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Tribo evaluation of Surface Treated Carbon Fiber Reinforced Friction Material

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ABSTRACT

Carbon fiber reinforced friction material is formulated by grafting MWCNT-F on its surface. This material combination is investigated in this work by using a wear test apparatus. The surface of CF is chemically inert and hydrophobic in nature and possesses poor bonding strength with polymer matrix. Hence, an attempt is made to improve the bonding behaviour between CF and remaining ingredients. CF surface is modified by grafting multi walled carbon nano tubes functionalized (MWCNT-F) on CF surface. CF content after surface modification is varied in wt% (2%, 3%, 4% and 5%) and mixed with remaining ingredients of friction material. Composite sheets are prepared by using hand layup method. Multi walled Carbon Nano Tubes grafted friction material (MWCRFM), is characterized for SEM. MWCNTs-F on CF surface is observed. Sample specimens are cut from the friction composite sheets and the influence of performance properties like friction, wear, speed, load and time on friction is studied. The behaviour of the samples are also analyzed using regression analysis L9 (3x3) experimental design method for 3 different loads, time periods and speeds. The results reveal that, time and braking pressure plays an important role to control the wear rate and coefficient of friction of the composite. It was also observed that, MWCNT-F grafted on CF specimens for sample M5 (CF 5 wt%) possess less wear rate and high stable coefficient of friction compare to other formulations of materials.

Keywords: Multi walled carbon nano tubes, Carbon fibers, Chemical grafting, and Tribological properties

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1. Introduction

Brake friction material present in an automobile converts the kinetic energy of automobile to thermal energy by means of friction generated at the contact surface. Friction material selection primarily depends on the ability of the material to dissipate heat to the surroundings, wear rate, coefficient of friction, fade resistance, squealing, and atmospheric conditions. The other parameters that affect the friction material selection are engine size, drive train gearing system design, braking system design and tire - road conditions [1].The friction materials selected for any application in an engineering field has to provide stable coefficient of friction and low wear rate at various operating speeds, pressures, temperatures and environmental conditions [2-6]. In the past asbestos reinforced friction material is widely used to produce brake pads, due its strength, resistance to heat and fire proof. Since 1980s, asbestos was known as harmful content and was banned from being used as an ingredient to produce brake pads, because it can cause lung cancer and other health problems [7]. Therefore, non asbestos contents like Kevlar (aramid fiber), steel fiber, glass fiber and carbon fiber were used to replace asbestos. Brake friction material present in an automobile consists of more than 9 different ingredients. These ingredients often contain fiber, binder, lubricant, abrasive, fillers and other friction modifiers.

The reinforcing fibers and binder resin used in friction materials have substantial influence in determining the friction characteristics. The frictional heat generated at the interface between brake disc and pad can easily raise the temperature beyond the transition temperature zone, which results in abrupt change in friction force during braking. This occurs mainly due degradation mechanism of binder and other ingredients. Fade resistance is a phenomenon that, describes decreasing of frictional force at high temperature. Therefore, binder resin is usually preferred to be heat resistant. The type and amount of these ingredients are determined mostly based on experience, observation or a trail and error method to make a new formulation. At present, Carbon fiber reinforced polymer composites have been gaining their importance in all the fields of engineering sectors, namely 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. Hence carbon fiber reinforcements can be used in friction materials to have high wear resistance compared to other fibers [8-9]. 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. 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 [10]. 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 [11], 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 [12] 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 [13], 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. [14-17]. Naresh Kumar Konada and K.N.S.Suman also conducted experimental studies on usage of carbon fiber more effectively in friction materials [18-21]

2. Experimental Work

2.1 Materials and methods

The material selection for the brake pad depends mainly on the 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. The selection of ingredients for the friction material has to be carried based on the characteristics of a friction material.

The main characteristics of friction materials should possess are [22]

a) Maintain a sufficiently high coefficient of friction with the brake disc.
b) Not to decompose or break down in such a way that the friction coefficient with the brake disc is compromised, at high temperatures.
c) Exhibit stable and consistent coefficient of friction with the brake disc.
d) Wear resistant.
e) Able to dissipate heat to the surroundings.
f) Having sufficient fade resistance
g) 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 given 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) shown in fig 2. MWCNTs are used widely, as filler materials in polymer matrix composites in 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 material composites .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 MWCNT

