I.J. Engineering and Manufacturing, **2018, 3, 23-39**
Published Online May 2018 in MECS (http://www.mecs-press.net)
DOI: 10.5815/ijem.2018.03.03

Available online at http://www.mecs-press.net/ijem

Effect of Surface Treatments on Tensile and Flexural Properties of Carbon Fiber Reinforced Friction Material

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Received: 19 January 2018; Accepted: 15 March 2018; Published: 08 May 2018

Abstract

The mechanical properties of a friction material primarily depend on the interfacial adhesion between all the ingredients of a friction material. In this work, a new friction material is developed by combination carbon fiber (CF), polymer matrix and other ingredients. The surface of CF is chemically inert and hydrophobic in nature and does not possess good bonding property with resin. Therefore, an attempt is made to improve the bonding strength between all the ingredients of a friction material. CF surface is modified by three different surface treatment techniques to increase hydroxyl or carboxyl groups on the surface. First, surface oxidation treatment, Second nitric acid treatment and third grafting multi walled carbon nano tubes functionalized (MWCNT-F) on CF surface. CF content after surface modifications is varied in wt % and mixed with remaining ingredients. Friction composite sheets are fabricated by using hand layup method. The resulting materials are characterized by SEM, TGA and FTIR analysis. MWCNTs-F on CF surface is observed. Twelve composite sheets with varying content of CF and surface treatment method is fabricated. Sample specimens are cut from the friction composite sheets to evaluate tensile and flexural properties of friction material. The best surface treatment method and optimum ingredients are selected for the improvement of tensile and flexural properties of friction material.

Index Terms: Multi walled carbon nano tubes, Carbon fibers, Chemical grafting, Tensile & flexural properties.

1. Main Text

Carbon fiber reinforced polymer composites have been gaining their importance in all the fields of

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engineering such as mechanical, civil, aerospace etc. CF is primarily preferred for composite materials due to its excellent properties, such as high specific strength and stiffness, thermal stability, corrosion resistance, high tensile modulus, self lubrication, lower density, good electrical conductivity, lower linear coefficient of expansion and outstanding fatigue characteristics. They are also find applications where high damping and chemical inertness are important [1-4]. Carbon fiber reinforced polymers found to posses superior wear resistance compared to other fibers [5]. The performance and mechanical properties of carbon fiber reinforced composite primarily depends on the interfacial adhesion between fiber and matrix and ingredients selected for the composite. However, CF surface is having poor damage resistance, early fiber matrix de bonding, transverse cracks and de lamination in several applications and it is compensated by over dimensioning of composite parts [6]. The best promising method to improve damage resistance is by growing CNTs on CF. The interfacial properties of the CF and polymer can be improved by modifying the surface of CF and introducing hydroxyl or carboxyl groups on the surface. Therefore, many efforts have been carried out from the past to improve the surface properties of CF by using different treatment techniques like sizing, plasma, chemical oxidation, γ-ray irradiation, electrochemical, dip coating, MWCNT grafting on carbon fiber surface by CVD etc [7].

Among the above mentioned various techniques to improve the interfacial adhesion between fiber and matrix, MWCNT grafting on carbon fiber surface under chemical vapour deposition (CVD) achieved good bonding strength between polymer and CF surface. Qiang Song et al [8], Observed that grafting straight carbon nano tubes radially on carbon fiber surface has improved its mechanical properties. The mechanical properties such as compressive strength and inter laminar shear strength are increased by 275% and 138% compared to pure C/C Composite. S.P.Sharma et al [9] identified that, coating carbon fibers by using CVD on CF surface improves its tensile strength to 69% for CF/epoxy/amine polymer matrix composites. Hui Qian et al [10], modified the carbon fiber surface by grafting carbon nano tubes on carbon fibers by CVD technique and observed that, there is 26% increase in inter laminar shear strength for carbon fiber and poly methyl methacrylate (CF/PMMA) composite. Based on the work carried by many researchers to graft CNTs on CF surface by CVD technique improved its interfacial shear strength, mechanical and tribological properties to a greater extent. But, grafting CNTs on CF surface by using CVD is a costlier process and involves care in controlling of the operating temperatures. Therefore, an alternative method is followed in this work by modifying the CF surface by three chemical treatment methods and, the best surface treatment method is selected with optimum ingredients for improving the tensile and flexural properties of a friction material. [11-16].

2. Materials and Methods

The friction materials selection depends on ability of the material to with stand the given pressure and satisfying all the important characteristics of a friction material. The wear rate of friction material depends on the type of friction material used, pressure applied on the pads, friction material temperature, friction material contact area, friction material finish, Heat removal rate etc. Therefore, selection of ingredients for the friction material was carried out based on the characteristics of a friction material.

