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Studies on Mechanical Behaviour of E-Glass- Kevlar fiber reinforced epoxy Hybrid Composites with nano integration of Functionalized MWCNTs

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ABSTRACT
Composite materials were systematically hybridized using high modulus synthetic Kevlar fibers and low modulus E glass fibers in bidirectional plain oven orientation in equal proportion and fabricated with epoxy resin 5052 then the mechanical properties of the Kevlar based hybrid composites were studied and comparatives studies were done by integrating the functionalized multi walled carbon nanotubes in the volumetric proportion of 0.5%, 1.0% and 1.5% respectively. The post curing procedures were followed and health of the composite laminates was monitored using ultrasonic B-Scan. In the investigations it was seen that nano integration has significantly enhanced the mechanical properties and effects on composites under various modes of mechanical failures. In Thermogravimetric analysis (TGA) the actual reinforcement ratios were found to be 66.5%, 67.42%, 66.88% & 67.75% for 0%, 0.5%, 1% & 1.5% MWCNTs integration. The mechanical properties under the influence of MWCNTs integrations in compression was seen to be improved by 23%, 33% & 65% whereas flexural modulus was seen enhanced by 26.84%, 100.86% & 200.84% and interlaminar shear strength was improved by 81.6%, 94.2% & 176% respectively for nano integration of 0.5%, 1.0% & 1.5% by volume.
Keywords - G-KFRP hybrid composites, MWCNTs reinforced Kevlar composites, Thermogravimetric analysis, Mechanical properties of Kevlar hybrid composites

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I. INTRODUCTION

Carbon nanotubes (CNTs) have acquired great interests in various fields of engineering and sciences, due to their outstanding mechanical, thermal and electrical properties and possess high aspect ratio with low density [1-5]. Combining the excellent properties of CNTs, it portray great potential in the applications of polymer composites [6, 7]. Due to the intrinsic clustering and entangling of CNTs, it is a challenge to disperse in common solvents and polymer matrix (Resin) [8]. Recently tremendous efforts were made for surface modification of CNTs, in order to achieve effective dispersion and interfacial interaction with polymer matrix, therefore ultrasonic dispersion technique should be used to homogenize the MWCNTs in reins [9-11]. Nano particles exhibits the 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, several mechanical and chemical dispersion methods have been proposed to disperse inorganic nanoparticles in organic solvents or resins [12, 13]. Since composite possess high applicability in various industrial areas including aerospace, shipbuilding, furniture& appliances, 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 [14,15]. Although composites exhibits excellent mechanical properties, sometimes it limits its applicability due to high cost of material therefore it emerged to the term hybridization. Conceptual hybridization is to satisfy the functional requirements of various applications by tailoring the mechanical properties using high modulus and low modulus fibers while reducing the total cost of material [16,17]. Whereas with further addition of nano reinforcement significantly enhances the properties of material at comparatively lower cost [18].

Kevlar fibers as synthetic polymeric fibers exhibits high strength and toughness to resist against the structural and mechanical loading Varelidis et al. [19] has experimentally investigated the effect of polyamide coating on fracture toughness, mechanical properties and moisture absorption behaviour of Kevlar epoxy composites and found that fracture toughness and Interlaminar shear strength was diminished with coating and affinity of water. Reis et al. [20] studied the effect of particulate reinforcement, micro (cork powder) filler and nano (silane treated nanoclays Cloisite) fillers on low-velocity impact response of Kevlar epoxy composites and found that nano reinforcement enhanced the resistance to impact load by 16% and cork powder enhanced to 4.5%. Taraghi et al. [21] also studied the low velocity impact response on MWCNTs integrated Kevlar epoxy composites in ambient and low temperatures and it was found that composites absorbed impact energy 35% more with 0.5% MWCNTs inclusions in ambient temperature and 34% more with 0.3% of MWCNTs inclusion in low temperature. However, various investigators have reported that micro and nano fillers have significantly improved the mechanical properties in FRP composites [22]. As every composite part is more likely to bear various external loads, resulting in 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 [23].