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 method

2.3.1 MWCNT surface oxidation treatment

The multi- walled carbon nano tubes (MWCNTs) are treated to attach carboxylic acid groups on the surface to form functionalized MWCNTs called MWCNT-F.In this study, 2gms of MWCNT is added to 100 ml of concentrated sulphuric acid and 35 ml of nitric acid (Purity of 98.08%H_2SO_4 and 70% HNO_3) (3:1 by volume ratio) .The mixture is sonicated in a bath for 3 hours at a temperature of 70^0C. The reaction mixture is then diluted with 200ml of deionised water followed by vaccum filtration process using filter paper of 2µm porosity. This washing operation is repeated three times to remove metal particles adsorbed by MWCNTs .The sample is allowed to dry in an oven at 100^0C. After drying operation, the collected powder particles are immersed in 40 ml of acetone solution .Finally, MWCNT powder after vaccum filtration process is added with acetone solution and placed on ultra sound bath sonicator to allow the acetone solution to completely mix with MWCNTs. During sonication process, acetone gases will leave the sample because the low boiling point of acetone is at 30^0 C. The sample is later dried in oven at 100^0C for 4 hours followed by drying in the open air to form MWCNT-F powder. This process will completely remove metal particles present in MWCNT powder in order to use MWCNT-F more effectively in polymer matrix composites. The process of using MWCNT-F on CF surface increases the damping characteristics and reduces squeal generation at the contact region between brake disc and pad. Figure 3 provides the sequential operations carried out in functionalizing MWCNTs powder .

Fig 3. Sequential operations in MWCNT surface oxidation to form MWCNT-F

2.3.2 Grafting MWCNT-F on oxidised CF surface

Multi walled carbon nano tubes functionalized (MWCNT-F) of qty 1.5 gms obtained after filtration and drying operation is dispersed in a 20 ml of acetone solvent using an ultra sound bath at 70^0 C for 1 hr. Complete mixing operation is carried out using a ultra sound bath sonicator. Now, chopped carbon fibers are placed on a glass substrate and suspension containing MWCNT-F is deposited drop by drop using a droppler over the entitre surface of carbon fiber.The deposition operation is repeated several times with evaporation of the sovent between each deposition.Heat treament process is carried out on the resulting CFs grafted MWCNT-F at 100^0C for 2hrs.The figure 4 gives the sequential operations carried in grafting MWCNT-F on carbon fiber surface.

3.Preparation of composite sheets

Hand lay up method is used to fabricate friction composite sheets for the ease of fabrication and control of all operating variables. CF content after grafted with MWCNTs-F is varied in (2,3,4,5 vol %) along with other ingredients.Initially all the ingredients are mixed using a foculator for 1 hr . After proper mixing of all the ingredients , friction composite sheets are fabricated by using hand lay up process. The details of ingredients selected for fabrication of composite sheets are given in table 3.

Fig 4. Grafting MWCNT-F on CF Surface

Table 3. Composition of friction material studied in this study

Ingredient	Vol%
Phenolic Resin	70
CF (MWCNT-F grafted)	(2,3,4,5)
Zirconium silicate	15
Graphite Powder	1.5
Barium Sulphate	2.5
Rubber Powder	3
Molybdenum disulphide	Balance

Fabrication of composite sheet starts with an initial step of 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 using gas welding. The mixing operation of all the ingredients is carried in a foculator. Initially resin is taken in a foculator and all the ingredients are added slowly one after the other with an interval time gap period of 10 min. Total mixing operation for all the ingredients was carried for 30 min for each sample sheet. Three composite sheets with variation of fiber content are fabricated. Sample specimens are cut according to ASTM G-99 standard to evaluate tribological properties of the composite specimens. The sequence of operations involved in fabrication of friction composite sheets and cutting the specimens are given in fig 5.

Fig5 .Sequence of operations performed in fabrication of composite specimens

6. Test set up and procedure

Pin on disc technique was used for the tests with software data acquisition system as (WIN DUCOM; TL-20) shown in fig 6 .The surface of the rotor is made of hardened ground steel disc (EN-32) having hardness 65 HRC and surface roughness (Ra) 0.5μm.Wear samples are prepared with the dimensions of square pin (30mm × 5mm × 5mm) as per ASTM G99 standards. Before starting of the test, Initially, the Contact surfaces were cleaned with 600-grit silicon carbide paper and finally with acetone solution. The disc rotates with the help of a D.C. motor having speed range 0-1000rpm, track diameter 70mm, and a load of 0 to 100 N. Load is to be applied on pin (specimen) by dead weight through pulley string arrangement. In this experiment the load applied on the friction material is varied from 2Kg, 4 Kg and 6 kg for a time interval period of 5min, 10 min and 15 min. The speed of the rotor disc was varied with the values of 300 rpm, 600 rpm and 900 rpm. Counter disc temperature was measured during the tests by using non contacting infrared (IR) thermometer. The thermometer is placed at approximately 15 cm away from the trailing edge of the brake pad specimen. Frictional force at the sliding interface was measured using strain gauge mounted on the level arm that holds the specimen while the wear rate was determined by weighing the specimen before and after each test. The values of coefficient of friction, wear rate, frictional force and temperature generated at the contact region during application of load was measured and graphs are drawn. The morphologies of worn surfaces are observed by using scanning Electron Micro Scopy- SEM.

