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Influence of MWCNTs integration on Mechanical Behavior of E Glass-Carbon Fiber Reinforced Epoxy Hybrid Nano Composites

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ABSTRACT: Composite materials are developed by hybridizing in a systematic integration of functionalized multi walled carbon nano tubes by ultrasonic dispersion technique to homogenize the MWCNTs in Epoxy resin 5052 (Matrix), then layed up using Carbon fibers as high modulus and E glass fibers as low modulus fibers in bi-directional twilled oven fabric form as a primary reinforcement and then compared with MWCNTs integration as a secondary reinforcement in a volume fraction of 0.5%, 1.0% and 1.5% of the composites. Post curing of the composites, the laminates were inspected for defects using ultrasonic B-Scan, then to ensure the calculated matrix to reinforcement ratios, the matrix constituent analysis was done by resin digestion method. Composite specimens were then subjected to mechanical testing. It was observed that Nano integration in composites significantly enhances the mechanical properties in different loading conditions. Compression strength was improved by 2.85%, 11.57% and 17.81% with the MWCNTs integration of 0.5%, 1.0% and 1.5% by volume respectively. Similarly, flexural modulus was enhanced by 20.14%, 52.78% and 58.8% for MWCNTs addition of 0.5%, 1.0% and 1.5% volume respectively. Also, Interlaminar Shear strength was improved by 40.89%, 63.49% and 102.56% with 0.5%, 1.0% & 1.5% volumetric addition of MWCNTs.

Keywords: E glass-Carbon hybrid nano composites, MWCNTs, Mechanical Properties, Compression strength of G-CFRP composites, Flexural Modulus of G-CFRP composites, ILSS of G-CFRP composites

I. INTRODUCTION

Composites have acquired widespread area of applications in various industrial sectors, notably in aerospace, marine, shipbuilding, furniture, sports and construction industries, over which fiber reinforced composites possess extended applicability due to its high functionality, high specific strength and specific stiffness, enhanced dimensional stability, corrosion resistance, lower density and cost effectiveness [1, 2]. Indeed composite possessed incredible mechanical properties in specific orientation that satisfied its functionality and purpose to serve in different applications, but in some cases it limited the applicability due to high cost of material, which emerged the term called hybridization of composites.

Conceptual hybridization is to tailor the properties for specific purpose to fit for functional requirements of the applications in turn reducing the total cost of material. By designing the material composing high modulus and low modulus fiber reinforcements, the specific strength can be customized to the mechanical requirements, thus total cost of the material can be reduced with optimal strength [3, 4]. In addition, Integration of Nano tubes improved the interfacial bonding between matrix and reinforcements, thus enhancing the interlaminar strength improving the mechanical properties in different modes of failures [5].

Stacking sequence and volume fraction of fibrous and particulate reinforcements depend on mechanical properties of hybrid composite [6-8]. Effect of Hybridization of composites exhibit either better performance or it shows adverse effect of it therefore it is termed as positive and negative hybrid effect respectively [9]. However, various investigators have reported that micro and nano fillers have proved improvement in mechanical properties in fiber reinforced polymer matrix composites [10]. As every composite part is likely to bears various external loads, as a result, subjected to numerous stresses. Because of the inflicted stresses, acoustic signals were emitted from different failure mechanisms e.g. debonding, delamination, matrix cracking and fiber breakage that are measurable through many strategies [11].

Delamination is the most common problem in FRP laminates and this is because of the poor interlaminar strength. Defects such as impact damages, peel off layers may occur during manufacturing processes and in service, which leads to delamination of layers, which significantly diminishes the mechanical properties which may later leads to catastrophic failure of composite structure. The type of matrix and reinforcement used and constituent individual properties, manufacturing/fabrication techniques and processes and uniform distribution of resin in plies plays an important role for the failure mechanisms or interlaminar strength of the composite [12-16].

As the thickness of the composite laminate increases the tensile strength increases by after certain critical point, it deteriorates as the difference in stresses among the layers of composites leads to delamination and thus in outward of the specimen it tensed and compressive loads acts on internal layers of the composite[17]. Whereas it enhances the flexural strength for higher thickness of laminates/ specimens, as it strongly bonds, it offers significantly higher resistance against bending loads and thus it retains against flexural loading for thicker sections [18].

Effective mechanical properties were observed by additional bristled interphase layer formed with the presence of micro or nano fillers between matrix and fiberous reinforcement [19]. Nano composites are widely being used in modern science & technology such as electromechanical automation systems, optics & photonics, biomaterials etc. [20]. A lot of investigations were conducted on elastic and electroelastic properties of nanostructured materials. Mori-Tanaka’s micro-macro transition method was proposed to determine the effective shear and in plane bulk moduli of particulate composite [21].