The main characteristics of friction materials should possess are [17]:

(i) Maintain a sufficiently high coefficient of friction with the brake disc.
(ii) Not to decompose or break down in such a way that the friction coefficient with the brake disc is compromised, at high temperatures.
(iii) Exhibit stable and consistent coefficient of friction with the brake disc.
(iv) Wear resistant.
(v) Able to dissipate heat to the surroundings.
(vi) Having sufficient fade resistance.
(vii) Induce less squealing action and should be operated over different atmospheric conditions.

2.1. Carbon Fiber

Commercially available, polyacrylonitrile (PAN) based chopped carbon fibers were used for this study. Chopped carbon fibers having a carbon content of 95% is used in the present work. The collected chopped carbon fibers before thermal oxidation treatment are shown in fig 1. The properties of chopped carbon fibers given by the supplier are indicated in table1.

Fig.1. Chopped Carbon Fiber

Table 1. Properties of Carbon Fiber

Material	Diameter (μm)	Length (mm)	Tensile strength (MPa)	Tensile modulus (GPa)	Sizing	Resistivity Ω/cm	Carbon content
Carbon fiber	6.9	6	4810	225	1-1.2%	$1.54x10^{-3}$	95%

2.2. Multi Walled Carbon Nano tubes (MWCNT)

Multi walled carbon nano tubes (MWCNT) used in the present study is produced by using chemical vapour deposition method (CVD). This is shown in fig 2. MWCNTs are used widely, as filler materials in polymer matrix composites applications like structural, industrial, and aerospace sectors. The damping characteristics and toughness behaviour of the composites reinforced with MWCNTs are observed to be greatly improved. Hence, in this work MWCNTs are selected to use in organic friction composite .The properties of MWCNT supplied by the supplier for the given study are given in table 2. Chemicals such as NaOH, HNO_3, H_2SO_4, acetone solutions used in the current study is purchased from chemical laboratories, Visakhapatnam, India.

Fig.2. MWCNT Powder

Table 2. Properties of Multi Walled Carbon Nano tubes

Material	Diameter (nm)	Length (microns)	Metal particles	Amorphous Carbon	Specific surface area(m^2/g)	Bulk density g/cm^3	Nano tubes purity
MWCNT	10 to 30	10	<4%	< 1%	330	0.04-0.06	>95%

2.3. Carbon fiber Surface Treatment Methods

2.3.1 HNO_3 treatment

Carbon fibers (CF) of quantity 180 gms were modified by dipping in a solution of 40% HNO_3 i.e. (200ml of HNO_3 & 300ml of distilled water) for 48hrs at room temperature. The fibers were allowed to immerse completely in the nitric acid solution and distilled water. Few gases will generate during mixing process of (CF+HNO_3 +distilled water).The complete mixing operation has to be performed slowly. Initially, 50ml of (HNO_3 +distilled water) is poured on the surface of CF. Allow the sample to rest for 5 min. This operation is continued for four times with interval time gap period of 5 min for allowing the gases to escape to the atmosphere. The collected carbon fibers were allowed to drain out the immersed liquid. Then, CF surface was diluted with distilled water of 3lit qty. First CF surface was diluted with 1 lit qty of distilled water and wait for 30 mins to allow the distilled water to completely mix with the CF surface. Then, the liquid is drained out. This process is repeated for 3 times to remove HNO_3 liquid gases adsorbed on CF surface. Now, CF surface is immersed in NaOH solution of 10% qty (300ml of distilled H_2O +30 gms of NaOH) and allow the sample to completely soak for 30 mins. Finally, CF surface is diluted with distilled water of 2 lit qty to remove left over acid gases adsorbed on its surface. This process of dilution, initially with HNO_3 and finally with NaOH makes the surface completely free from adsorbed gases on CF surface. The collected carbon fibers after complete

dilution process were allowed dry in an oven at a temperature of 150^0C for 2 hrs followed by drying in atmosphere for 1hr. The sequence of operations carried in HNO_3 treatment is shown in fig 3.

Fig.3. Sequence of operations carried in HNO_3 treatment on CF

2.3.2 Surface Oxidation Treatment On Carbon Fibers

Chopped carbon fibers collected in the crucible are subjected to surface oxidation treatment in an oven at 600 ^{0} C for 1hr. First, temperature is increased from 20^0C to 600^0C for 30 min under nitrogen gas and in a second step temperature is kept at 600^0C for remaining duration time of 30 min under air. The CF surface is modified by thermal oxidation treatment in this step to improve the bonding behaviour of CF with remaining ingredients.