Table 4. Chemical Composition (Vol %) of grade EN-32 case hardened steel rotor disc

Material	Element (Vol %) C	Mn	Si	S	Tensile strength (N/mm^2)	Elongation (%)	Impact strength (Izod J)
En -32 Case hardening steel	0.10-0.18	0.60-1.00	0.005	0.005	430	18	39

Fig 6(a). Pin on disc machine

Fig 6(b) EN-32 Rotor Disc

In the full factorial design approach, the total number of experiments required to analyze the behaviour of friction material are (3x3) = 27. But, using L9 orthogonal array, it requires only 9 experiments to analyze the behaviour of the friction composite against the application of load. The plan of experiments for the present study starts with L9 Orthogonal Array. These experiments were carried to analyze the influence of all the derating factors on dry sliding wear behaviour of fiber reinforced friction material. The control factors and their levels for L9 orthogonal array of experiments are shown in Table 5

Table 5 .Control factors and their levels

Factors	Level 1	Level 2	Level 3
Speed(rpm)	300	600	900
Load (kg)	2	4	6
Time (min)	5	10	15

Table6. Orthogonal Array 3x3 matrix experiments to be conducted for wear test for all samples (MWCRFM, AFRFM, and OCRFM)

Ex No	Speed (rpm)	Load (Kg)	Time (Min)
1	300	2	5
2	300	4	10
3	300	6	15
4	600	2	10
5	600	4	15
6	600	6	5
7	900	2	15
8	900	4	5
9	900	6	10

Table7. Results of MWCNT-F grafted CF reinforced friction material

Speed RPM)	Load (Kg)	Time (Min)	Wear (Micrometers)	Frictional force (N)	Coefficient of Friction
300	2	5	119	12.3	0.512
300	4	10	212	16.8	0.414
300	6	15	166	29.2	0.483
600	2	10	140	8.2	0.395
600	4	15	149	17	0.404
600	6	5	89	26.3	0.419
900	2	15	62	10.7	0.49
900	4	5	111	15.2	0.336
900	6	10	268	22.3	0.392