Tensile strength of the (high modulus & low modulus fibrous reinforced) hybrid composites is high with nano integration, as the percentage of Nano tubes (MWCNTs) increases, it enhanced the tensile strength, but after some critical level of addition it deteriorates the tensile strength as a result of increase in brittleness in resin, the matrix element [22]. The effective antiplane shear modulus is depends on its size in nanoscale whereas its interface effect is negligible with large characteristics dimensions, the interface effect of nanofiber varies with the variation of fiber section aspect ratio, higher the fiber volume fraction, greater is the interact effect. When the modulus of fiber is small then, the effective modulus of nano composite depends strongly on fiber interface effect, whereas for larger modulus of fibers, there a little influence on effective antiplane shear modulus [23]. Nano particles exhibits the significant characteristic of tendency to agglomerate between them and around the particles (Wall-effect). In general, due to the high surface free energy (High surface to volume ratio), it is difficult to achieve a non-aggregated Nano Particle system. In order to homogenize the nano particles, different mechanical and chemical dispersion methods have been proposed to disperse inorganic nanoparticles in organic solvents or resins [24, 25].

II. MATERIALS AND METHODS

II.1. MATERIALS SELECTION AND FABRICATION PROCESS

The composites were hybridized using High modulus- carbon fibers and low modulus- E Glass fibers in bi directional twilled oven fabric as a fibrous reinforcements a primary reinforcing elements and then the COOH functionalized Multi walled carbon Nano tubes (MWCNTs) were added into it as a secondary reinforcing element- a particulate reinforcement. Epoxy resin 5052 and hardener LY5052 by Araldite was used as a matrix element. Epoxy resin 5052 has been most commonly used as a matrix element in high performance composites as a thermoset polymer matrix due to its incredible characteristics such as high stiffness, dimensional stability and resistance to chemical integrity [26].

The effect of functionalization has its greater impact over dispersion mechanism, as functionalization helps in effective dispersion of CNTs in Viscous fluids (Resin). For uniform dispersion ultrasonic dispersion technique was adopted thus homogenizes the CNTs in resin and avoiding the agglomeration of CNTs.

The composite laminates were fabricated using hand layup and vaccum bag molding techniques. The purpose of hand layup is to obtain the high reinforcement to matrix ratios and vaccum bag molding helps in uniform distribution of resin in laminate. The MWCNTs were integrated in a volume fraction of 0.5%, 1.0% and 1.5% to the hybrid composites.

Post fabrication, the laminates were cured in a vaccum position for 24 hours and then cured in a programmable oven to ramp up of temperature in a controlled way and steady at that temperature and again ramp up procedure recommended by Araldite for epoxy 5052 resin.

Thus, the hybrid composites have upgraded with nano integration into it calling it to be a Hybrid Nano Composite. The purpose of hybridization is to optimize the strength for functional requirements of various applications where the cost of composite can be minimized with effective and systematic integration of high strength and low strength fibrous reinforcements. Furthermore, to enhance the mechanical properties again MWCNTs were included as a nano inclusion which played important role in bonding the laminates by improving the interfacial bonding strength of the composites.

II.2. ULTRASONIC SCANNING

Post fabrication and curing, the composite laminates were examined for any defects internal or external which usually occurs due to satrvation of resin (improper distribution of resin) causing interlaminar debonding or densification of resin (excess of resin in some places) or internal defects, voids, fiber breakages etc. For the specimens to be extracted it is important to do NDT to ensure the laminate is free form internal and external defects. The ultrasonic B Scan has been done on laminates and it is found that composite laminate is free from internal and external defects.

Fig-3.1. Ultrasonic B-scan on composite laminates

II.3.MATRIX CONSTITUENT ANALYSIS - RESIN DEGRADATION TEST:

To ensure the theoretical matrix to reinforcement ratio, it is needed to examine the actual content of matrix in composite. So the composite has been taken from different places in a laminate and subjected to acid degradation after weighing the weight of composite specimen. The Composite has been subjected to acid degradation for 6 hours following the ASTM D-3171 standard procedure. Hybrid composite specimens were subjected to resin digestion in concentrated nitric acid HNO_3 for 6 hours then the specimen were filtered and dried in oven then final weight is recorded, the loss of weight determines the resin digestion and fiberous remains determines the actual volume fraction of fibrous reinforcement.

$$V_f = = \frac{W_i - W_f}{W_i} \times 100 \qquad \text{............. (2.1)}$$

Thus, $V_m = 1 - V_f$ ....(2.2)

III. MECHANICAL TESTING

Compression Test:

Compression test is one of the most fundamental mechanical destructive tests; the test is done to determine the compression strength. Different materials have different way of test, to determine the compression strength. According to the ASTM standard ASTM D-3410 for fibre reinforced composites, the specimen architecture for compression test.

Specimens were subjected to Compression test according to ASTM D-3410, A fixture was used to align the specimen in the wedge grips and the grips are then tightened. Wedges were inserted into the compression fixture, and an extensometer was used to measure the deformation, therefore it was attached to the specimen. The specimen was compressed to failure.

In this test, the specimen is placed between the two platforms of the machine and then zero setting in software using computer or control panel. Set the loading rate/ strain rate, maximum loading range (Approximate) then apply load and observe the load versus compression graph and the mechanism of fracture in composites. Once the material is crushed to fail, the broken specimen is taken off the machine and the results are noted down.