2.3.3 MWCNT Surface Oxidation Treatment

Multi walled carbon nano tubes (MWCNTs) are treated to attach carboxylic acid groups on its surface to form functionalized MWCNTs (MWCNT-F). In this step, 2gms of MWCNT are added to 100 ml of concentric sulphuric acid and 35 ml of nitric acid of (Purity of 98.08%H_2SO_4 and 70% HNO_3) (3:1 by volume ratio) .The mixture is sonicated in a bath for 3hrs at a temperature of 70^0C. Now, the reaction mixture is diluted with 200ml of deionised water followed by vaccum filtration process using a filter paper of 2µm porosity. This dilution is repeated for three times to remove the metal particles adsorbed on MWCNTs. The sample is allowed to dry in an oven at 100^0C. After drying operation, the collected MWCNT powder particles are immersed in 40 ml of acetone solution and placed on a ultra sound bath sonicator to allow the acetone solution to completely mix with MWCNTs. During sonication process, acetone gases will escape to the atmosphere because of having low boiling point of acetone i.e 30^0 C. Now the collected sample powder is dried in oven at 100^0C for 4 hrs followed by drying in atmosphere to form MWCNT-F powder. This process will completely removes metal particles present in MWCNT powder to use MWCNT-F more effectively in polymer matrix composites. This process of using MWCNT-F on CF polymer matrix composites can increase the damping characteristics of the friction composite and reduce the squeal genetation at the contact region between brake disc and pad. Fig 4. gives sequential operations performed in functionalisation of MWCNTs powder.

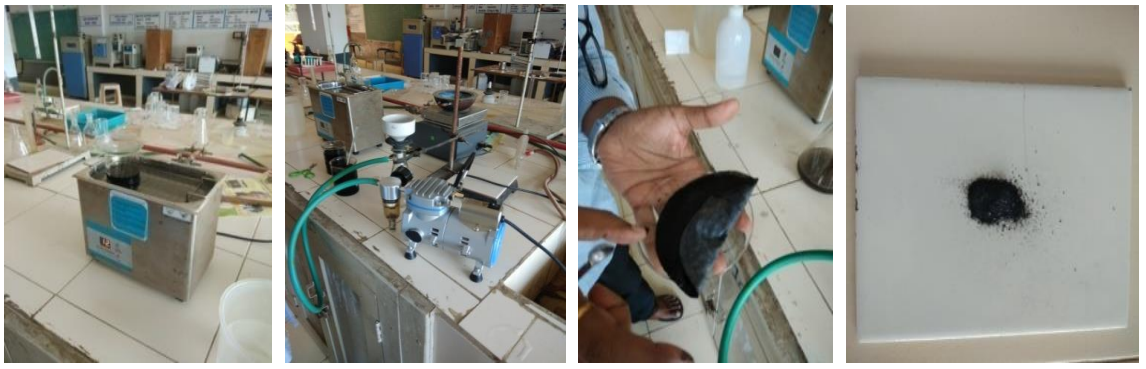

Fig.4. Sequential Operations Performed in MWCNT Surface Oxidation to form MWCNT-F

2.3.4 Grafting MWCNT-F on Carbon Fibers

Multi walled carbon nano tubes functionalized (MWCNT-F) of qty 1.5 gms obtained after vaccum filtration and drying operation is dispersed in a 20 ml of acetone solution. Ultra sound bath sonication method is used for complet dispersion of MWCNT-F and acetone solution. The operating temperature of ultra sound bath system is kept at 70^0 C for 1 hr . Now, chopped carbon fibers are placed on a glass substrate and suspension containing MWCNT-F is deposited drop by drop using a droppler technique on the complete surface of carbon fiber.The deposition operation is repeated several times with evaporation of the sovent between each deposition. Heat treament process is carried on the resulting CFs grafted with MWCNT-F at 100^0C for 2hrs. Fig 5. gives sequential operations performed in grafting MWCNT-F on carbon fiber surface.

Fig.5. Grafting MWCNT-F on CF Surface

3. Preparation of Composite Sheets

Preparation of friction composite sheets are carried by using hand lay up process, owing to its cost effectiveness and significant control over operating parameters compared to remaining methods. CF after surface treatment is mixed with other ingredients using a foculator for 30 min for each sample sheet. Initial step of fabrication involves preparing a die with dimensions of 42cmx22 cmx1.2 cm made of mild steel material. The die is finished to remove the unwanted material of thickness 2cm on all the sides by gas welding operation. Initially resin is taken in a foculator and all the ingredients are added slowly one after the other with an interval time period gap of 10 min. Total mixing operation for all the ingredients was carried for 30 min for each

sample sheet. Twelve composite sheets with variation of surface treatment performed on CF are fabricated. Samples are cut as per ASTM standards to evaluate tensile and flexural characteristics of each specimen. The details of ingredients selected for fabrication of composite sheets are given in table 3 and the sequence of operations involved in fabrication of friction composite sheets is given in fig 6.

