# Investigations of friction and wear in pultruded glass fibre epoxy composites

Piyush P. Gohil[1)]*, Hiral H. Parikh[2)], Vimal B. Patel[3)]

[1)] Professor and Head, Department of Mechanical Engineering, CSPIT-CHARUSAT, Gujarat, India - 388421
[2)] Assistant Professor, Department of Mechanical Engineering, DJMIT, Mogar, Gujarat, India – 388340
[3)] M.Tech Student, Department of Mechanical Engineering, CSPIT CHARUSAT, Gujarat, India - 388421
*Corresponding author: piyushgohil.me@charusat.ac.in

## *1.* Abstract

Polymer composites are well known for offering high strength-to-weight ratios and flexibility in material design. Physical properties of a composite can be satisfied various functional requirements of a target application, including stiffness and strength, thermal and electrical transport, and wear resistance. Composites are designed to fulfill several functions simultaneously. Friction and wear experiments of pultruded glass fibre epoxy composite (GFEC) were carried out at ambient conditions using Pin on disc (POD) machine arrangement. Tribological characterization of material determining wear and friction coefficient at different operating parameters. This paper outlines a methodology based on Taguchi's experimental design approach to make a parametric analysis of sliding wear and friction behaviour. The systematic experimentation leads to determination of significant process parameters that predominantly influence on the wear and friction co efficient.

**Key words:** composite, wear, friction, putrusion, pin on disk(POD)

## *2.* Introduction

Tribology is a language of engineers covering friction wear and lubrication science. Today it extends over the scientific fields of physics, chemistry, solid mechanics, fluid mechanics, heat transfer, materials science and lubricant [1]. In material selection and designing process tribology is very important element to be considered with physical and mechanical properties [2,3]. Wear is the progressive material loss from solid surfaces in contact which occurs as a result of friction. Most of failure occurred in designed component is due to wear progress during operation [4]. Friction is the resistance to motion whenever one solid body moves over another. It is one of the oldest problems in physics and is of great practical importance in many of the industrial operations .Therefore, attention has been paid by many engineering designers in investigation the friction and wear behaviour of materials under different operating parameters like applied load, sliding distance and sliding speed, etc [5,6].

Fiber reinforced polymer(FRP) composites which have been established as the one of the most promising modern materials to replace conventional metals and alloys in numerous structural and tribological applications. FRP materials developed using thermoplastic and thermosets as matrices, natural and synthetic fibres as reinforcements and organic and inorganic materials as fillers. They have tremendous potential owing to their high strength-to-weight ratio, tailoring potential and resistance to wear, corrosion and impact. Synthetic fibers such as glass, carbon, aramid, etc [7], have been used largely with both thermoset and thermoplastic to develop FRP materials.

Polymer matrix composite(PMC) reinforced with discontinuous, continuous and woven fabric of fibers have always been considered as good structural materials [8]. PMC are promising as tribological materials because of their inherent properties such as self-lubrication, low cost, lightweight, quiet operation, better friction properties, ease of fabrication and resistance to wear, corrosion and organic solvents. They are used as seals, bearings, gears (low fabrication, low wear), conveyer belts (low wear), turbine or pump blades (low wear), brakes, tyres (low wear and moderate friction), dental applications (low wear) and hip replacements in which the substitute material should have low wear and low friction coefficient. Based on type (short fiber, unidirectional long fiber, woven fabric), content and orientation (parallel, anti- parallel and perpendicular to sliding direction) of fibrous reinforcement, the wear resistance of composites materials is either enhanced or lowered. Appropriate filler along with fiber reinforcement generally reduces the wear rate, increases the thermal conductivity and creep resistance and modifies the wear mechanism including interfacial wear phenomena. There are number of investigations exploring the influence of test conditions, contact geometry and environmental condition on the friction and wear behavior of polymers and composites [9, 10].