Flexural test:

Flexural test is very important to validate the material stronger enough under bending and can sustain the loads in flexes. It is natural that when a composite is loaded in bending it would fail when the stress in the outer layer of fibers reaches the normal composite tensile strength. However, early flexural tests often exhibited considerably lower strength than the tensile strength. One of the reasons were the loading points in flexural test rigs were designed for metals often caused localized damage in specimen which initiated premature failures. But even when this defective test procedure was rectified, low-stress failures still occurred. It was then considered that this was because in materials with poor in-plane shear resistance and with compression strengths that were lower than the tensile strengths, it was shear and/or compression damage modes that initiated the premature flexural failures. Controlled fibre surface treatments have now significantly improved both the interlaminar shear and compression responses of many commercial materials, and it is usually possible to measure flexural strengths, that are at least equal to the normal tensile strengths.

***Interlaminar Shear Strength (ILSS) Test*:**

Most laminated continuous-fiber composites contain planes of weakness between the laminations and along fiber/matrix interfaces. In shear the composite strength will be dominated by these weaknesses unless the stress direction intersects the fibers. Shear stresses at the interfaces between the plies can seldom be avoided by lay-up design because of the anisotropies of neighbouring plies. These interlaminar shear stresses are usually high at edges, and often give rise to delamination which propagate into the composite from the edges, significantly reducing the laminate tensile strength Delamination is a major cause of failure in laminated composites, and one of the concerns of the designer is to ensure that shear stresses are diffused safely away from stress concentration points.

Interlaminar shear failure is seen in the three-point bending of short beams, a method commonly used to measure the interlaminar shear strength, or ILSS, although this is often regarded as unsatisfactory because the state of stress is not pure shear. If the level of horizontal shear stress at the midplane point M reaches the interlaminar shear strength, τ_{IL}, of the composite before the tensile stress level at T reaches the composite strength, σ_c, then the beam will fail. If the beam is longer than a certain critical length, however, it will fail in a normal bending mode by a tensile failure initiating at the mid-point of the outer face.

ILSS test is one of the most important mechanical tests for fiber reinforced laminated composites; the test is done to determine the shear strength of the laminated composite. Different materials have different way of test, to determine the interlaminar shear strength. The following ASTM standard has to be applied to obtain the ILS strength.

Microstructural Analysis:

Microstructural analysis was done on fracture surfaces in scanning electron microscope in different resolutions to understand the mechanism of fracture of composites for compression and Flexural failures. Fibre breakage, debonding and resin starvation and densification mechanism etc.

IV. RESULTS AND DISCUSSIONS

In the investigation, the G-CFRP composites were developed systematically and thoroughly examined to evaluate the mechanical properties and effects in different modes of failures and mechanism of failure were studied and discussed in detail as follows:

The G-CFRP hybrid composites were tested under compression loading and the results are noted and discussed as follows:

1. Matrix Constituent analysis:

It was an important part of investigation to assure the volume fraction of reinforcement in composite or matric reinforcement volumetric ratio, therefore resin digestion method was adopted and in the test it was found that the resin was completely degraded and fiberous or reinforcement remains were carefully weight and by loss of weight method the matrix to reinforcement ratio was determined.

In the matrix constituent analysis, for the E glass Carbon bi directional fabric twilled oven hybrid composite it is found after resin digestion test following ASTM D 3171 it is found that,

a. E glass- Carbon Epoxy Hybrid Composite = 67.2 : 32.8
b. E glass- Carbon Epoxy, 0.5% MWCNTs Hybrid Nano Composite = 67.8 : 32.2
c. E glass- Carbon Epoxy, 1.0% MWCNTs Hybrid Nano Composite = 68.7 : 31.3
d. E glass- Carbon Epoxy, 1.5% MWCNTs Hybrid Nano Composite = 69.5 : 30.5

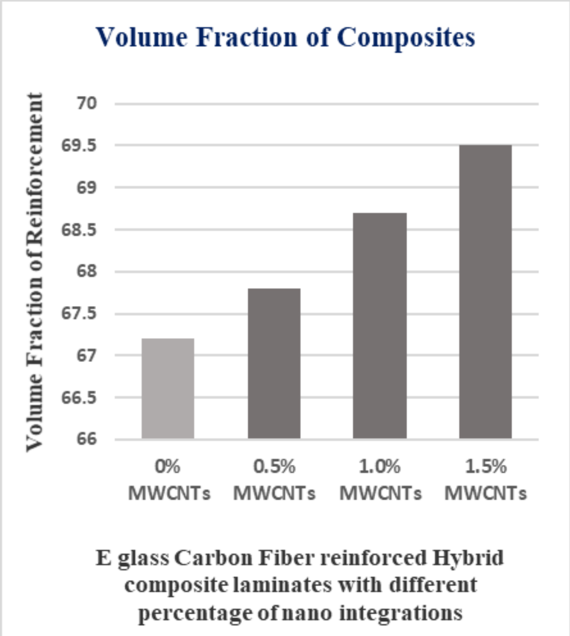
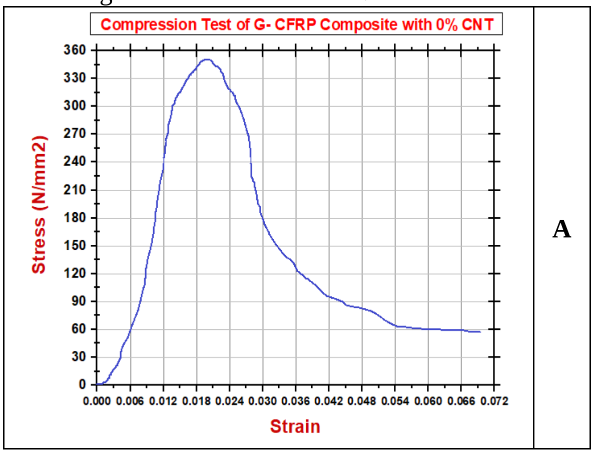
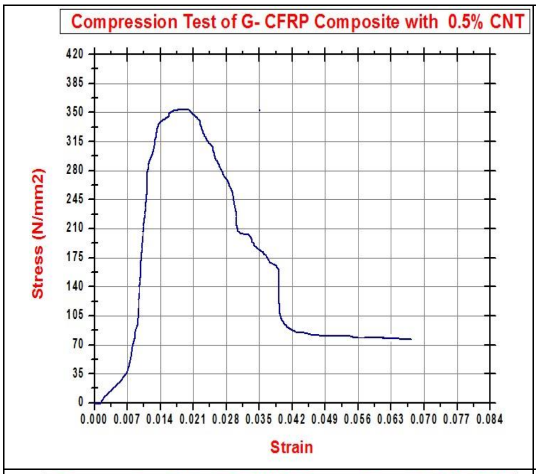


