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COMPARATIVE ANALYSIS OF GFRP & GFRP DOPED WITH MWCNTS COMPOSITES SLIDING UNDER DRY AND OIL LUBRICATED ENVIRONMENTAL CONDITIONS

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ABSTRACT

Tribological properties of GFRP (glass fiber reinforced polymer) and GFRP doped with MWCNTs(carbon nanotubes, diameters of order nanometers) fabricated by vacuum bagging process were experimentally investigated under three different loads and two different sliding environments, (a) Dry environment and (b) Oil lubricated environment. Wear tests were conducted on a pin on disc type tribometer and steel as counter body with three different loads and two sliding velocity. Experimental results depict that coefficient of friction and wear rate is less in nano composites as compared with GFRP composites. Wear rate shows a similar behavior in both type of composites as it is comparatively less in oil lubricated sliding when compared with sliding in dry environment. In oil lubricated sliding, the coefficient of friction is reduced due to presence of softer epoxy resin body matrix in between layers of glass fibers. Initial wear of polymer mixes with absorbed lubricant on steel surface which acts as lubricant storage reservoir, due to which the protruding glass fibers pick up lubricant molecules to effectively and avoids direct contact between steel and fiber. In the dry sliding environment condition, images taken by FESEM shows that the rate of wear of composite increases due to increasing load and high friction as a result they undergo bending at the ends.

Keywords: Tribology; Nano Composites; Polymer Matrix Composite; Wear resistance; Carbon Fiber; Carbon Nanotubes

I. INTRODUCTION

Fabrication of composites by inserting fibers in a base of polymer or epoxy resin materials has emerged as a low cost, high strength to weight ratio and high impact strength has led to its use in day to day life. Uses of composite materials have emerged in shipbuilding, automobile, chemical and aerospace industries etc [1–3] and all these application requires knowledge of both mechanical and tribological properties.

Some research have been done regarding the sliding wear of GFRP composites[5-6].Even though the epoxy resin polymer reinforcement with fibers improves the tribological characteristics of epoxy resins but sometimes it degrades its properties as well[4].In research among the various categories of composites available glass fiber reinforced polymer (GFRP) is focused more because of its promise in terms of engineering applications[5-6]. These are comparatively more expensive, but are used for variety of engineering applications due to its superior mechanical properties and uses [7-9]. Density of GFRP is comparatively very less and is easily shapeable as compared with other engineering materials. The different sequences of stacking of laminates in composites results in increasing strength and attain heavy loads[10]. As per required mechanical property and applications selection of epoxy resin and reinforcement are done to fabricate any composite material [11-14]. Prior researchers have been done regarding the sliding wear of GFRP composites. Some common mechanisms of wear for GFRP composites are: fiber–matrix deboning, Delamination and fiber breaking [15]. Some additional mechanisms noted are fiber pull out, pealing of the resin, matrix wear associated to fiber separation, deformation of the edges of the wear track and shear deformation of the fibers. Thus application of GFRP composites in mechanical parts requiring adequate wear resistance in actual service conditions would require an adequate knowledge through research, of the friction and wear characteristics of such composites when used in conjunction with other sliding material e.g. steel.

There are various research done on polymer composites for various applications including enhancing its strength at low temperatures over glass thermoset systems[16] .To enhance the mechanical properties of GFRP it is mixed with CNTs(carbon nano tubes with diameters in nanometers)[17-18].In this research laminates mixed with epoxy and carbon nanotubes for the manufacture nano composites. CNTs are aligned along the existing glass fibers and epoxy resins binds all the filaments (CNTs and fiber) together. The reinforcements of CNTs in epoxy along with woven glass fiber, so as to provide enhance strength and toughness. Alignment and adhesion of CNTs in epoxy plays a very important criteria for application of composites and several difficulties are reported in prior research articles[19], these difficulties arises due to impregnation of high volume fraction of CNTs in aligned fiber advanced composites. There are several issues like dispersion and agglomeration slight mechanical properties are improved in case of nano composites [20-21].