Many of the researchers have carried out no. of experiments using hand layup and resin transfer moulding (RTM) techniques which has restriction for fibre volume fraction. While in pultrusion we can achieve higher fibre volume fraction. Pultrusion is a continuous process for manufacturing of composite materials with constant cross-section. Reinforced fibers are pulled through a resin, possibly followed by a separate pre forming system, and into a heated die where the resin undergoes polymerization. Many resin types may be used in Pultrusion including polyester, polyurethane, vinyl ester and epoxy. Pultrusion is a continuous, automated closed-moulding process that is cost effective for high volume production of constant cross section parts. Due to uniformity of cross-section, resin dispersion, fibre distribution, excellent composite structural materials can be fabricated by Pultrusion [11]. The basic process usually involves pulling of continuous fibres through a bath of resin, blended with a section is partially pre-shaped and excess resin is removed. It is then passed through a heated die, which determines the sectional geometry and finishing of the final product.

### *3. Research review*

Friction and wear behaviour of GFEC were reviewed and results shows that in general, friction and wear are strongly influenced by all the test parameters such as applied load, sliding speed, sliding distance and fiber orientations [12]. Pihtili and Tosun [13] shows that applied load and sliding speed play significant role on the wear behavior of polymer and composites. They also show that applied load has more effect on the wear than the speed for composites. Several authors [14] observed that the friction coefficient of polymers and its composites rubbing against metals decreases with the increase in load though some other researchers have different views. Stuart [15] and other researchers show that value of friction coefficient increases with the increase in load. Friction coefficient and specific wear rate values for different combinations of polymer and its composite were obtained and compared by Mimaroglu A. in [16].

### *4.* Material and methods

Pultruded glass fibre epoxy composite (GFEC) rod 12 mm in diameter was procured. It has 75% glass fibre and unidirectional fibre orientation. Test pins were cut from pultruded rod where each has 32 mm length. Both top and bottom surface were produce by grinding and polishing as shown in fig.1. The Tribometer uses a POD system to measure wear (fig.2). The unit consists of a gimballed arm to which the pin is attached, a fixture which accommodates disks up to 165 mm in diameter & 8 mm thickness, an electronic force sensor for measuring the friction force, and a computer software (on Lab view platform) for displaying the parameters, printing, or storing data for analysis. Users have to specify the turntable speed, the load, and any other desired test variables such as time limit and number of rotations.

#### Test Parameters

Load (L)—Values of the force in Newton's at the wearing contact.
Speed (N) — the relative sliding speed between the contacting surfaces in metres per second.
Sliding Distance (SD) — the accumulated sliding distance in meters.
Temperature— temperatures of one or both specimens at locations close to the wearing contact.