Fig.6. Sequence of Operations Performed In Fabrication of Composite Sheets

Table 3. Material Selection

Material	Sample S2	Sample S3	Sample S4	Sample S5
CF After surface treatment [Oxidation, HNO_3,MWCNT-F grafted]	2%	3%	4%	5%
Phenolic Resin	70%	70%	70%	70%
Zirconium Silicate (ZrSiO4)	20.50%	20%	19%	20%
Graphite	1.50%	1%	1%	0.50%
Barium sulphate (BaSO4)	2.50%	3%	2.50%	1.50%
Rubber Powder	3.50%	3%	3.50%	3%
Total	100%	100%	100%	100%

4. Thermo Gravimetric Analysis (TGA)

TGA is a method of thermal analysis in which the mass of a sample is measured over time as the temperature changes. This measurement provides information about physical phenomena, such as phase transitions, absorption and desorption, chemical phenomena including chemisorptions, thermal decomposition and solid

gas reactions (eg. oxidation or reduction). A thermo gravimetric analyzer continuously measures mass while the temperature of a sample is changed over time. Mass, temperature, and time in thermo gravimetric analysis are considered as base measurements while many additional measures may be derived from these three base measurements. The present analysis is performed on powder sample collected from the friction composite specimen S5 with (MWCNT-F grafted on CF wt5%). The temperature is increased slowly from 0^0C to 1000^0C for an ending time period of 112.6 min. The oxidative mass loss is continuously observed with increase in temperature. The weight loss for the sample S5 is observed to be very less compared to other formulations of the material (i.e 2.11 mg). The optimum selection of ingredients makes the sample S5 (MWCNT-F grafted on CF wt5%) to sustain high temperatures easily and there is no considerable mass loss is observed after TGA analysis. Fig 7 gives TGA performed on sample S5 (MWCNT-F grafted on CF wt5%) of sample powder with increase in temperature.

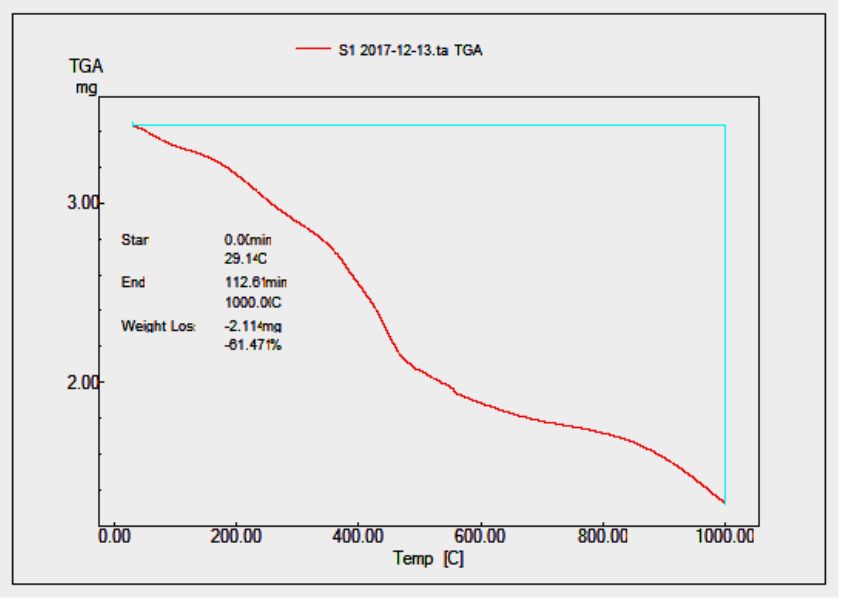

Fig.7. TGA Analysis on Powder Sample of S5 (MWCNT-F grafted on CF)

5. Fourier Transform Infrared Spectroscopy Analysis (FTIR)

FTIR is a technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. An FTIR spectrometer simultaneously collects high spectral resolution data over a wide spectral range. This converts the raw data in to the actual spectrum. The main aim of FTIR is to observe how well the sample absorbs light at each wavelength. FTIR spectroscopy of make shimadzu is used for this purpose. All the samples are subjected to infrared monochromatic light and intensity of peaks at each wavelength varying from 4000cm^- to 400 cm^- is observed. It was observed that, the intensity of peak begins at 44.416 and stops at a value of 40.824 for the sample S5 (CF wt5%) for CF grafted with MWCNT-F. The intensity of peak value is having fewer fluctuations with increase of wavelength and the variation between all the values of intensity of peaks is very less. The inter laminar cohesive forces between all the ingredients are greatly improved after surface treatment method by grafting MWCNT-F on CF surface compared to remaining methods. The sample specimen S5 (CF wt5% and CF grafted by MWCNT-F) possess good bonding strength with resin compared to other formulations of the material. The absorption spectra and intensity of peaks with respect to wavelength for sample S5 is given in fig 8.