Investigation done by researchers has shown that when the polymer resins are reinforced with fibers, it reduces the wear rate of composites [22].But the tribological behavior of composites depends on other parameters like composition, angle of orientation of the fibers, shape and size of laminates etc[23]. To extend that prior work, the present research is aimed at determining the effects of all such parameters on tribological behavior of GFRP and GFRP mixed with CNT composite materials. Wear analysis of GFRP materials were studied under various normal loads, sliding velocities and sliding conditions and lubricating media such as dry and oil lubricated environmental conditions.

II. EXPERIMENTAL DETAILS

2.1 Materials used for GFRP

GFRP specimens were prepared using plain weave glass fiber include E-glass fibers of diameter 10– 15 µm and Epoxy Resin(epoxy resin with viscosity 300cP mixed with K-6 Hardener) supplied by Atul Limited, Gujarat, India. The property of epoxy resin was not modified i.e no other solvent was used to reduce its viscosity. Epoxy have various advantages over other polymeric resins like good whetting properties, high cohesive strength and minimal

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shrinkage on curing. GFRP is a good engineering material with high impact strengths, easily shapeable, high strength to weight ratio and that is also desirable in commercial applications due to lower cost. Carbon nanotubes(diameters in nanometers) were used for fabrication of nano composites. Curing of composites was done at room temperature.

2.2 Fabrication of GFRP and Nano Composites

The GFRP composite plates having dimensions 270mm×320mm×6mm were prepared by the vacuum bagging process (Fig. 1). 6 mm nominal thickness was achieved by eight layers of glass fabric laminates. Different layers of glass fabric were laid one over other by stacking sequence as $[0^\circ/ \pm45^\circ/ 90^\circ]_s$ 3 % Carbon nanotubes (diameters in nanometers) were mixed with epoxy for the fabrication of nano composites. Due to vacuum created by vacuum bagging technique, it promotes easy flow of excess epoxy and results in better wetting and accelerates the curing time. Surface of specimen having 0◦ fiber orientation direction was used to contact with steel disc for friction and wear test. Composite were cured at room temperature for 24 hrs and was prevented from damage from external environment.

Fig.1 Vacuum bagging process for manufacture of GFRP and GFRP mixed with Carbon Nanotubes

2.3 Tribological testing

Tribological behavior (wear analysis and coefficient of friction) were performed using pin on disc type tribological machine. Track diameter of 100mm has been used for all the sets of experiments. The loads and sliding velocities varied from 30 N to 90 N and 3.14 m/s(600 rpm) respectively. Weight of the specimen were taken before and after wear test with help of balance having least count of 0.01,all sets of experiments were conducted five times in the same manner and average weight loss was taken for calculation of specific wear rate. All the GFRP and Nano Composite specimens were cut to smaller pieces and glued to pin before carrying out experiment There were several other parameters such as increase in coefficient of friction, rise in temperature of disc, mark of abrasion were absorbed when machine was running under extreme load.

Oil used for lubricating disc was SAE20 with kinematic viscosity of 20-30cSt. Prior to every experiment disc surface was cleaned by rubbing with emery paper and washed with acetone. Further oil was poured at 0.05ml/min. In experiment 0.025 bar pressure was applied at rate of 1.5lit/min.

The specific wear rate was calculated by the given equation, $K_0(mm^3/Nm)=\Delta m/\rho Ld$ (1)

Where Δm is the weight loss in kg, ρ the density in kg/mm3, L the load in N and d the sliding distance in m(Table 1 &2).Coefficient of friction for different sliding conditions are shown in Table 3&4.

Table 1

Weight loss and specific wear rate for dry, oil lubricated environmental conditions sliding at 3.14 m/s with variable loads.

GFRP specimen $\rho=1.7842\times10^{-6}$ kg/mm^3 , N=600 rpm , ΔT=600sec , Track dia = 100 mm, v=3.14 m/s

LOAD (N)	WEIGHT LOSS (Δm) mg	SPECIFIC WEAR RATE (k_0)
Dry 30 N	1.9	2.10×10^{-5}
Dry 60 N	3.5	2.28×10^{-5}
Dry 90 N	7.8	2.59×10^{-5}
Oil 30 N	1.3	1.11×10^{-5}
Oil 60 N	2.2	1.42×10^{-5}
Oil 90 N	6.2	2.10×10^{-5}

Table 2

Weight loss and specific wear rate for dry, oil lubricated environmental conditions sliding at 3.66 m/s with variable loads.