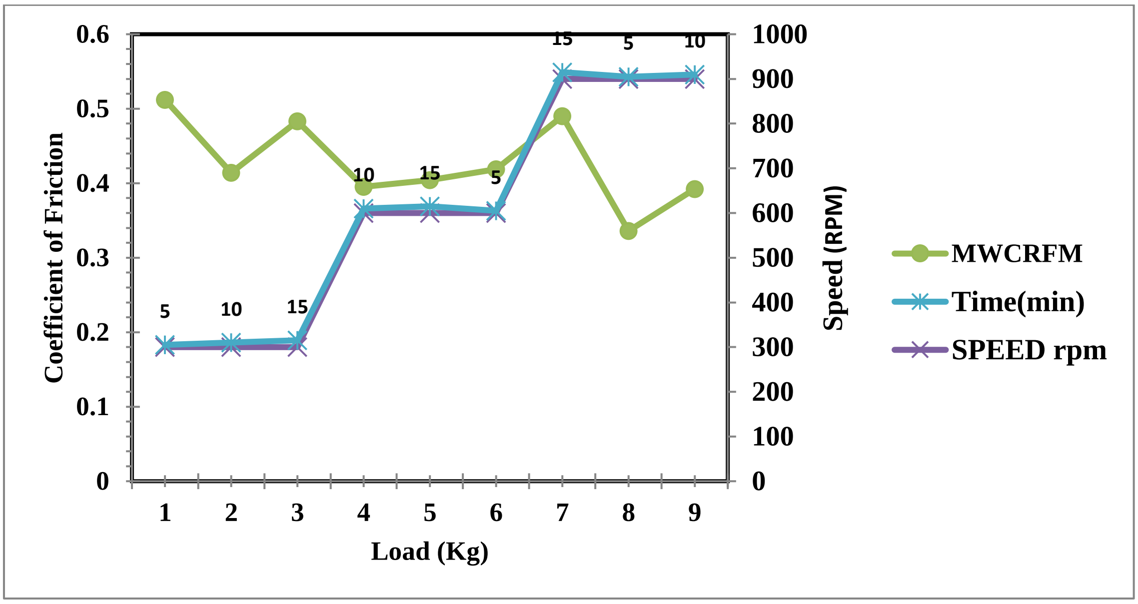

Fig 7.Load vs Coefficient for MWCRFM

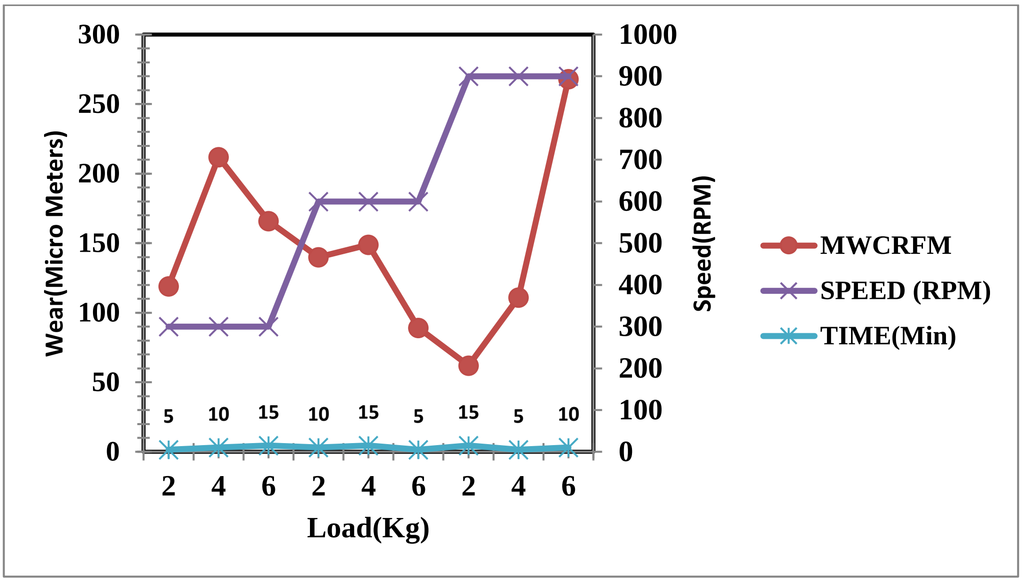

Fig8. Load vs Wear rate for MWCRFM

The friction material MWCRFM is subjected to loading conditions of (2Kg, 4Kg, and 6Kg), time (5min, 10min, and 15 min), and rotor speed of (300 rpm, 600 rpm and 900 rpm). It is observed that, µ is in the range of 0.512 to 0.483 and wear rate of 119 to 166 micrometers for a speed of 300 rpm. It is also noticed that, with increase in speed and same operating conditions in table 7, it was observed that, wear rate decreases from 0.478 to 0.317 and wear rate first decreases at moderate speed conditions of the rotor and there after increases with increase of rotor speed. MWCRFM possess stable and high coefficient of friction and less wear rate compared to remaining formulations of the materials.

6.1 S/N Ratio Analysis

Signal-to-noise ratio (S/N) is a measure of signal strength relative to background noise. The ratio is usually measured in decibels (dB) using a signal-to-noise ratio formula. The influence of control parameters sliding speed, load, and time on wear rate, friction, coefficient of friction is evaluated using S/N ratio response analysis. The wear rate, friction, coefficient of friction was considered as the quality characteristic by considering smaller is the better for wear rate and higher is the better for coefficient of friction. This was calculated by using following equation.

S/N ratio = -10 Log_{10} $[\frac{1}{n}\sum y^2]$. Here n is 1 & y is response value.

Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Higher the difference between the mean of S/N ratios, the more influential will be the control parameter.

6.2 Analysis of variance (ANOVA)

ANOVA was used to determine the design parameters significant influence on response values. This analysis was evaluated for a confidence level of 95%, and the parameter response indicates the degree of influence on the result.

Total sum of squares = sum of squares groups + sum of squares with in group

Mean squares (MS) = $\frac{\text{sum of squares}}{\text{degrees of freedom}}$

F-test is a statistical test in which the test static has an F-distribution under null hypothesis. Exact F-test mainly arise when the models have been squares. F statistic like regression tries to find the connection between the two P values of equal or smaller than 0.05.

F=$\frac{\text{Variance of group means}}{\text{Mean in group variance}}$

P is probability of obtaining a result at least as extreme as the one that was actually observed, by giving null hypothesis has true. Delta is the difference between the maximum and minimum average S/N ratio for factors. Rank is the rank of each delta and the largest delta.

