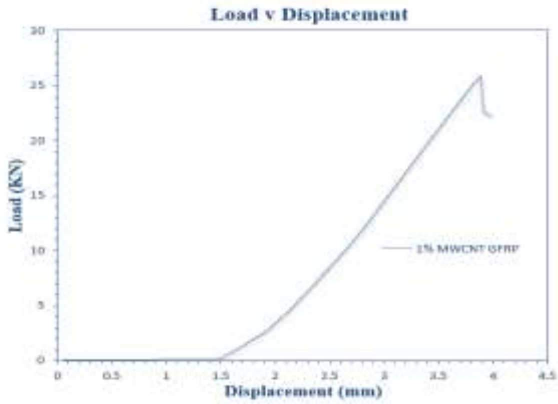

Fig 20: Load vs Displacement graph for 1% CNT infused GFRP Beam

The hardness of the indentor (Stainless steel) is higher than the GFRP. Therefore, the beams initially underwent deflection even at lower loads until a certain point. Then they started to resist the load, the 0%, 0.5%, 1% CNT infused GFRP showed constant stiffness up to their peak loads i.e. 23.73 KN, 31.43 KN, 25.87 KN respectively. After reaching their peak loads, the plain GFRP beam alone showed a little ductility as the fibers started weakening due to the absence nano fillers. Later the curves started to drop as the materials underwent failure.

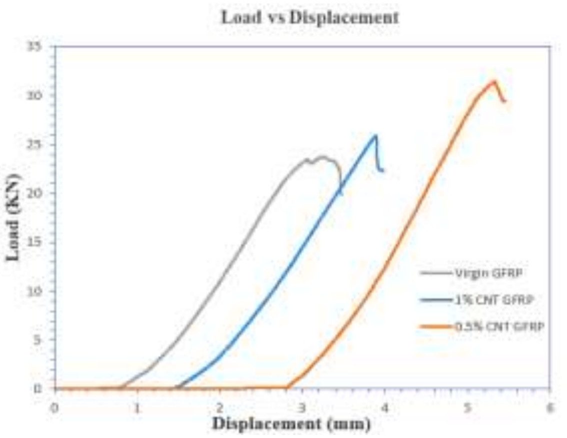

Fig 21: Comparison of compression test result of 0%, 0.5%, 1% CNT infused GFRP Beams

Fig 21. shows that 0.5% CNT infused glass fiber box beam showed higher compression strength of 85.371 Mpa followed by the 1% CNT infused box beam with strength of

70.281 Mpa compared to the virgin glass fiber box beams with compression strength 64.471 Mpa.

6. CONCLUSION

The influence of multi-walled carbon nanotubes on the mechanical properties of glass fiber reinforced epoxy hollow box beam is investigated. The multi-walled carbon nanotubes are mixed (0%, 0.5%, 1%) with epoxy resin using the ultrasonication process. The carbon nanotube infused glass fiber epoxy beams with the dimensions 300mm x 30mm x 2.6 mm are fabricated using hand lay-up followed by vacuum bagging procedures. Three pairs of specimens are fabricated, a pair in each category of weight proportion. Three-point bending and Edgewise compression properties of the GFRP hollow box beams with various weight percentages of MWCNT are investigated experimentally. The failure investigation for the GFRP beams is done to explain the process of failure during the bending test.

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