Fig-4.1: Volume fraction of reinforcement in G-CFRP Hybrid composite laminates with different percentage of MWCNT inclusions

2. Compression Test:

Compression test was carefully carried out on specimens of hybrid composites with different grade of nano integrations following the ASTM test standards and procedure in Instron® electromechanical Universal Testing Machine.
Following the results obtained in compression loading of the hybrid nano composites, the following features were recorded.





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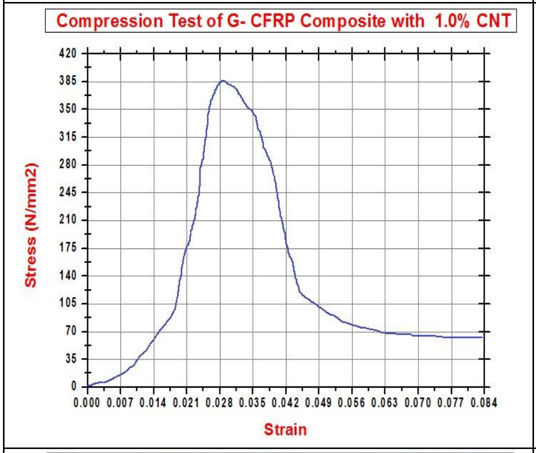

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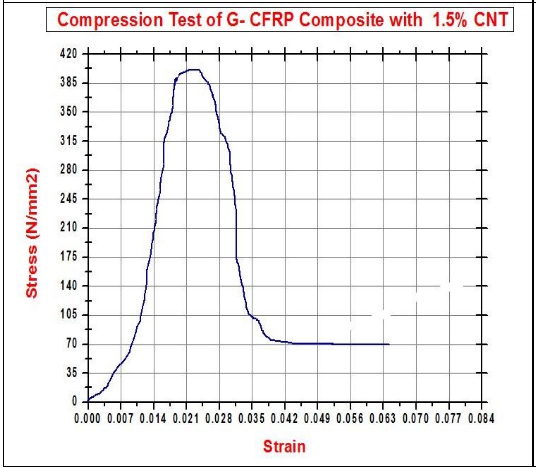

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Fig 4.2: Stress strain curves determining the Compression strength of G-CFRP hybrid composites with different grades of (A)-0%, (B)-0.5%, (C)-1.0%, and (D)- 1.5% MWCNT inclusions

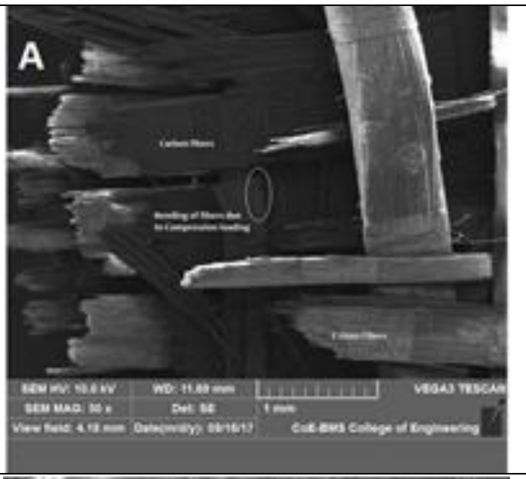
In the results obtained during the compression testing of the composites, , it is seen that compression strength of the composites varies with the variation of carbon nano tubes integration as the volume of MWCNTs increases, compression strength also increases, as a result of CNTs excellent interfacial bonding characteristics that initiates the strong bond between fibrous reinforcement and epoxy matrix, also CNTs are brittle in nature and it resists against crushing of the composite, it is also observed that it makes linear characteristic curve for increase in MWCNT inclusions to increase in compression strength.

TABLE 4.1. Percentage of increase in Compression Strength with increase in vol. % of MWCNTs

Composite Material	Vol. % of MWCNTs	% Increase In Compression Strength
G-CFRP	0.5 %	**2.85 %**
G-CFRP	1.0 %	**11.57 %**
G-CFRP	1.5 %	**17.81 %**

2.1. Mechanism of Fracture: A microstructural analysis under compression loading:

2.2.