Improved Mechanical properties were seen with bristled interphase layer formed due to nano fillers between fibers and epoxy resin [24]. Tensile strength of the (high modulus & low modulus fibrous reinforced) hybrid composites is increased with MWCNTs inclusions, as the nano reinforcement is increases the tensile strength also seen enhanced while after some critical level it deteriorates, as a result of increase in brittleness in resin, the matrix element [25].The interfacial effect of nanofiber varies with the variation of fiber section aspect ratio, higher the fiber volume fraction, greater is the interact effect resulting in high resistance against externally acting load. 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 [26].

II. MATERIALS AND METHODS

II.1. Materials Selection and Fabrication Process

To develop the hybrid composites Kevlar fibers were selected as high modulus fibers and e glass as low modulus supporting feverous reinforcement to optimize the strength requirements of the industry whereas for matrix Epoxy resin 5052 and hardener LY5052 by Araldite was used. Epoxy resin 5052 has most commonly been used as a matrix element in high performance composites as a thermoset polymer matrix due to its excellent characteristics such as high stiffness, dimensional stability and resistance to chemical integrity [27]. The composites were again developed by adding COOH functionalized multi walled carbon nano tubes by suspending the nano fillers in epoxy resin 5052 using ultrasonic dispersion technique. 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 hybrid composite laminates were developed with hand layup and vaccum bag molding processes in order to achieve the high reinforcement to matrix aspect ratio by adding 0.5%, 1.0% and 1.5% volume fractions of MWCNTs in Kevlar/ glass/ epoxy combination.

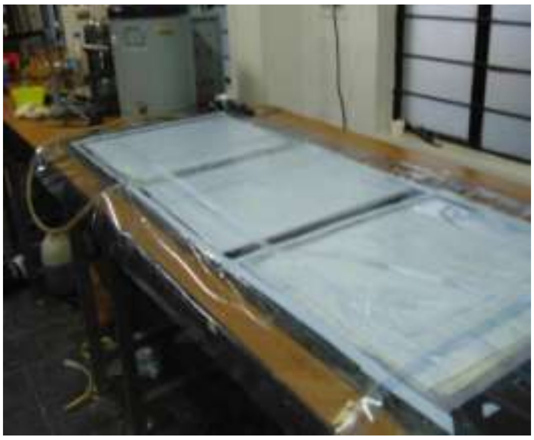


Fig-2.1: Moulded laminates under vaccum bagging process

II.2. Thermogravimetric Analysis (TGA) Test

Thermogravimetric test is the thermal degradation technique used to evaluate the reinforcement constituent content in composites. The test was conducted under controlled condition by selecting random samples from each of the composite laminates. Following ASTM E-1131 specimens were subjected to the elevated temperature of 450°C for 6 hours for the matrix (Epoxy resin 5052) to completely burn off. In the process matrix get burned and get converted into ash hence the ash was be blown off to separate the reinforcement form composite, then the fibrous remains was carefully weighed to determine the weight fraction of reinforcement and weight loss determine the part of matrix, hence the actual matrix to reinforcement ratios was be determined and compared with theoretical calculated matrix to reinforcement ratio.

$$V_f = = \frac{W_i - W_f}{W_i} \times 100, \quad ……..……… (2.1)$$

Thus, $V_m = 1\text{-}V_f$ ……………...….……(2.2)

II.3. MECHANICAL TESTING

1. Compression Test:

Compression test was conducted on G-KFRP composites to study the strength of composite under compression loading, following ASTM D-3410

In this test, the specimen was 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 were noted down.

2. Flexural test:

The G-KFRP composites were tested for bending under controlled conditions. The specimens were drawn from composite laminates and by following ASTM standard test conditions, procedures and guidelines stated in ASTM D-790 the specimens were tested in 3 point bending as shown below.

Fig 2.2: 3 point bending test of composites, Specimen loaded in Universal Testing Machine

3. Interlaminar Shear Strength (ILSS) Test:

In laminated composites, there are more chances of delamination of layers under different loading conditions, therefore interlaminar shear test is needed. 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.

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 D-2344 standard has to be applied to obtain the ILS strength.

Fig 2.3: ILSS test of composites, Specimen loaded in Universal Testing Machine

4. Microstructural Analysis

The fracture surfaces were examined and fractographic analysis was done using Scanning electron microscope under various resolutions and mechanism of fracture was studied in detail.