Nano Composite(GFRP+CNT) specimen ρ= 0.923 g/cm^3, N=600 rpm , ΔT=600sec , Track dia = 100 mm, v=3.14 m/s

LOAD (N)	WEIGHT LOSS (Δm) mg	SPECIFIC WEAR RATE (k_0)
Dry 30 N	1.3	1.12×10^{-5}
Dry 60 N	1.9	1.54×10^{-5}
Dry 90 N	2.3	1.92×10^{-5}
Oil 30 N	1.1	1.00×10^{-5}
Oil 60 N	1.4	1.08×10^{-5}
Oil 90 N	1.9	1.43×10^{-5}

Table 3

Coefficient of friction for dry, oil lubricated environmental conditions sliding at 3.14 m/s with variable loads.

GFRP specimen $\rho=1.7842\times10^{-6}$ kg/mm^3 , N=600 rpm , ΔT=600sec , Track dia = 100 mm, v=3.14 m/s

LOAD (N)	COEFFICIENT OF FRICTION
Dry 30 N	0.200
Dry 60 N	0.220
Dry 90 N	0.310
Oil 30 N	0.060
Oil 60 N	0.068
Oil 90 N	0.120

Table 4

Coefficient of friction for dry, oil lubricated and inert gas environmental conditions sliding at 3.14 m/s with variable loads.

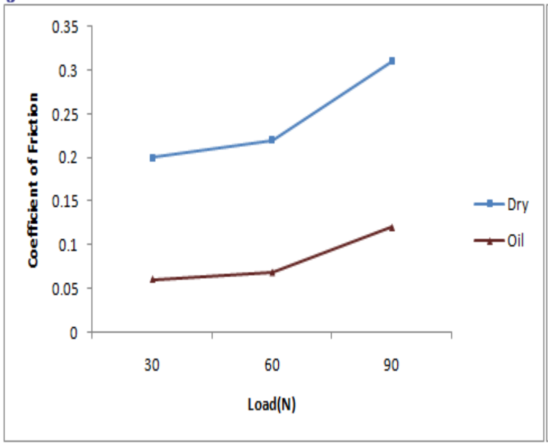
Nano Composite(GFRP+CNTs) specimen ρ= 0.923 g/cm^3, N=600 rpm , ΔT=900sec , Track dia = 100 mm, v=3.14 m/s

LOAD (N)	COEFFICIENT OF FRICTION
Dry 30 N	0.100
Dry 70 N	0.130
Dry 100 N	0.210
Oil 30 N	0.008
Oil 70 N	0.026
Oil 100 N	0.100

III. RESULTS AND DISCUSSION:

3.1. Coefficient of friction

The values of coefficient of friction of GFRP and GFRP doped with MWCNTs are given in Table 3& 4. The obtained results of coefficient of friction are plotted in Fig. 2 (a) & (b). The figure shows the deviations of coefficient of friction (average value taken at each situation) with load and velocity of sliding for two mediums under which the sliding had taken place for the GFRP and Nano Composites. Coefficient of friction increases with increase in load and sliding velocity for glass fiber reinforced composites. In GFRP composites angle of fiber does not significantly relate with coefficient of friction and medium of sliding. The values of coefficient of friction is comparatively very less in nano composites than GFRP thus mixing up of carbon nanotubes increases the mechanical properties of GFRP. In oil lubricated sliding the wear debris which get accumulated on the disc surfaces comes in between the composite and rotating disc and this soft debris prevents direct contact between fiber and disc thus results in lowering of coefficient of friction.