Table 8. L9 (3× 3) Orthogonal Array for MWCRFM

SPEED(RPM)	LOAD(KG)	TIME(MIN)	WEAR(MICRO METERS)	SNRA1	FITS_SN1	RESI_SN1	%ERROR
300	2	5	119	-41.5109	-39.5686	-1.94235	4.908817
300	4	10	212	-46.5267	-48.6427	2.11598	-4.35005
300	6	15	166	-44.4022	-44.2285	-0.17363	0.392575
600	2	10	140	-42.9226	-42.7489	-0.17363	0.406162
600	4	15	149	-43.4637	-41.5214	-1.94235	4.677949
600	6	5	89	-38.9878	-41.1038	2.11598	-5.14789
900	2	15	62	-35.8478	-37.9638	2.11598	-5.57368
900	4	5	111	-40.9065	-40.7328	-0.17363	0.426266
900	6	10	268	-48.5627	-46.6203	-1.94235	4.166318

Table 9. Analysis of Variance for S/N ratios for MWCRFM

Source	DF	Seq SS	ADJ MS	F	P	Contribution
SPEED(RPM)	2	11.18	5.592	0.45	0.69	9.493886
LOAD(KG)	2	27.78	13.89	1.12	0.472	23.59035
TIME(MIN)	2	53.95	26.975	2.17	0.315	45.81352
Residual ERRR	2	24.84	12.42			21.09375
Total	8	117.76				100

Table 10. Response table for S/N ratio Smaller is better for MWCRFM

Level	SPEED(RPM)_1	LOAD(KG)_1	TIME(MIN)_1
1	-44.15	-40.09	-40.47
2	-41.79	-43.63	-46
3	-41.77	-43.98	-41.24
Delta	2.37	3.89	5.54
Rank	3	2	1

Table 8 indicates L9 (3× 3) orthogonal array analysis of variance for MWCRFM for wear rate. It can be observed from table 9 that, time was considered as the most significant parameter having the highest statistical influence (45.81%) on the dry sliding wear of composites followed by load (23.59%) and speed (9.49%). When the P-value for the model is less than 0.05, then the parameter or interaction can be considered as statistically significant. From the results, it was observed that, the interaction affect of load and time is having significant influence on wear rate of MWCRFM. Table 10 gives rankings to influence of parameters. Based on the values it was observed that, time is considered as most influencing parameter for wear rate on MWCRFM.

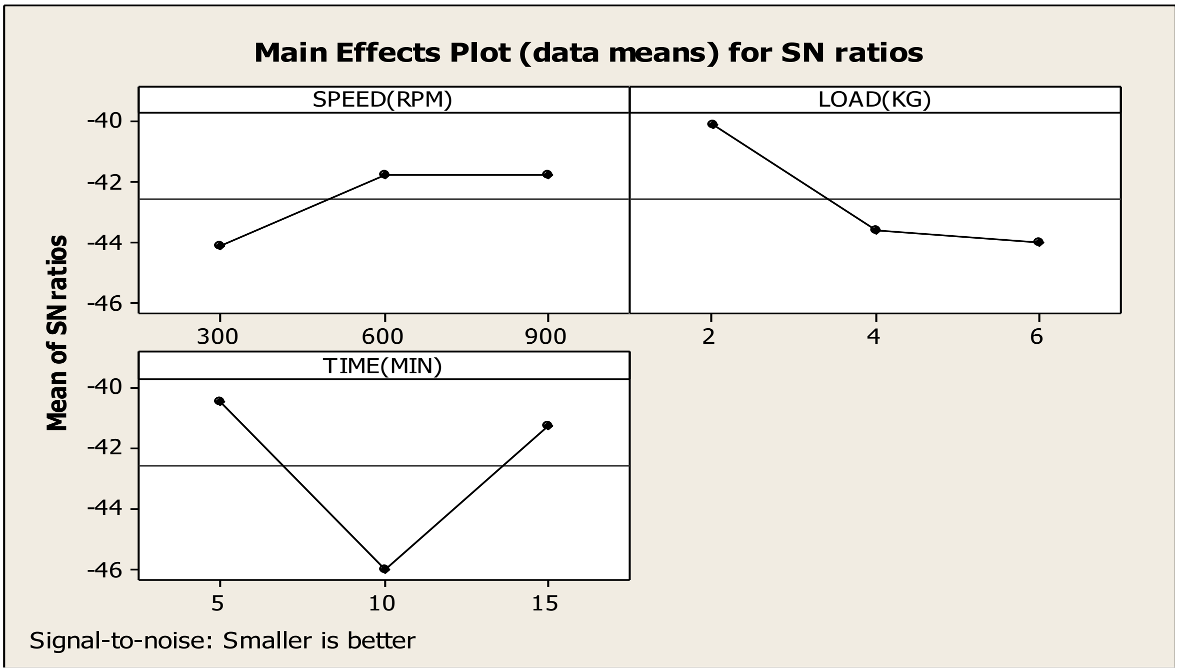

Fig 9. Wear rate main effect plots of S/N ratio for MWCRFM

Fig 9 shows the wear main effective plots of S/N ratio for MWCRFM. It is observed that if the speed of the rotor increases then, S/N ratio of wear increases. Similarly, it was observed that, if load increases then S/N ratio of wear decreases. As the time increases then, S/N ratio of wear decreases initially up to 10min and thereafter it increases.