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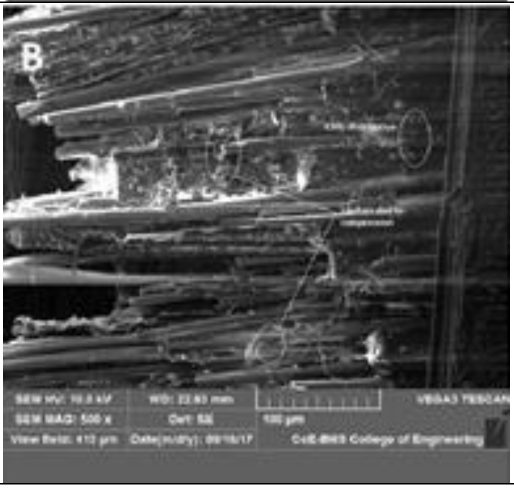

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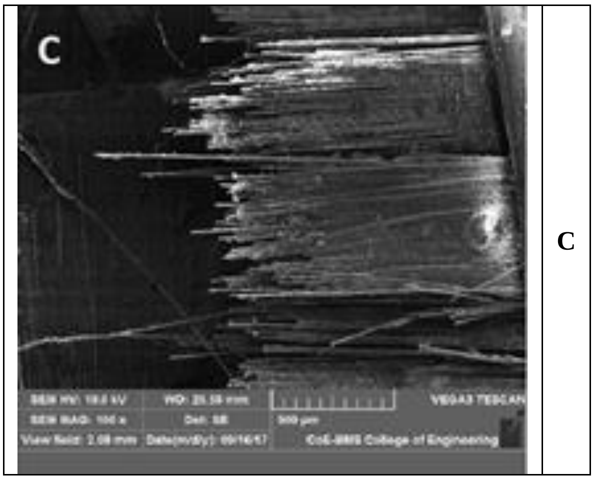


Fig 4.3: SEM images of compression fractures surface of G-CFRP hybrid composites, determining the mechanism of failure- direction from left to right (A) 0.5% MWCNTs, (B) 1.0% MWCNTs and (C) 1.5% MWCNTs

From the Microstructure images, it is seen that the resin plays a very important role in bonding of fibers, but when there is excess of resin, the density increases and so quality of composite will be compromised. On other hand, if there is insufficient resin content in some areas of laminate, leads to the starvation of resin and resulted in debonding of fibers and that will offer lower strength. In the G-CFRP Nano composites, integration of multi walled carbon nano tubes enhances the strength by adhering the fibers and fills the gap between fibers layers thus improving the interlaminar bonding of fibers and making it more stronger in compression, as glass fibers are low modulus fibers where as carbon fibers are high modulus and brittle, as CNTs are added in hybrid composites, it acts as a medium in binding and optimizing the strength features of both E glass and Carbon fibers.

3. *Flexural Test:*

The test was conducted on three samples of G-CFRP hybrid composite each with the three grades of CNT volume fraction and as a hybrid condition, viz., 0%, 0.5%, 1.0% and 1.5% respectively. The data Obtained from the mechanical testing was used to determine the behavior of material under bending and its bending strength. Peak load & bending strength were determined. The table shows the average Bending properties of multiple specimens for each grade of CNTs reinforcement.

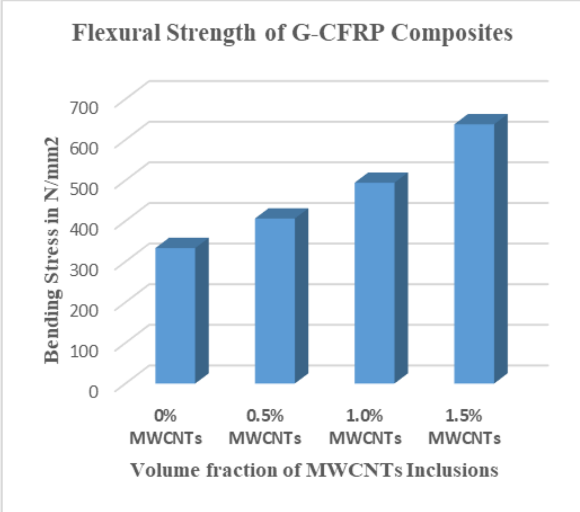


Fig 4.4: Flexural Strength of G-CFRP hybrid composites with Nano integration in different volume fractions