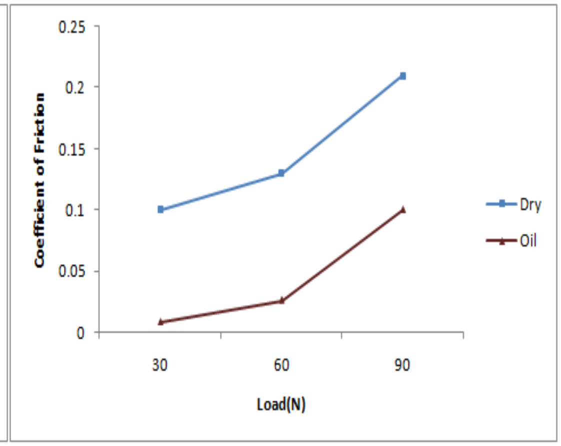


Fig 2(a): Coefficient of friction v/s Load of GFRP composite

Fig 2(b): Coefficient of friction v/s Load of (GFRP+MWCNT) composite

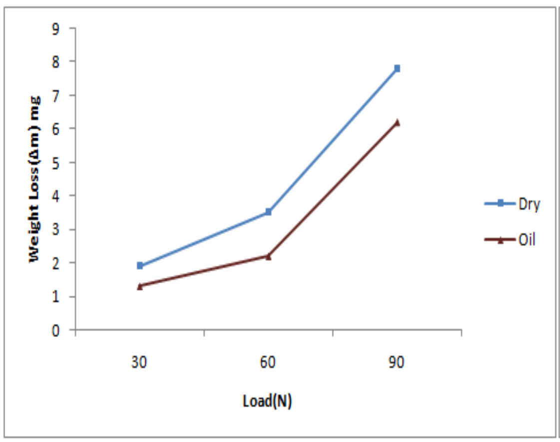
3.2. Wear studies

3.2.1. Weight loss and Specific wear rate

Fig 3 and 4 shows the weight loss and specific wear rate of GFRP and GFRP doped with MWCNTs composite. Weight loss and specific wear rate generally depends on the factors like normal load, sliding environment, sliding distance of specimens on rotating disc, and velocity of sliding. The effects of the variable normal load, sliding speed and sliding environment on the weight loss of GFRP and Nano Composites are shown in fig 3&4. The weight loss and specific wear rate in GFRP and Nano Composite specimens was measured at 3.14 m/s speeds and under 30N-90 N loads on the dry and oil lubricated sliding environment. The weight loss for all the composite specimens normally increased with the increase of normal loads for GFRP and GFRP+CNTs composites at constant sliding speeds of 3.14 m/s. However under both sliding environment weight loss in case of Nano Composites is comparatively less than GFRP specimen this is due to presence of CNTs which aligns radially around the existing glass fibers thus provides enhanced strength and toughness. The GFRP specimens show a lower coefficient of friction and lesser wear rate in oil lubricated medium, as compared with dry sliding environment. Due to this reason, the weight loss also becomes comparatively less for the same sliding distance.

Results obtained through experiment also show that temperature of specimen increases with increase in normal load and sliding velocity. From table 1& 2 it can be observed that the “loss of weight due to wear” is increased with increase in sliding velocity and normal loads. Due to thermal softening effect of epoxy matrix in GFRP composites because of rise in temperature, the matrix gets more softened attaining more depth i.e. softening of matrix in proportion to the increment in temperature, it was observed that the softened layers of matrix and the glass fibers embedded and gets separated from the surface of the specimen, as a result, the weight loss increased with an increase in load and sliding speed. In Oil lubricated sliding environment the decrease in specific wear rate and weight loss for both GFRP and Nano Composites is because of the formation of thin film of lubricant over the counter face of rotating disc i.e in oil lubricated sliding, the wear rate is reduced due to presence of softer epoxy resin body matrix in between layers of glass fibers. Initial wear of polymer mixes with absorbed lubricant on steel surface which acts as lubricant storage reservoir, due to which the protruding glass fibers pick up lubricant molecules to effectively and avoids direct contact between steel and fiber. Generally oil as a lubricating material minimizes the loss due to wear of GFRP and Nano Composites which is dependent on the quality of the transfer film and its adsorption on the metallic surface.

Value obtained from experiments shows that specific wear rate mainly depends on the load, velocity, density of matrix and sliding environment. Experimental data reveals that for both GFRP and GFRP+CNTs during oil lubricated sliding environment there is a considerable decrease of specific wear rate when compared with dry sliding environment. By observing the trend of specific wear rate, weight loss and nature of wear the wear mechanism of GFRP and Nano Composites can be classified in two groups such as the matrix wear(matrix plastic deformation, matrix cracking etc) and the fiber wear(Delamination of fiber, fiber cracking, fiber rupture, dislocation of fiber from its orientation etc).