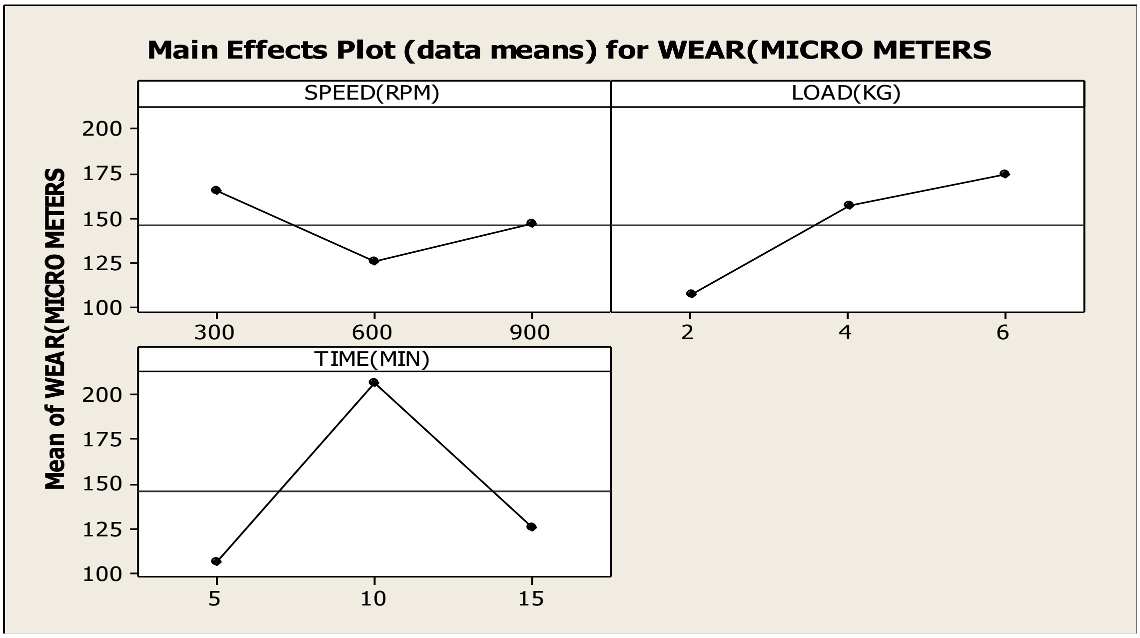

Fig 10. Main effect plots of control factors of wear for MWCRFM

Fig 10 shows the wear main effective plots of control factors for MWCRFM material. It is observed that if speed increases then, the Mean of wear decreases. Similarly it was observed that if load increases then, the Mean of wear increases. It was also observed that, as the time increases then , the Mean of wear increases initially up to 10min and thereafter it decreases.

Table 11. L9 (3× 3) Orthogonal Array and analyzed Taguchi Design for coefficient of Friction in MWCRFM

SPPED(RPM)	LOAD(KG)	TIME(MIN)	COF	SNRA1	FITS_SN1	RESI_SN1	%ERROR
300	2	5	0.512	5.8146	5.99589	-0.18129	-3.02359
300	4	10	0.414	7.65999	7.97777	-0.31778	-3.98329
300	6	15	0.483	6.32106	5.82199	0.499069	8.572138
600	2	10	0.395	8.06806	7.56899	0.499069	6.593601
600	4	15	0.404	7.87237	8.05366	-0.18129	-2.25104
600	6	5	0.419	7.55572	7.8735	-0.31778	-4.03604
900	2	15	0.49	6.19608	6.51386	-0.31778	-4.87849
900	4	5	0.336	9.47321	8.97415	0.499069	5.561184
900	6	10	0.392	8.13428	8.31557	-0.18129	-2.18014

Table 12. Analysis of Variance for S/N ratios for MWCRFM

Source	DF	Seq ss	M	F	P	Contribution
SPPED(RPM)	2	3.317	1.6584	2.89	0.257	31.0058
LOAD(KG)	2	4.108	2.0542	3.58	0.219	38.3997
TIME(MIN)	2	2.125	1.0623	1.85	0.351	19.86353
Residual	2	1.149	0.5744			10.74033
Total	8	10.698				100

Table 13. Response Table for S/N Ratio larger is better for MWCRFM

Level	SPPED(RPM)_1	LOAD(KG)_1	TIME(MIN)_1
1	6.599	6.693	7.615
2	7.832	8.335	7.954
3	7.935	7.337	6.797
Delta	1.336	1.642	1.158
Rank	2	1	3