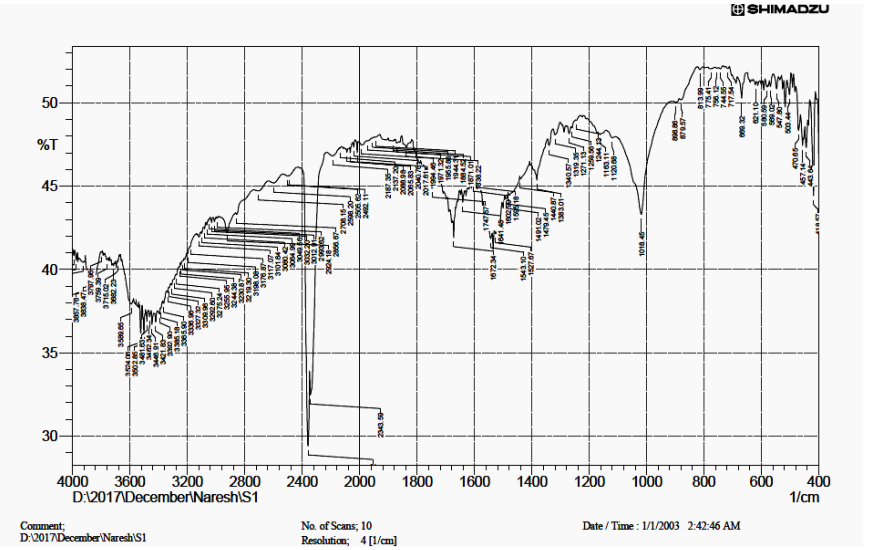

Fig.8. FTIR analysis on Specimen S5 (MWCNT-F grafted on CF)

6. Scanning Electron Microscopy Results

The SEM images given in Fig 9(a), Fig 9(b) & Fig 9 (c) demonstrate the three different surface treatments performed on CF. The surface visualization can be observed from each fabricated composite specimen in the SEM images. Fig 9(a) represents the CF surface subjected to oxidation treatment. The chemical inertness of the CF surface is not greatly improved by this treatment. This can be visualised in Fig 9(a) with shiny colour on its surface.

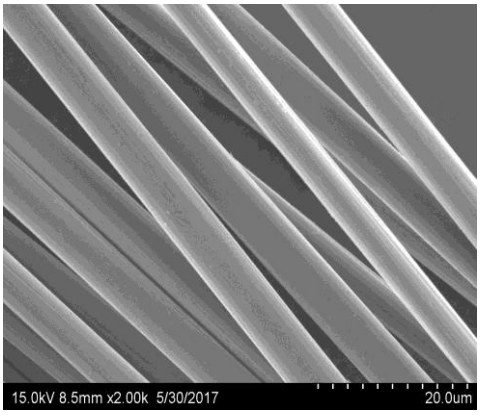

Fig.9(a). Surface Oxidation Treated CF

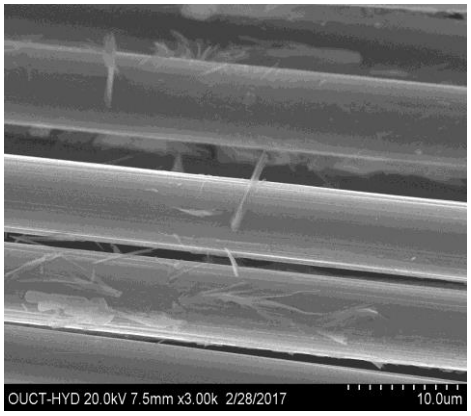

Fig.9(b). HNO3 Treated CF

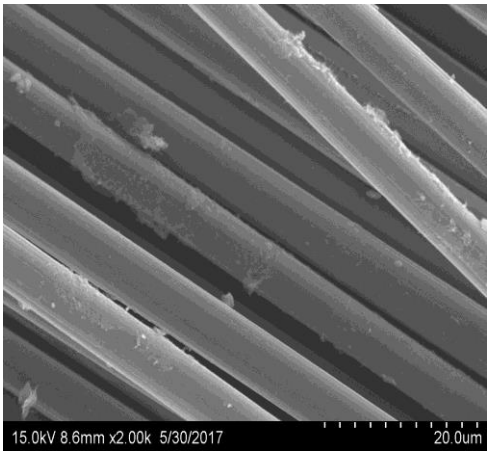

Fig.9(c). MWCNT-F Grafted on CF

Fig 9(b), shows HNO_3 treated CF with improved chemical inertness of the fiber to greater extent by incorporation of hydroxyl groups on the surface of CF. The fiber surface after HNO_3 treatment becomes soft and smooth to increase bonding strength, when mixed with all ingredients and resin. Further improvement of chemical inertness of the surface is increased by introducing more carboxyl groups on the surface by grafting MWCNT-F on CF surface shown in Fig 9(c). The surface structure of the carbon fiber becomes rough and there may be greater chance for increase of cohesive forces between all the ingredients. This type of grafting MWCNT-F on CF surface improves bonding strength of all ingredients with resin and possesses good mechanical and tribological properties without compromising its strength.