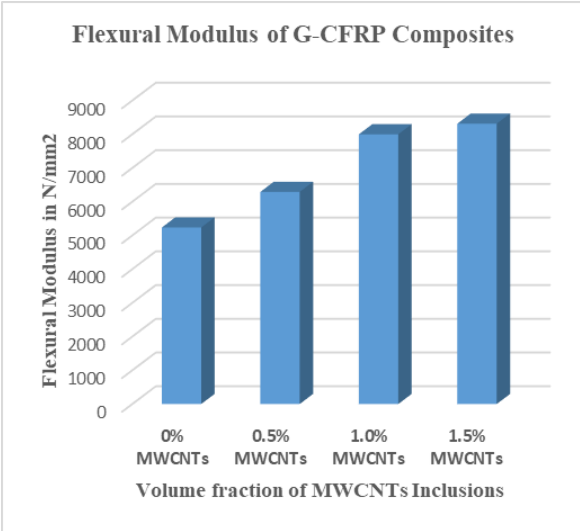
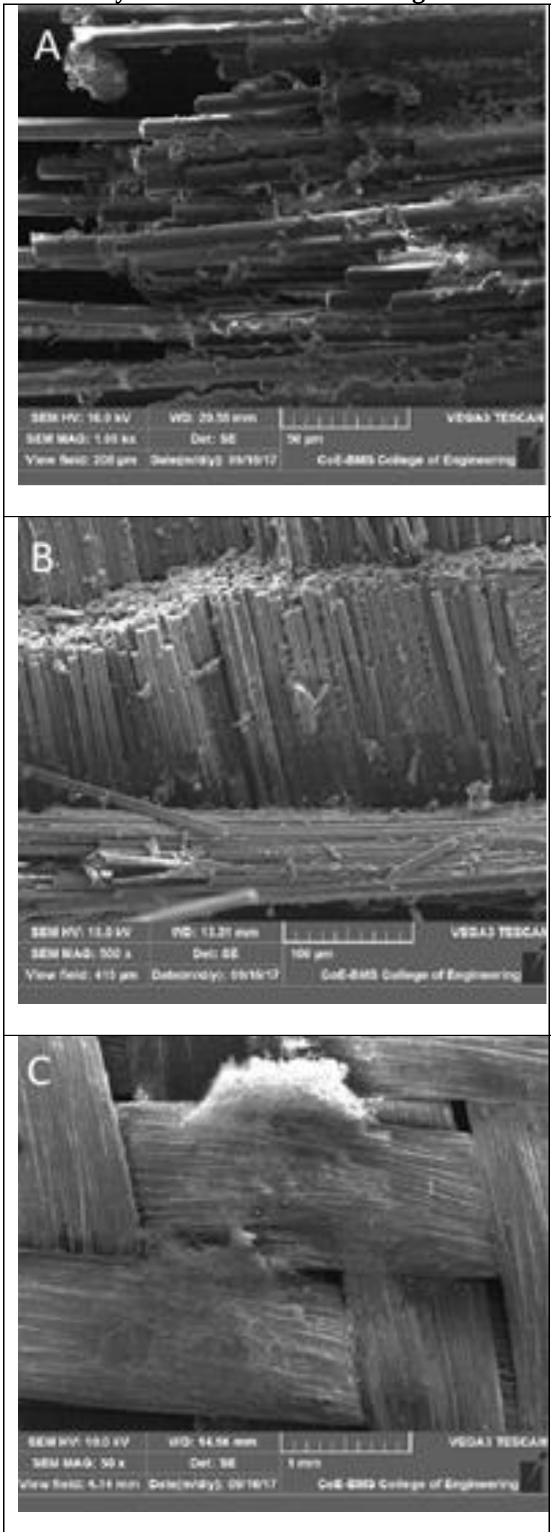


Fig 4.5: Flexural Modulus of G-CFRP hybrid composites with Nano integration in different volume fractions

TABLE 3.2. Percentage of increase in Flexural Modulus with increase in vol. % of MWCNTs

Composite Material	Vol. % of MWCNTs	% Increase in Flexural Modulus
G-CFRP	0.5 %	**20.14 %**
G-CFRP	1.0 %	**52.78 %**
G-CFRP	1.5 %	**58.80 %**

3.1. Mechanism of Fracture: A microstructural analysis under Flexural loading:



A

B

C

Fig 4.6: SEM images of Flexural fractures surface of G-CFRP hybrid composites, determining the mechanism of failure- direction from left to right (A) 0.5% MWCNTs, (B) 1.0% MWCNTs and (C) 1.5% MWCNTs

From the Microstructure images, it is seen that the resin plays a very important role in bonding of fibers, but when there is excess of resin, the density increases and so quality of composite will be compromised. On other hand, if there is insufficient resin content in some areas of laminate, then that starves the area and resulted in debonding of fibers and that will offer lower strength. In the G-CFRP Nano composites, integration of multi walled carbon nano tubes enhances the strength by adhering the fibers and fills the gap between fibers layers thus improving the interlaminar bonding of fibers and making it more stronger in tension, as glass fibers are low modulus fibers where as carbon fibers are high modulus and brittle, as CNTs are added in hybrid composites, it acts as a medium in binding and optimizing the strength features of both E glass and Carbon fibers.

4. *Interlaminar Shear Strength (ILSS) Test:*

The Inter laminar shear test was conducted by keeping the specimen between two supports, and then the load is applied. The applied load is recorded and the amount of deformation experienced by the specimen for the applied load determines the Inter laminar bonding strength and thus the ILSS of the composite is determined. The test was conducted on three samples of 2mm, 3mm and 4mm each. The data Obtained from the mechanical testing was used to calculate the Inter laminar shear strength of the laminates. Peak load & displacement were determined. The table shows the laminar shear properties of multiple specimens for each thickness.