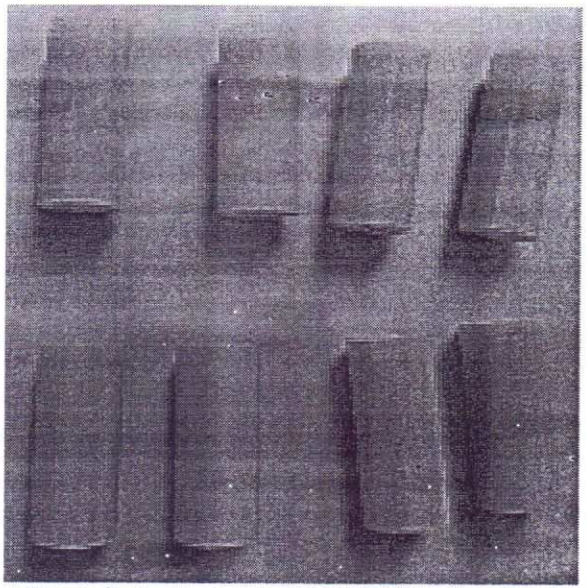

*Figure 1 pin of pultruded GFEC (75% glass fibre)*

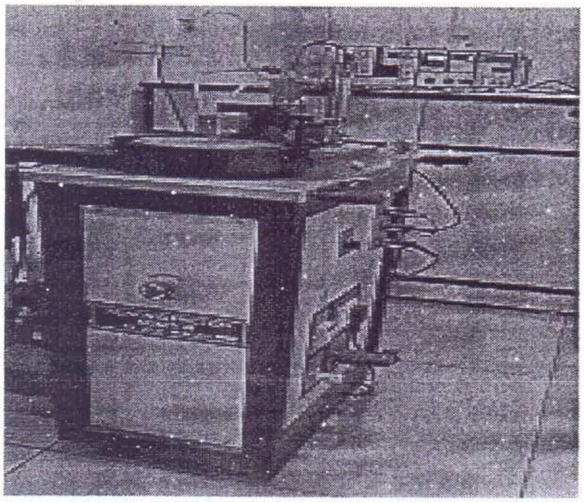

*Figure 2 pin on disk (POD) test machine*

*Table 1 Process Parameters with their values at four levels*

| Parameter | Level1 | Level2 | Level3 | Level4 |
|---|---|---|---|---|
| Sliding dist. (m) | 1000 | 1500 | 2000 | 2500 |
| Load (kg) | 1 | 2 | 3 | 4 |
| Speed(rpm) | 500 | 750 | 1000 | 1250 |

*Table 2 experimental conditions*

| | |
|---|---|
| Material of pin | Glass fibre with epoxy resin |
| Fibre content | 75% |
| Fibre orientation | Unidirectional |
| Pin length and diameter | Length 32mm, dia 12 mm |
| Density | 2.6(gm/cm$^3$) |
| Environment condition | Dry |
| Experiment time | 600 sec |

### *4.1 Experiment design*

The most important stage in the design of experiment lies in the selection of the control factors. In this work by using Minitab 16 software, three factors and four levels, (shown in Table 1) are selected to build a proper orthogonal array for Taguchi experiments. Since, conventional full factorial experiment design would have required $4^3 = 64$ runs to study three factors each at four levels. As per Taguchi methodology it reduces to 16 runs, and from the L16 orthogonal array 16 experiments are required. In this Taguchi design and no interaction is incorporated [17]. The experimental observations are transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of characteristics. The S/N ratio for minimum wear rate is (smaller-the-better) characteristic, which can be calculated as logarithmic transformation of the loss function as shown below *Smaller-the-better characteristic:*

$$\frac{s}{n} = -10\log\frac{1}{n}\sum_{i=2}^{n} y^2 \qquad (1)$$

Table 3 $L_{16}$ orthogonal array based on taguchi design

| SD(m) | L(kg) | N (rpm) |
|---|---|---|
| 1000 | 1 | 500 |
| 1000 | 2 | 750 |
| 1000 | 3 | 1000 |
| 1000 | 4 | 1250 |
| 1500 | 1 | 750 |
| 1500 | 2 | 500 |
| 1500 | 3 | 1250 |
| 1500 | 4 | 1000 |
| 2000 | 1 | 1000 |
| 2000 | 2 | 1250 |
| 2000 | 3 | 500 |
| 2000 | 4 | 750 |
| 2500 | 1 | 1250 |
| 2500 | 2 | 1000 |
| 2500 | 3 | 750 |
| 2500 | 4 | 500 |

Equations

$$\text{Sliding distance(SD)} = \frac{\pi DNt}{60000}\,(\text{m}) \qquad (2)$$

$$\text{co-efficient of friction}(\mu) = \frac{ff}{fn} \qquad (3)$$

$$\text{wear rate}(W_r) = \frac{\text{wear} \times \pi \times (D^2)}{4 \times \text{load} \times \text{SD} \times \text{time}}\,(\text{mm}^3/\text{Nm}) \qquad (4)$$

### *5. Results and discussion*

The experiments were conducted with an aim of relating the influence of sliding speed (N), applied load (L) and sliding distance (SD) on wear and friction of GFEC. To evaluate the friction and sliding wear performance, wear tests were carried out on POD type friction and wear monitoring test ring (DUCOM) as per ASTM G 99. The counter disc body is made of hardened ground steel (EN-32, hardness 72 HRC, surface roughness 0.7 µ Ra). The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism.