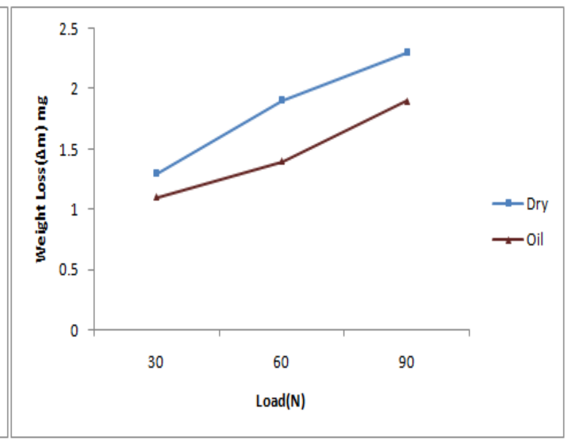
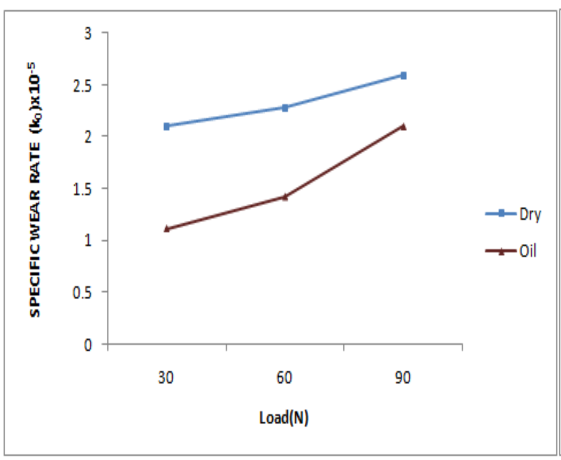


Fig 3(a): Weight Loss v/s Load of GFRP composite **F ig 3(b):** Weight Loss v/s Load of (GFRP+CNT) composite



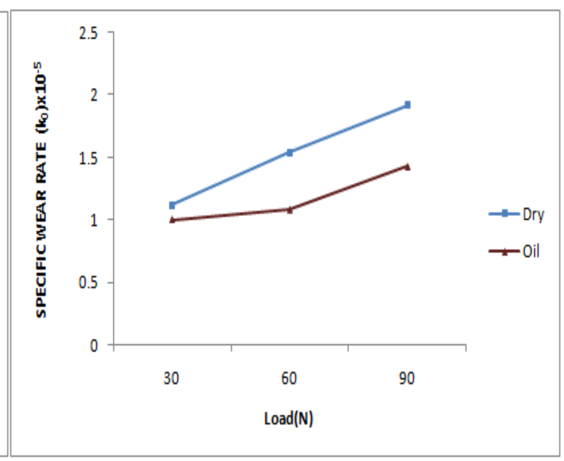


Fig 4(a): Specific wear rate v/s Load of GFRP composite **Fig 4(b):**Specific wear rate v/s Load of (GFRP+CNT) composite

3.2.2. FESEM analysis of worn surface

Worn surfaces of the composites after tribological testing on pin on disc machine were studied by FESEM analysis to understand and get insights into the process of wear and Delamination of fibers. Micrographs of surfaces of selected composites are shown in Fig. 5 at higher magnification (×500).

Damage of fiber and matrix increases with increase in normal load on fibers and it gives a correlation with wear rate. With the help of FESEM micrographs it is observed that stacking of fibers (which acts as wear resistance of composites) and fiber debris(responsible for high coefficient of friction and low wear resistance)diminished with increase in normal load. Delamination and dislocation of fibers in GFRP doped with MWCNTs composites is comparatively very less when compared with GFRP composites.

The effect of normal load and sliding environment i.e. dry environment and oil-lubricated environment up to the level of fiber damage in different mechanisms or up to a limit of deterioration in fiber–matrix bonding followed by fiber micro-cracking which leads to pulverization and removal in form of debris(which may be thrown out of the surface or may get embedded) in the matrix in random directions plays a significant role in change of wear rate and coefficient of friction which can be clearly observed in SEM micrographs.