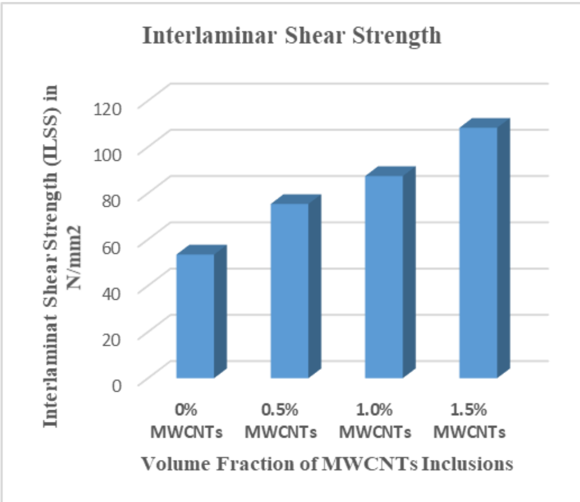


Fig 4.7: Interlaminar Shear Strength of G-CFRP hybrid composites with Nano integration in different volume fractions

In the results obtained during the ILSS testing of the composites, it is seen that shear strength of the composites varies with the variation of carbon nano tubes integration as it increases the shear strength also increases, this is because CNTs enhances the interlaminar bonding of the composite and under shear it resists against delamination of the composite, it is also observed that increase in CNTs enhances the shear strength linearly.

TABLE 3.3. Percentage of increase in Interlaminar Shear strength with increase in vol. % of MWCNTs

Composite Material	Vol. % of MWCNTs	% Increase in ILS Strength
G-CFRP	0.5 %	**40.89 %**
G-CFRP	1.0 %	**63.49 %**
G-CFRP	1.5 %	**102.56 %**

V. CONCLUSION

In the process of developing and investigating the mechanical properties of the E glass carbon bi directional twilled oven fiber reinforced Epoxy hybrid polymer matrix composites with nano integration of COOH functionalized Multi walled carbon nano tubes in different grades of 0.5%, 1.0% and 1.5% by volume, the following conclusions were drawn.

The Composites were hybridized by taking high modulus and low modulus fibers as primary reinforcement in epoxy resin as a matrix element and fabricated using hand layup and vaccum bag molding technique under controlled environment. Then the cured composite laminates with different grades of CNT reinforcements were subjected to Ultrasonic B-Scan.

The Ultrasonic Scanning proved that the composite laminates were free from external and internal defects though it is of internal fiber fracture, starvation of resin, densification of resin or delamination of fabric layers within the laminate. Therefore specimens were cut out of composite laminates for further mechanical investigations.

It was an important part of investigation to assure the volume fraction of reinforcement in composite or matric reinforcement volumetric ratio, therefore resin digestion method was adopted and in the test it was found that composite exhibit close values to the calculated value of reinforcement to matrix ratios of around 70: 30 by volume.

In compression test, composite linear characteristic curve representing the integration of MWCNTs into it as the CNTs added, the compression strength increased substantially and it is observed that the CNT integration enhanced the compression strength of composite. The compression strength was improved by 2.85%, 11.57% and 17.81% with the MWCNTs integration of 0.5%, 1.0% and 1.5% by volume respectively.

Similarly, Flexural modulus of the hybrid composite was significantly enhanced with the integration of CNTs by 20.14%, 52.78% and 58.8% for MWCNTs addition of 0.5%, 1.0% and 1.5% volume respectively.

In Interlaminar Shear strength, it exhibit excellent improvement with addition of MWCNTs, as it enhanced the ILS strength by 40.89%, 63.49% and 102.56% with 0.5%, 1.0% & 1.5% volumetric addition of MWCNTs.

These improvements were observed and it is recorded and to be concluded that, addition of CNTs enhances the mechanical properties significantly as a result of high surface to volume ratio and quantum confinement leads to strong interfacial bond between fibres and epoxy resin making it to bond effectively and thus composite offers high resistance against external loads by resisting delamination.

REFERENCES

[1]. L. Mishnaevsky, Povl Brøndsted, Micromechanical modeling of damage and fracture of unidirectional fiber reinforced composites: A review, Computational Materials Science. Volume 44, Issue 4, February 2009, Pages 1351-1359

[2]. G. Czél, M.R. Wisnom, Demonstration of pseudo-ductility in high performance glass/epoxy composites by hybridisation with thin-ply carbon prepreg, Composites Part A: Applied Science and Manufacturing, Volume 52, September 2013, Pages 23-30

[3]. M.M. Rahman, S. Zainuddin, M.V. Hosur, J.E. Malone, M.B.A. Salam, A. Kumar, S. Jeelani, Improvements in mechanical and thermo-mechanical properties of e-glass/epoxy composites using amino functionalized MWCNTs, Composite Structures, Volume 94, Issue 8, July 2012, Pages 2397-2406.