During the test, friction force was measured by transducer mounted on the loading arm. The friction force readings are taken as the average of 60 readings for every 60 seconds. For this purpose a microprocessor controlled data acquisition system is used. On conducting the experiments as per the orthogonal array, the dry sliding wear results for various combinations of parameters were obtained and shown in Table 4.

*Table4 observed data from POD*

| SD (m) | L (kg) | N rpm | W (microns) | $f_f$ (N) |
|---|---|---|---|---|
| 1000 | 1 | 500 | 27 | 0.4 |
| 1000 | 2 | 750 | 59 | 4.4 |
| 1000 | 3 | 1000 | 110 | 16.6 |
| 1000 | 4 | 1250 | 52 | 20 |
| 1500 | 1 | 750 | 29 | 1.1 |
| 1500 | 2 | 500 | 39 | 2.4 |
| 1500 | 3 | 1250 | 121 | 14 |
| 1500 | 4 | 1000 | 70 | 18.1 |
| 2000 | 1 | 1000 | 17 | 3.8 |
| 2000 | 2 | 1250 | 87 | 13.8 |
| 2000 | 3 | 500 | 58 | 7.6 |
| 2000 | 4 | 750 | 98 | 20 |
| 2500 | 1 | 1250 | 41 | 3.2 |
| 2500 | 2 | 1000 | 80 | 6.7 |
| 2500 | 3 | 750 | 46 | 9.8 |
| 2500 | 4 | 500 | 125 | 10 |

*Table5 calculated result after test*

| SD (m) | L (kg) | N (rpm) | $W_r(10^{-5})$ ($mm^3/Nm$) | µ |
|---|---|---|---|---|
| 1000 | 1 | 500 | 0.46 | 0.04 |
| 1000 | 2 | 750 | 7.28 | 0.22 |
| 1000 | 3 | 1000 | 5.01 | 0.56 |
| 1000 | 4 | 1250 | 1.174 | 0.51 |
| 1500 | 1 | 750 | 0.12 | 0.11 |
| 1500 | 2 | 500 | 0.16 | 0.12 |
| 1500 | 3 | 1250 | 5.46 | 0.48 |
| 1500 | 4 | 1000 | 3.44 | 0.46 |
| 2000 | 1 | 1000 | 4.503 | 0.39 |
| 2000 | 2 | 1250 | 7.26 | 0.7 |
| 2000 | 3 | 500 | 0.2 | 0.26 |
| 2000 | 4 | 750 | 0.11 | 0.51 |
| 2500 | 1 | 1250 | 8.68 | 0.33 |
| 2500 | 2 | 1000 | 0.13 | 0.34 |
| 2500 | 3 | 750 | 9.2 | 0.33 |
| 2500 | 4 | 500 | 0.42 | 0.25 |

Table 5 shows calculated wear rate and co-efficient Of friction after the test conducted. here wear rate in terms of height loss which is calculated by the equation[4].

### *5.1 Effect of operating parameters on friction.*

Co efficient of friction for glass epoxy composites were tested under normal loads of 1, 2, 3 and 4 (kg), sliding distance of 1000,1500,2000, and 2500 (m) and speed 500 ,750, 1000 and 1250(rpm) are shown in fig 3 and fig 4 .