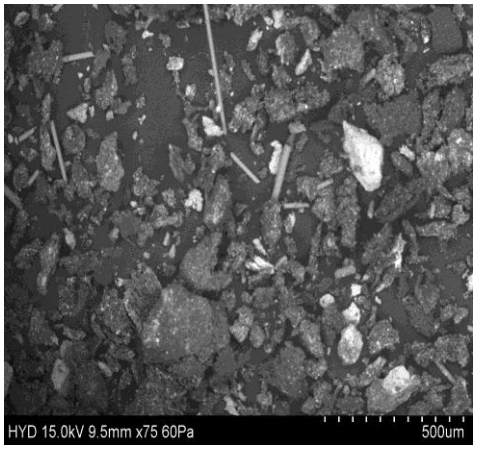

Fig.9(d). Surface Oxidation Treated Composite Sheet

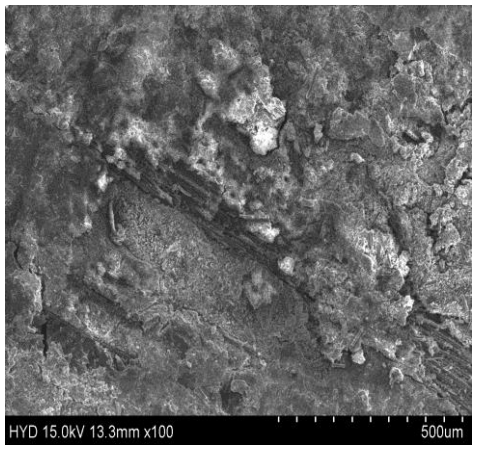

Fig.9(e). HNO3 Treated Composite Sheet

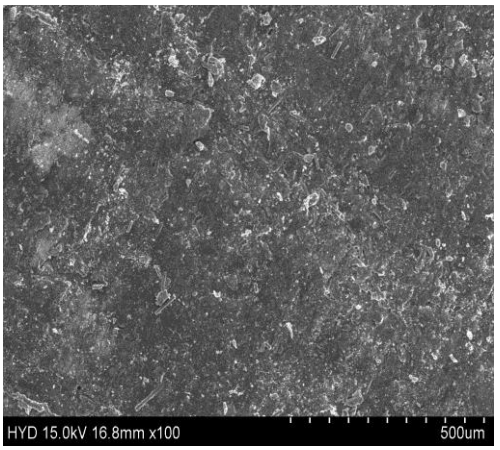

Fig.9(f). MWCNT-F Deposited on CF Composite Sheet

Scanning electron microscopy images are also taken on composite sheets fabricated for CF (wt 5%) for all the samples with different surface treatments performed on CF. It is clearly observed from Fig9(d) that, the bonding strength is very weak for CF treated with surface oxidation treatment and inter laminar shear forces between all the ingredients is very less. From Fig 9(e), it was observed that, HNO_3 treated CF composite specimen exhibits partial bonding strength and cohesive attractive forces between all the ingredients is better compared to Fig 9(d). The composite specimen containing CF grafted with MWCNT-F from fig 9(f) exhibits high bonding strength and good inters laminar cohesive forces between the ingredients compared to remaining treatment methods. There may be chance of increase of strength of the composite after CF grafted with MWCNT-F compared to HNO_3 treatment method. MWCNT-F grafted on CF composite sheet is shown in fig 9(f). The grains are distributed uniformly throughout the surface all the ingredients possess good bonding with resin.

7. Tensile and Flexural Test Results

The basic important tests to evaluate the properties of a friction material are tensile and flexural tests. The strength of any friction material is determined by conducting a tensile test and the amount of maximum load carried by the specimen is determined by conducting flexural test using three point bending method. The Instron testing machine of model No 8801, shown in fig 10 (a) is used to evaluate the ultimate tensile strength and flexural strengths of the materials. The machine is equipped with separate tensile and flexural test fixtures for mounting the specimens and the load is applied gradually until the specimen fractures. The values of ultimate tensile strength and flexural strengths of all the specimens with variation of surface treatments are tabulated. The best configuration of ingredients and surface treatment methods having good tensile and flexural properties are considered for design and fabrication of friction material in automobile applications.