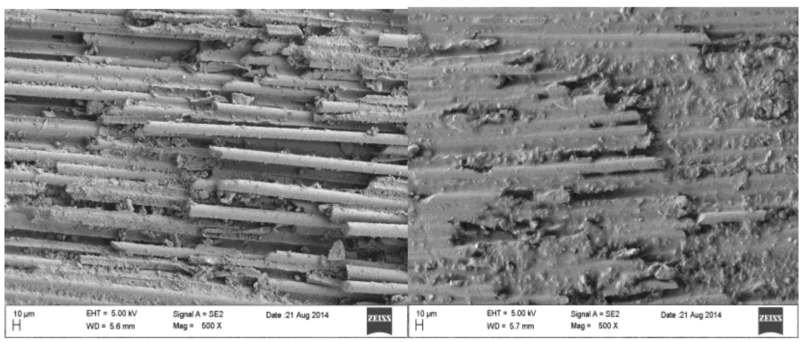


Fig 5(a): Worn surface of GFRP and GFRP doped with MWCNT sliding under Dry environment at 30N

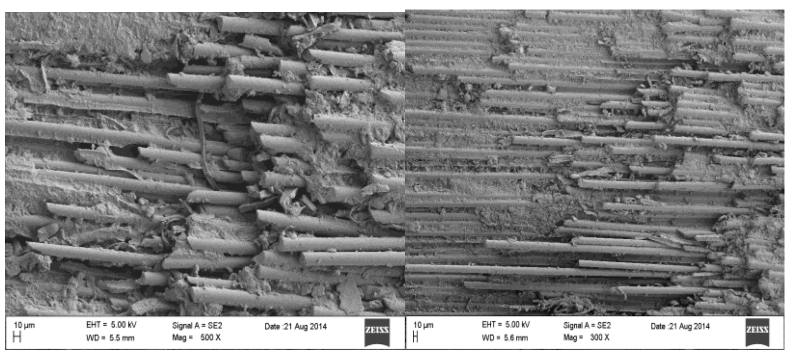


Fig 5(b): Worn surface of GFRP and GFRP doped with MWCNT sliding under Dry environment at 60N

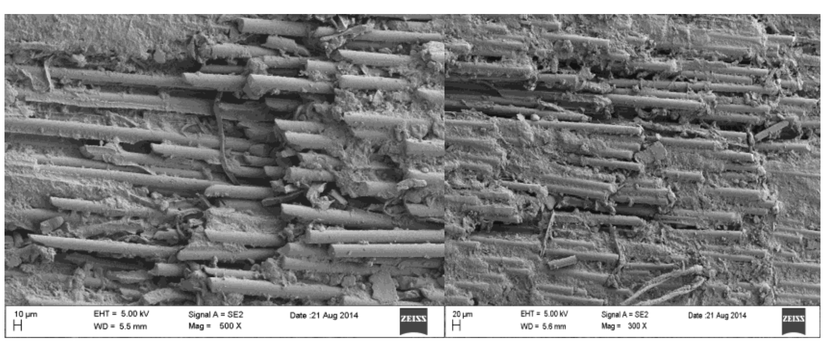


Fig 5(c): Worn surface of GFRP and GFRP doped with MWCNT sliding under Dry environment at 90N

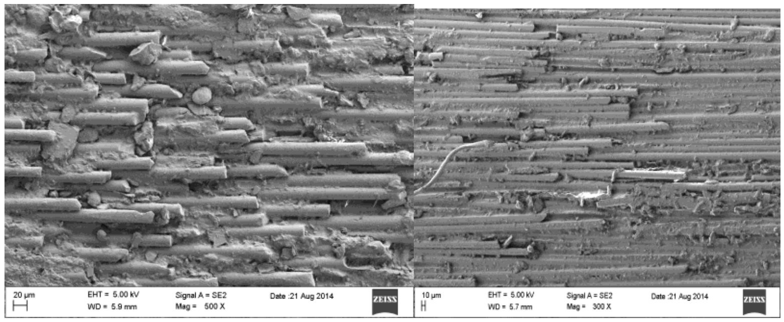


Fig 5(d):Surface of GFRP and GFRP doped with MWCNT sliding under Oil lub environment at 30N