III. RESULTS AND DISCUSSIONS

In the investigation, the Kevlar based (G-KFRP) hybrid composites were developed systematically under controlled conditions and thoroughly examined to evaluate the mechanical properties and effects in different modes of failures and mechanism of failure was studied and discussed in detail as follows:

III.1. THERMOGRAVIMETRIC ANALYSIS (TGA)

In the matrix constituent analysis using thermogravimetry, for the E glass Kevlar bi directional fabric hybrid composite following ASTM E-1131 the following reinforcement to matrix volumetric ratios were obtained.

a. E glass- Kevlar Epoxy Hybrid Composite = 66.50 : 33.50
b. E glass- Kevlar Epoxy, 0.5% MWCNTs Hybrid Nano Composite = 67.42 : 32.58
c. E glass- Kevlar Epoxy, 1.0% MWCNTs Hybrid Nano Composite = 66.88 : 33.12

d. E glass- Kevlar Epoxy, 1.5% MWCNTs Hybrid Nano Composite = 67.75 : 32.25

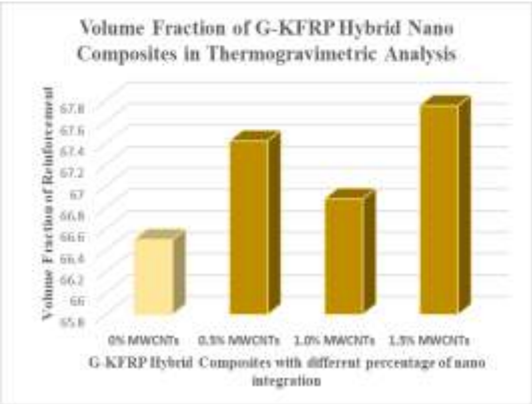


Fig-3.1: Volume fraction of reinforcement in G-KFRP Hybrid composite laminates with different percentage of MWCNT inclusions

III.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.

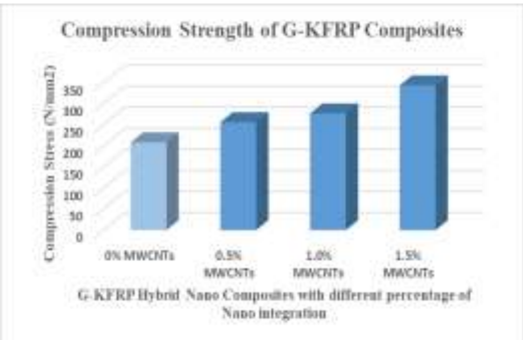


Fig-3.2: Compression strength of G-KFRP Hybrid composite laminates with different percentage of MWCNT inclusions

In the results obtained under compression loading of G-KFRP hybrid nanocomposites, it is seen that compression strength of the composites enhanced linearly with the integration of MWCNTs into it, due to the excellent interfacial bonding characteristics of CNTs that enabled the composites to withstand against compression.

TABLE 3.1. Percentage of increase in Compression Strength with increase in vol. % of MWCNTs

Composite Material	Vol. % of MWCNTs	% Increase in Compression Strength
G-KFRP	0.5 %	**23 %**
G-KFRP	1.0 %	**33 %**
G-KFRP	1.5 %	**65 %**

Mechanism of Fracture: A microstructural analysis under compression loading:

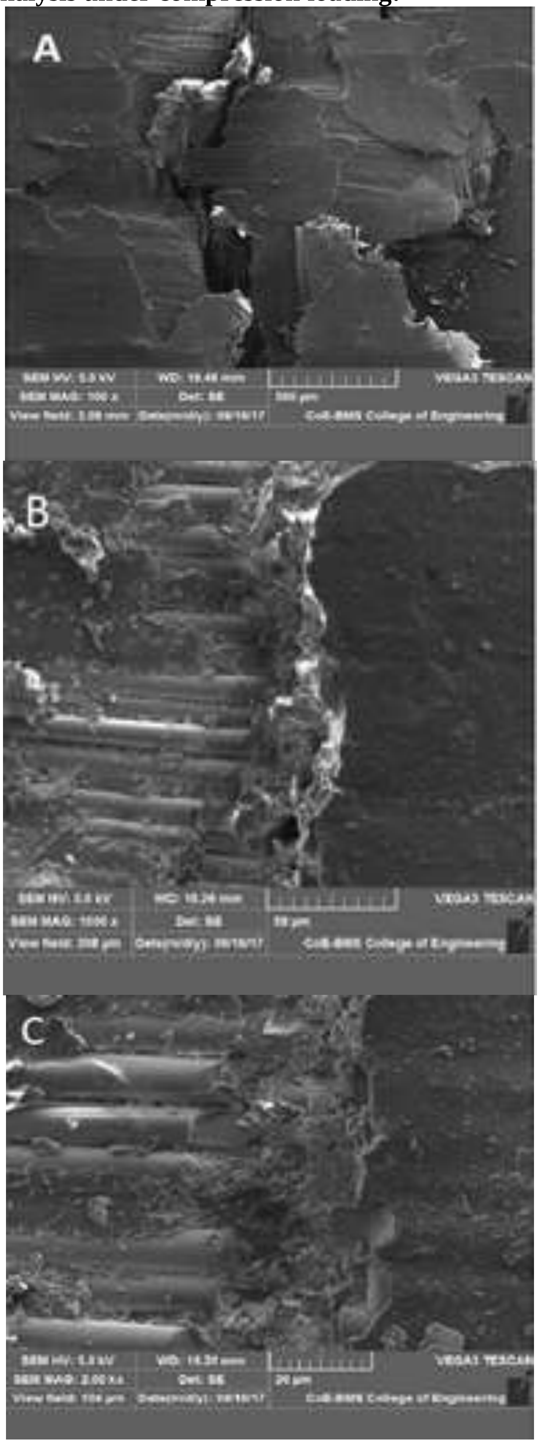


Fig 3.3: SEM images of compression fractures surface of G-KFRP hybrid composites, determining the mechanism of failure- direction from left to right (A) 0.5% MWCNTs, (B) 1.0% MWCNTs and (C) 1.5% MWCNTs

In the SEM graphs it is observed that Kevlar fibers are though offers incredible strength in impact, but in comparison doesn't stand against compressive forces, as the fibers are soft and chemically synthesized polymers into fibers, they bend quicker and as compared to carbon fibers. In these e glass and Kevlar fibers, CNT integration boosts the strength of the composites and mediates with in the e glass and Kevlar fibers. CNTs sticks the Kevlar fibers and thus offers the optimum interlaminar bonding strength and resists in compression.

III.3. FLEXURAL TEST

The 3 point bending test was carefully conducted on samples of hybrid nano composites and following ASTM standard procedures and guidelines under controlled conditions. The data obtained from flexural test shown the influence of MWCNTs on G-KFRP hybrid composite.

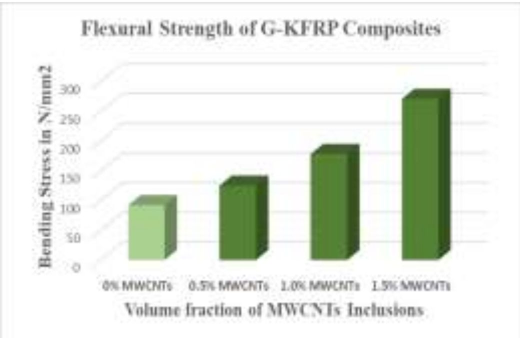


Fig 3.4: Flexural Strength of G-KFRP hybrid composites with Nano integration in different volume fractions