7.1. Tensile Test

Tensile test is the basic important test to evaluate the strength of any material. This test is performed on all fabricated samples with varying surface treatment methods on CF. The machine is equipped with advanced load cell technology for faster testing and reduction of inertia errors. Tensile test is performed based on ASTMD638-02a standard of (Type1) shown in fig 10(f). The specimens before test and after test are indicated in fig 10(b), fig 10(c), fig 10(d) & fig 10(e).

Fig.10(a). Tensile Test Apparatus

Fig.10(b). Oxidation Treated CF tensile test Specimens

Fig.10(c). HNO3 Treated CF Before Tensile Test

Fig.10(d). MWCNT-F Grafted on CF Before Tensile Test

Fig.10(e). Specimens after Tensile Testing

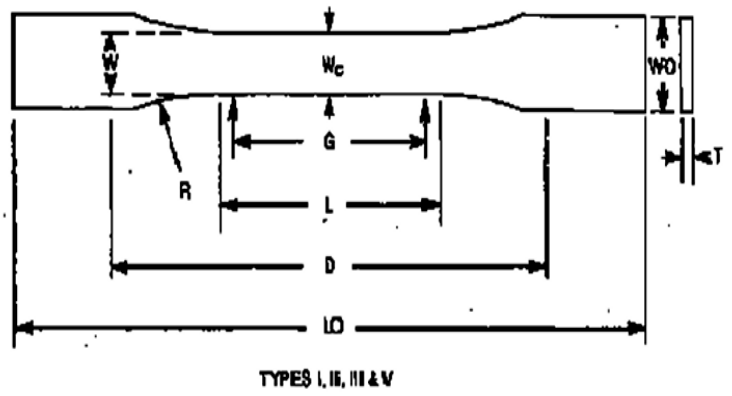

Fig.10(f). Tensile Test Specimen as Per ASTM Standard

The notations used in Fig 10 (f) are indicated with the dimensions Lo – Overall length 165(6.5) mm, D- Distance between grips 115(4.5) mm, L- Length of narrow section 57 (2.25) mm, G- Gauge length 50(2) mm, R- Radius of fillet 76(3.0) mm, Wo- Width overall 19 (0.75) mm, Wc- Width of narrow section 13(0.50) mm, T – Thickness of the specimen 10 (0.50) mm.

Initially, the specimens are fixed between two clamping jaws firmly and loaded gradually with incremental load until failure of the specimen takes place. The values of deformation against each load are noted and tabulated. The breaking load for each specimen is noted and ultimate tensile strength values of all the samples with varying surface treatments are observed and indicated in table 4.

Table 4. Ultimate Tensile Strength Values of Specimens

Type of composite	Maximum load (KN)	Load at break (KN)	Ultimate tensile strength(Mpa)
UT2	1.421	0.93	7.11
UT3	0.914	0.56	4.57
UT4	1.296	0.79	6.48
UT5	1.038	0.98	5.19
H2	1.534	0.94	7.67
H3	2.487	1.54	12.44
H4	0.792	0.48	3.96
H5	2.958	2.28	14.79
M2	8.968	8.01	44.84
M3	9.129	7.06	45.65
M4	10.304	10.17	51.52
M5	14.571	14.09	72.86

From table 4, it was observed that, the sample S5 with (MWCNT-F grafted on CF wt5%) with remaining ingredients can sustain more load (i.e 14.09KN) and possess high ultimate tensile strength value (i.e 72.86 MPa) compared to remaining formulations of the material. This sample specimen S5 (MWCNT-F grafted on CF wt5%) with selected ingredients possess increase in bonding strength between all the ingredients to enhance its mechanical strength. The main reason to have better tensile properties for the sample specimen S5 is having (CF wt5%) and grafting MWCNT-F on CF surface to reduce chemical inertness of the CF surface and increase carboxyl groups on its surface for better absorptive characteristics with resin. The load carried by the specimen is taken initially by the fiber and transmitted to the ingredients. Therefore, CF selected for the given application by grafting MWCNT-F on its surface have the greater ability to sustain the applied load after mixing with all the ingredients and polymer matrix.

7.2. Flexural Test

Flexural test is performed on all specimens by mounting a three point bending load fixture, shown in fig 11 (a). The sample to be tested is placed on the two end supports and a concentrated load is applied at the centre of the specimen. This test determines the maximum amount of load carried by the specimen under bending load. The samples to be tested are shown in fig 11(b) and fig 11(c) and fig 11(d).