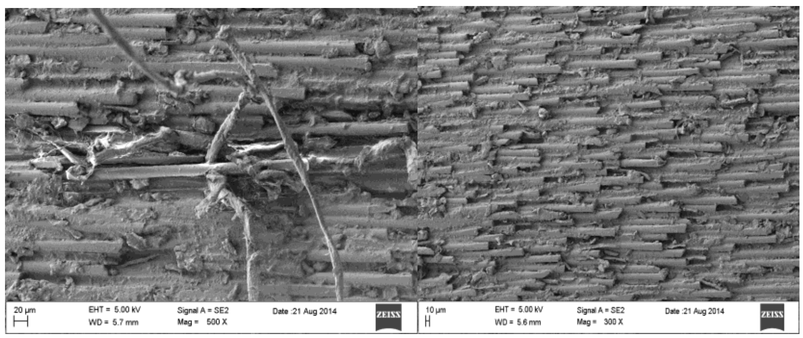


Fig 5(e):Surface of GFRP and GFRP doped with MWCNT sliding under Oil lub environment at 60N

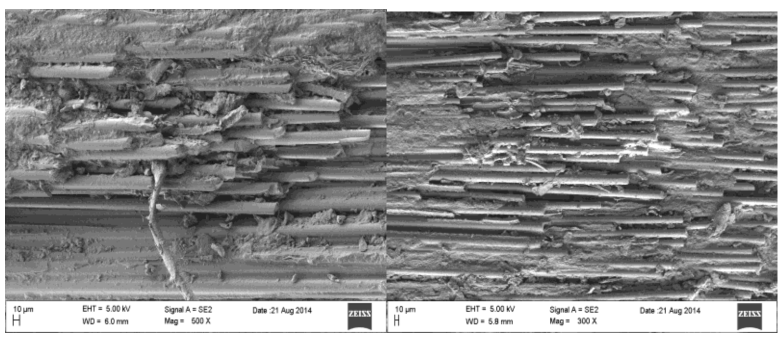


Fig 5(f): Surface of GFRP and GFRP doped with MWCNT sliding under Oil lub environment at 90N

IV. CONCLUSIONS

By the help of graph obtained from experimental data and FESEM micrographs the results obtained out of tribological testing of GFRP and GFRP doped with MWCNT composite the following conclusions can be drawn:

1. The coefficient of friction of the GFRP and GFRP doped with MWCNT tested was in the range of 0.2-0.3 sliding against steel under dry and oil lubricated environmental conditions.

2. Tribological behavior of a GFRP and GFRP doped with MWCNT composite material depends on variable loads, sliding velocity and sliding environment. For all values of normal loads and sliding velocities studied, the obtained values of coefficients of friction and wear rates for GFRP composites are greater as compared to GFRP doped with MWCNT composites.

3. Value of coefficient of friction in oil lubricated sliding environment for both GFRP and GFRP+MWCNTs is less because of formation of lubrication film in between two contacting surfaces. Debris which gets embedded in between laminates and rise in temperature while working at higher load also plays an important role in lowering the coefficient of friction.

4.Fibres of GFRP and GFRP doped with MWCNT composites sliding under dry sliding environment undergo shearing at the ends due to increase of normal load thus higher values of wear rate is obtained when compared with oil lubricated sliding environment. This can be clearly observed using FESEM micrographs

5. Lubricating oils with higher absorption capacity and high viscosity can play a vital role in decreasing the wear rate as they can easily form thin films in between two mating surfaces.

6. Wear rate for all the composite specimens increased with the increase of normal loads for GFRP and GFRP doped with MWCNT composites at constant sliding speeds of 3.14 m/s. However under both sliding environment weight loss in case of Nano Composites is comparatively less than GFRP specimen this is due to presence of CNTs which aligns radially around the existing glass fibers thus provides enhanced strength and toughness.

7. Mechanism of wear identified in the samples were adhesion and surface fatigue.

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