[4]. R. Murugan, R. Ramesh, K. Padmanabhan, Investigation on Static and Dynamic Mechanical Properties of Epoxy Based Woven Fabric Glass/Carbon Hybrid Composite Laminates, Procedia Engineering, Volume 97, 2014, Pages 459-468

[5]. Jun Hee Song, Pairing effect and tensile properties of laminated high-performance hybrid composites prepared using carbon/glass and carbon/aramid fibers, Composites Part B: Engineering Volume 79, 15 September 2015, Pages 61-66

[6]. Kedar S.PandyaCh.VeerrajuN.K.Naik, Hybrid composites made of carbon and glass woven fabrics under quasi-static loading, Materials & Design, Volume 32, Issue 7, August 2011, Pages 4094-4099

[7]. Jin Zhang Khunlavit, Chaisombat, Shuai He Chun H. Wang, Hybrid composite laminates reinforced with glass/carbon woven fabrics for lightweight load bearing structures, Materials & Design (1980-2015), Volume 36, April 2012, Pages 75-80

[8]. T. Sreekantha Reddy K.Mogulanna I.Srikanth V.Madhu K. Venkateswara Rao, Ballistic Impact Studies on Carbon and E-glass Fibre Based Hybrid Composite Laminates, Procedia Engineering, Volume 173, 2017, Pages 293-298.

[9]. N.K Naik R Ramasimha, HArya, S.VPrabhu, NShama Rao, Impact response and damage tolerance characteristics of glass–carbon/epoxy hybrid composite plates, Composites Part B: Engineering, Volume 32, Issue 7, October 2001, Pages 565-574

[10]. Ramesh K. Nayak D. Rathore B.C. Ray B.C. Routara, Inter Laminar Shear Strength (ILSS) of Nano Al_2O_3 Filled Glass Fiber Reinforced Polymer (GFRP) Composite - A Study on Loading Rate Sensitivity,

Materialstoday Proceedings, Volume 4, Issue 8, 2017, Pages 8688-8696.
[11]. Nima Beheshtizadeh, Amir Mostafapour, Hossein Abbasi, Effect of fiber layout on signal analyzing of carbon/glass/epoxy hybrid composite laminates flexural loading using acoustic emission, Measurement 136 (2019) 608–614
[12]. Y. Hirai, H. Hamada, J.-K. Kim, Impact response of woven glass-fabric composites—I.: effect of fibre surface treatment, Compos. Sci. Technol. 58 (1998) 91–104.
[13]. V lot, Low-velocity Impact Loading: on Fibre Reinforced Aluminium Laminates (ARALL and GLARE) and Other Aircraft Sheet Materials, (1993).
[14]. M. Sadighi, R.C. Alderliesten, R. Benedictus, Impact resistance of fiber-metal laminates: a review, Int. J. Impact Eng. 49 (2012) 77–90.
[15]. W.J. Cantwell, J. Morton, The impact resistance of composite materials — a review, Composites 22 (1991) 347–362.
[16]. L. Vogelesang, A. Vlot, Development of fibre metal laminates for advanced aerospace structures, J. Mater. Process. Technol. 103 (2000) 1–5.
[17]. M. Nayeem Ahmed, P. Vijaya Kumar, H.K. Shivanand, Syed Basith Muzammil,A Study on Effect of Variation of Thickness on Tensile Properties of Hybrid Polymer Composites (Glassfibre-Carbonfibre-Graphite) and GFRP Composites International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 4, Jul-Aug 2013, pp.2015-2024
[18]. M. Nayeem Ahmed, P. Vijaya Kumar, H.K. Shivanand, Syed Basith Muzammil, a study on flexural strength of hybrid polymer Composite materials (e glass fibre-carbon fibre-graphite) on different matrix material by varying its thickness, International Journal of Mechanical Engineering and Technology (IJMET), ISSN 0976 – 6340(Print), ISSN 0976 – 6359(Online) Volume 4, Issue 4, July - August (2013) © IAEME
[19]. Lurie, S., Minhat, M., 2014. Application of generalized self-consistent method to predict effective elastic properties of bristled fiber composites. Compos. B Eng. 61, 26–40.
[20]. Luo, J., Wang, X., 2009. On the anti-plane shear of an elliptic nano inhomogeneity. Eur. J. Mech. A/Solids 28 (5), 926–934
[21]. Xun, F., Hu, G.K., Huang, Z.P., 2004. Effective in plane moduli of composites with a micropolar matrix and coated fibers. Int. J. Solids Struct. 41 (1), 247–265.
[22]. Syed Basith Muzammil, P. Vijaya Kumar, H. K. Shivanand, B. G. Sumana, and S. C. Ramesh Kumar, Effect of MWCNT inclusions on tensile behavior of G-CFRP and G-KFRP hybrid nanocomposites, AIP Conference Proceedings 2057, 020042 (2019); https://doi.org/10.1063/1.5085613 , anuary 2019
[23]. Junhua Xiao a, Yaoling Xu a, Fucheng Zhang, A generalized self-consistent method for nano composites accounting for fiber section shape under antiplane shear, Mechanics of Materials 81 (2015) 94–100
[24]. Seekkuarachchia IN, Tanaka K, Kumazawa H. Dispersion mechanism of nano particulate aggregates using a high pressure wet-type Jet Mill. Chem Eng Sci 2008;63:2341–66.
[25]. Júlio C. Santos a, Luciano M.G. Vieira a, Túlio H. Panzera a,⇑, Marco A. Schiavon b, André L. Christoforo a, Fabrizio Scarpa, Hybrid glass fibre reinforced composites with micro and poly-diallyldimethylammonium chloride (PDDA) functionalized nano silica inclusions, Materials and Design 65 (2015) 543–549.
[26]. Gay D, Hoa SV and Tsai SW (2003) Composite Materials, Design and Applications. Boca Raton, FL: CRC Press LLC.

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