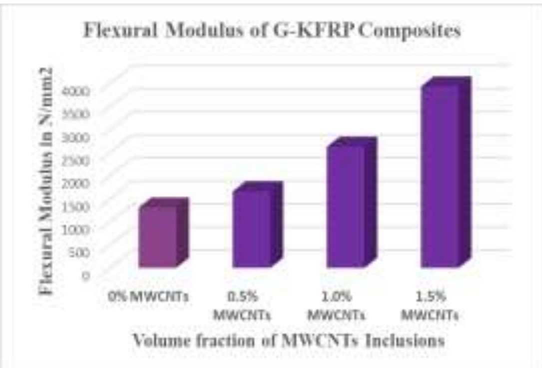
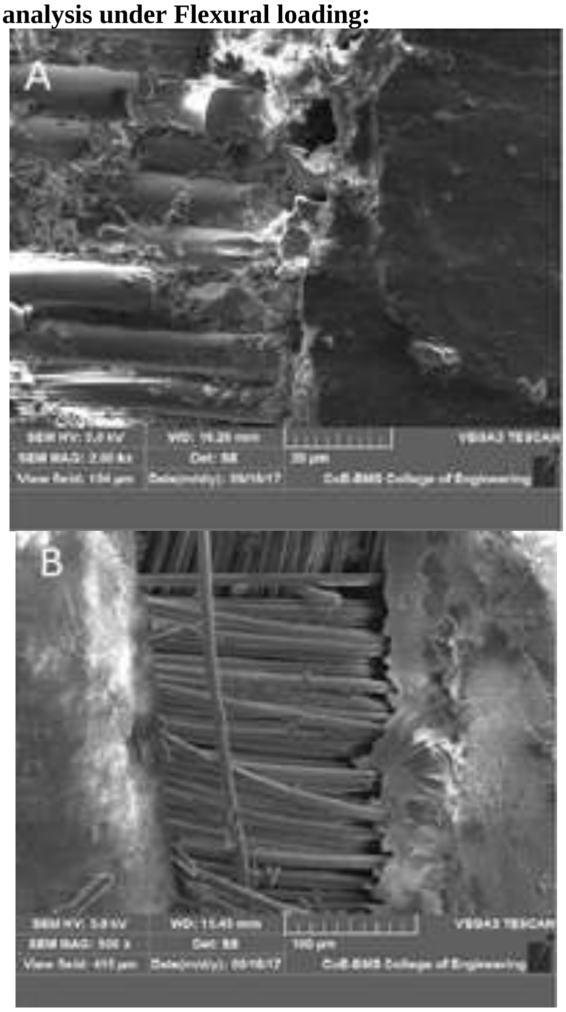


Fig 3.5: Flexural Modulus of G-KFRP hybrid composites with Nano integration in different volume fractions

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-KFRP	0.5 %	**26.84 %**
G-KFRP	1.0 %	**100.86 %**
G-KFRP	1.5 %	**200.84%**

Mechanism of Fracture: A microstructural analysis under Flexural loading:



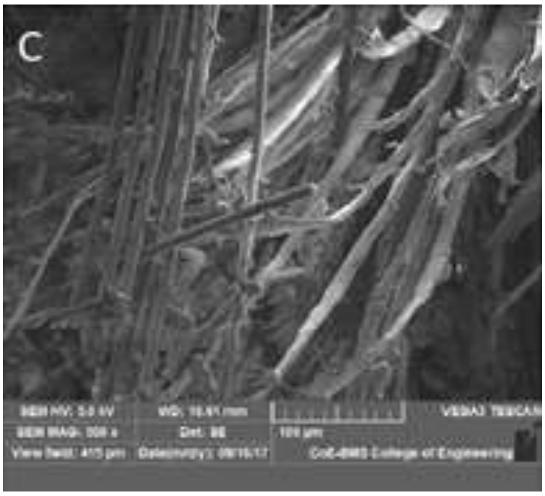


Fig 3.6: SEM images of Flexural fractures surface of G-KFRP hybrid composites, determining the mechanism of failure- direction from left to right (A) 0.5% MWCNTs, (B) 1.0% MWCNTs and (C) 1.5% MWCNTs

In the microstructural analysis it is observed that, resin plays important role in bonding of fibers, as it acts as a bonding agent in composite and thus uniformly distributes the load in reinforcements. Whereas composite strength and stiffness is entirely depends on reinforcements as it carries the actual load. Starvation sof resin results in debonding of fibers and thus resulting in delamination of layers and therefore it results in catastrophic failure of composites. In this nano fillers get mixed with resin and fills the gap between fabric warps and wefts and creates a stronger bond due to its quantum confinement and surface tension. In the fractographs it is clearly seen that Kevlar fibers are elongated and glass fibers fails due to its brittle nature and Kevlar fibers debonds and elongates iwthin the composite thus resulting in separation of resin and fibers.