Table 11 shows L9 (3× 3) orthogonal array and analyzed taguchi design for coefficient of friction MWCRFM. It can be observed from table 14 that, load was the most significant parameter having the highest statistical influence (38.39%) on the coefficient of friction of the composite material followed by Speed (31.005%) and Time (19.86%). When the P-value for the model is less than 0.05, then the parameter or interaction can be considered as statistically significant. From the results, it was observed that, the interaction effect of load and time is having significant influence on coefficient of friction for MWCRFM. Table 13 gives rankings to most influencing parameter for coefficient of friction for MWCRFM. It was observed that, application of load on rotor disc plays an important role for coefficient of friction induced in MWCRFM.

Fig 11 shows the coefficient of friction main effective plots of S/N ratio for MWCRFM. It is observed that, if speed increases then S/N ratio of coefficient of friction decreases. Similarly it was observed that if load increases, then S/N ratio of coefficient of friction decreases up to 4kg load and thereafter S/N ratio increases. It is also observed that, with increase in time S/N ratio of coefficient of friction decreases initially up to 10min and there after it increases slowly.

Fig 12 shows the coefficient of friction main effective plots of control factors for MWCRFM. It is observed from the graph, that if speed increases then mean of coefficient of friction decreases. Similarly it is observed that, with increase in load mean of coefficient of friction decreases initially up to 4kg and thereafter it increases. As the time increases then, mean of coefficient of friction decreases initially up to 10min and thereafter it increases.

7. Scanning Electron Microscopy Results

SEM images are observed using S 3700N Hitachi make presented in Fig 13. Figure 13 (a) and fig 13 (b) gives the SEM image taken for carbon fiber treated with oxidation treatment and MWCNT-F grafted on CF surface. It can clearly observed from fig14 (b) that, the fiber surface becomes rougher after this treatment to increase hydroxyl groups on the surface.

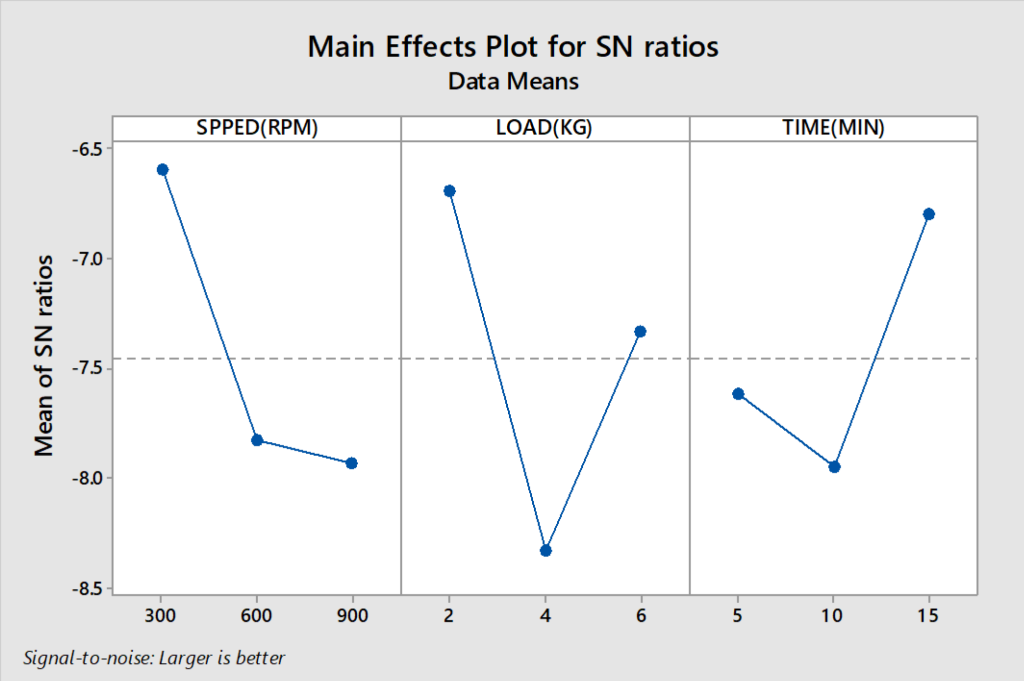

Fig 11. Coefficient of friction main effective plots of S/N ratio for MWCRFM Material