Fig.11(a). Flexural Test Apparatus

Fig.11(b). Oxidation Treated CF Flexural Test Specimens

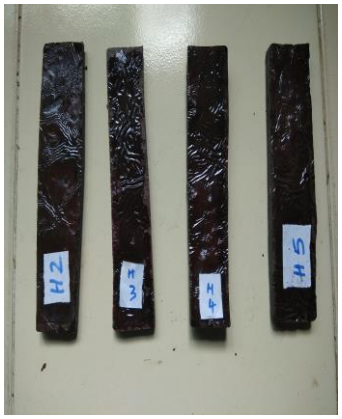

Fig.11(c). HNO3 Treated CF Flexural Test Specimens

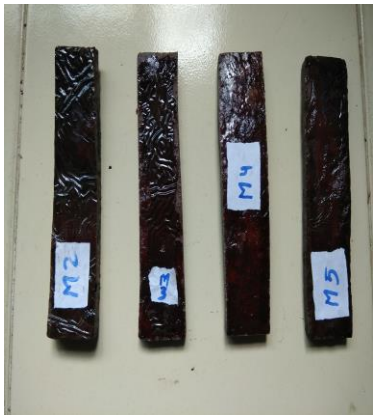

Fig.11(d). MWCNT-F Grafted on CF Specimens

This flexural test is useful for predicting the behavior of friction material against the bending load carried by the specimen. This data enables to calculate the maximum permissible bending load carried by the material under static conditions of automobile, which is useful for friction material design at the starting stage. The values of maximum flexural bending load and corresponding flexural stress for variation of surface treatments performed on CF is given in table 5.

Table 5. Flexural Stress Values for all Samples

Type of composite	Maximum flexural load (KN)	Flexural stress (Mpa)
UT2	0.097	5.49
UT3	0.731	41.14
UT4	0.22	12.42
UT5	0.613	34.51
H2	0.09	5.49
H3	0.18	10.57
H4	0.097	5.49
H5	0.191	10.79
M2	1.261	70.965
M3	0.942	53.022
M4	2.247	126.43
M5	3.095	174.11

From table 5, it was observed that, sample S5 with (MWCNT-F grafted on CF wt5%) along with remaining ingredients can sustain more bending load (i.e 3.095KN) and possess high flexural strength value (i.e 174.11 MPa) compared to remaining formulations of the material. This sample specimen S5 with selected ingredients can sustain more bending load and can extend its application in fabrication of brake friction material. The main reason to have better flexural properties for the sample specimen S5 is having (CF wt5%) along with other ingredients. The load carried by the specimen is initially transmitted to the fiber and then it is transmitted to the ingredients. The surface treatments performed on sample specimen S5 is also the main reason to have high bonding strength between all ingredients. The ingredients and surface treatments performed on fiber can increase the inter laminar cohesive forces with resin and can sustain more bending load. The fiber surface after grafting MWCNT-F on CF possesses good bending strength. The fiber surface is not damaged and fiber/matrix adhesion is greatly improved without any de lamination and transverse cracks on the surface. Therefore, grafting MWCNT-F on CF (S5) can sustain more bending load compared to other methods.

8. Conclusion

Tensile and flexural properties of the friction material specimens are determined by variation of surface treatment performed on CF (Oxidation, HNO_3, and MWCNT-F). The weight loss and bonding strength of all the samples are determined by using thermo gravimetric and FTIR analysis. Based on thermo gravimetric and FTIR analysis performed on all specimen sample powders, it was observed that sample S5 (MWCNT-F grafted on CF wt5%) with remaining ingredients possess low weight loss and good bonding strength with increase in temperature and wavelength compared to other formulations. It was observed that, tensile and flexural properties of the samples S5 (MWCNT-F grafted on CF wt5%) with remaining ingredients is greatly improved. The specimen S5 possesses high ultimate tensile strength (72.82 MPa) and flexural strength (174.11 MPa) compared to remaining surface treatment methods and other formulations of the material. It was concluded that, optimum selection of ingredients for the sample specimen S5 and surface treatment method of grafting MWCNT-F on CF surface is responsible for improvement of tensile and flexural properties of friction material.

Acknowledgement

The authors would like to thank Anits Engineering College, Visakhapatnam for providing the chemical laboratory facilities for doing this project. The authors also thank Gitam University, Visakhapatnam for giving permission to carry out tensile and flexural tests using Instron testing machine.

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How to cite this paper: Naresh Kumar Konada, K.N.S.Suman,"Effect of Surface Treatments on Tensile and Flexural Properties of Carbon Fiber Reinforced Friction Material", International Journal of Engineering and Manufacturing(IJEM), Vol.8, No.3, pp.23-39, 2018.DOI: 10.5815/ijem.2018.03.03