III.4. INTERLAMINAR SHEAR STRENGTH (ILSS) TEST

The Interlaminar shear test was conducted on G-KFRP hybrid composites with 0.5%, 1.0% & 1.5% MWCNTs integration. The test was conducted under controlled and standard test conditions followed by ASTM. It is also called as short beam shear test as the specimen size is comparatively very small and 3 point bending principle was adopted. The data obtained from ILSS test signifies the influence of nano integration in hybrid composites.

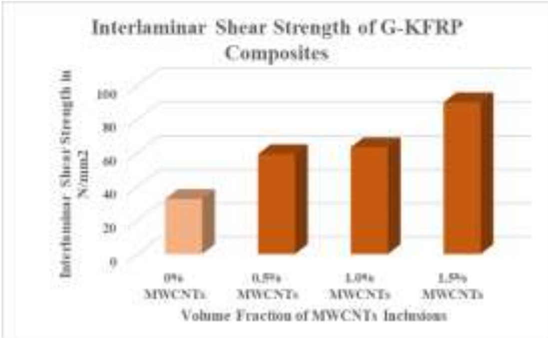


Fig 3.7: Interlaminar Shear Strength of G-KFRP hybrid composites with Nano integration in different volume fractions

In the results obtained in ILSS testing of composites, it is observed that strength of the composites varies with the variation of carbon nano tubes integration as the CNTs increases, the shear strength also increases, this is because CNTs are brittle in nature and it enhances the interlaminar bonding of the composite It is observed that, G-KFRP offers comparatively lower Modulus in tension, as a result of Kevlar characteristics that it is less stiffer in nature because it is made up of synthetic chemically processed polymers.

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-KFRP	0.5 %	**81.6 %**
G-KFRP	1.0 %	**94.2%**
G-KFRP	1.5 %	**176.0%**

IV. CONCLUSION

In the investigation of mechanical properties of E glass-Kevlar fiber epoxy hybrid composites with nano reinforcement of Carboxyl functionalized multi walled carbon nanotubes with volumetric percentage of 0.5%, 1.0% & 1.5%, the following conclusions were drawn.

In the ultrasonic B scan of composite laminates, al laminates were found to be free from flaws and resin density was found to be uniform with 10% variation, hence the composites were declared as healthy to draw specimens for further testing.

In Thermogravimetric Analysis (TGA), the actual reinforcement constituent aspect ratio of the composites was found to be 66.5%, 67.42%, 66.88% & 67.75% for 0%, 0.5%, 1.0% & 1.5% of MWCNTs inclusions.

Further investigations were carried out to determine the mechanical properties of the composites, hence the composite specimens were examined in different loading conditions to study the strength under various modes of failures.

In compression test It is recorded that, Compression strength of G-KFRP hybrid Nano Composites was significantly enhanced with CNTs integrations in composites, the improvement in compression strength was found to be 23%, 33% and 65% with 0.5%, 1% and 1.5% of CNTs Integration.

Similarly, flexural strength of the composites also exhibited the excellent properties and linear improvement in MWCNTs addition. The flexural strength was improved significantly with the increase in MWCNTs quantity. Improvement in flexural modulus in G-KFRP was recorded by 26.84%, 100.86% & 200.84% for 0.5%, 1.0% and 1.5% volume of MWCNTs inclusions respectively.

Short beam shear strength or also known as Interlaminar Shear Strength (ILSS) was also significantly improved with integration of CNTs, the rate of improvement was recorded in G-KFRP Nano Composites by84.6%, 94.2% and 176% respectively for 0.5%, 1% and 1.5% of MWCNTs inclusions.

In the overall observation, it is noted that composites exhibit excellent properties in different loading with integration of Multi walled carbon nano tubes into it. Due to the high interfacial bonding capability because of quantum confinement and high surface to volume ratio of nano tubes leading capillary action of resin into CNTs, making it to be bonded effectively after ultrasonically dispersion of CNTs into Resin. Dispersion technique plays important role in strength as poor dispersion exhibits adverse effects on bonding strength of matrix and reinforcements, so ultrasonic dispersion is effective dispersion technique to homogenize the nano particles into liquid.

The research work provides an insight to designers and researchers to select the constituents of reinforcement and matrix to design the composite for desired application with optimum strength to density ratio and cost effectiveness.

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An acknowledgement section may be presented after the conclusion, if desired.

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