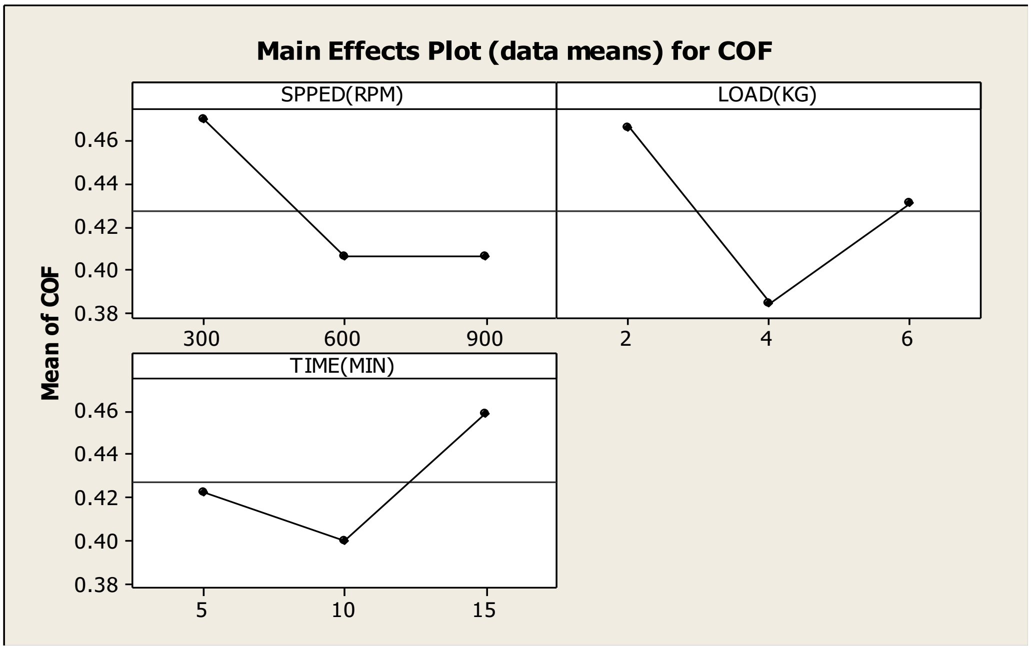

Fig 12. Main Effects of control factors to coefficient of friction for MWCRFM Material

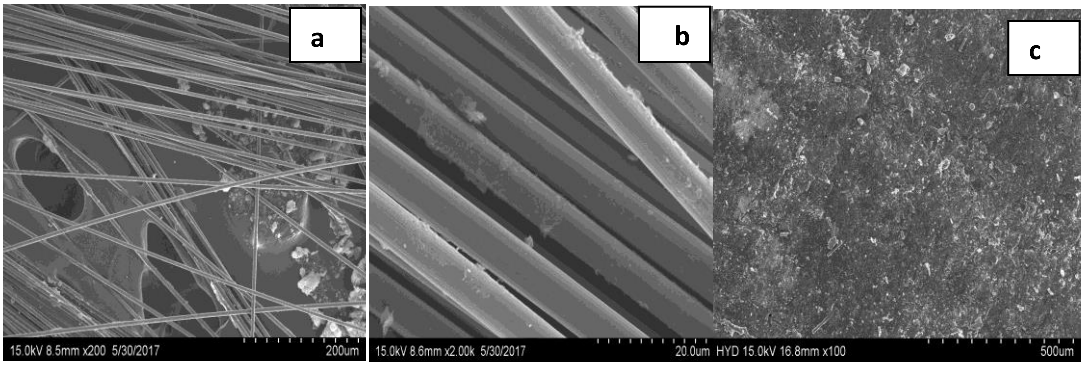

Fig 13. SEM images of different fibers and composite sheets

The fiber surface after oxidation treatment fig 14(a) is soft and smooth and only little improvement in the hydrophobicity of the surface occurs after this treatment.. It is clearly observed from fig 14(c) that, the composite specimen containing CF grafted with MWCNT-F exhibits high bonding strength and good inter laminar shear forces between all the ingredients compared to remaining formulations of materials. There is a greater possibility of enhancement of strength of the composite after CF grafted with MWCNT-F because of uniform distribution of all the grains in the structure along with good absorptive characteristics between all the ingredients with polymer matrix.

CONCLUSION

Multi walled carbon fiber reinforced friction materials were investigated in this work using a wear test apparatus for three different loading conditions, speeds and time under dry conditions . It was observed from the results that, MWCRFM sample specimen (M5,CF 5 wt%) possess low wear rate and high coefficient of friction.It was also observed from analysis of variance results that, the most influencing parameter for MWCRFM is observed to be time for wear rate and load for coefficient of friction .The surface treatments performed on CF by grfating MWCNT-F on its surface increases the bonding strength between CF , Polymer matrix and remaining ingredients. It was finally concluded that, MWCNT-F grafting on CF is the main reason to have higher wear resistance and high stable coeffient of friction compared to other formulations. Hence MWCRFM can be effectively used to replace current existing friction materials for automobile applications.

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