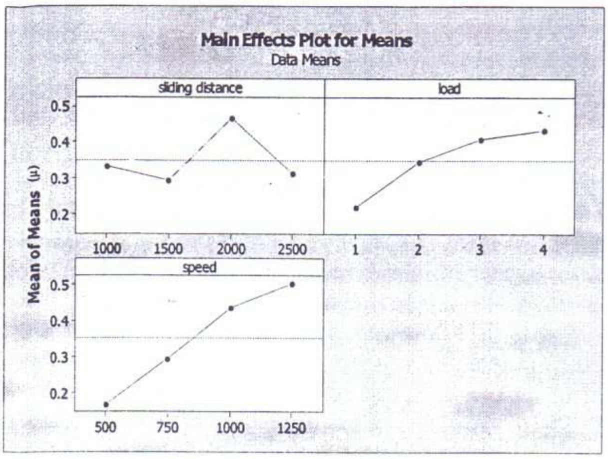

*Figure 3 means plots for parameter v/s friction co-efficient(μ)*

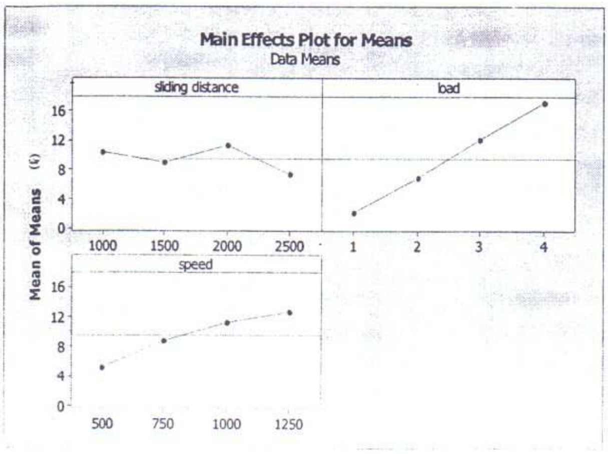

*Figure 4 means plots for parameter v/s friction force ($f_f$)*

Results show that the coefficient of friction increases with an increase in applied normal load under dry sliding condition. The maximum coefficient of friction was found for epoxy composites at sliding speed of 1250 rpm and applied normal load of 20N and minimum at sliding speed of 500 rpm and applied normal load of 10N. It is observed that coefficient of friction increases with increase in sliding speed under both dry conditions. At initial stage, friction force is low due to contact between superficial layer of pin and disc and then, friction coefficient increases due to ploughing effect which causes roughening of the test disc surface. The increase in friction coefficient with the increase in normal load is due to the detachment and removal of worn materials and more contact with reinforced fibers. Higher the normal load time to reach constant friction is less due to the fact that the surface roughness and other parameters attain a steady level at shorter period with the increase in normal load. When the applied normal load increases to the limit load values of the polymer the friction will increase due to the critical surface energy. These findings are in agreement with the findings of Nuruzzaman D.M., Chowdhury M.A [18].

Further it can be explained as the frictional power increases the temperature of the steel surface which leads to relaxation of polymer molecule chains and bond at fibre-matrix gets weakened. As a result, fibres are broken into fragments and form debris with matrix particles. At starting of the rubbing, the value of friction coefficient is low which increases for few minutes to a certain value and then decreases almost linearly over some duration of rubbing and after that it remains constant for the rest of the experimental time. In these cases, transfer film formed on the stainless steel couterface and the transfer film has important effects on the tribological behaviour of a material.

Friction behaviour of polymer sliding against a metal is strongly influenced by its ability to form a transfer film on the counterface .The transfer film formed on a non-polymer counterface is controlled by the counterface material, roughness, and sliding conditions.

Comparison of the variation of friction coefficient with sliding speed for different materials. Results show that friction coefficient increase almost linearly with sliding speed. With the increase in sliding speed, the frictional heat may decrease the strength of the materials and high temperature results in stronger or increased adhesion with pin. The increase of friction coefficient with sliding speed can be explained by the more adhesion of counterface pin material on disc.

### 5.2 Effect of operating parameters on wear.

Wear rate for GFEC tested under normal loads of 1, 2, 3, and 4 (kg), sliding distance of 1000,1500,2000,and 2500 (m) and speed 500 ,750, 1000 and1250(rpm) are shown in fig 5. Fig 6 shows wear in microns measured from POD.

*Figure 5 plots for parameter v/s wear rate ($w_r$)*

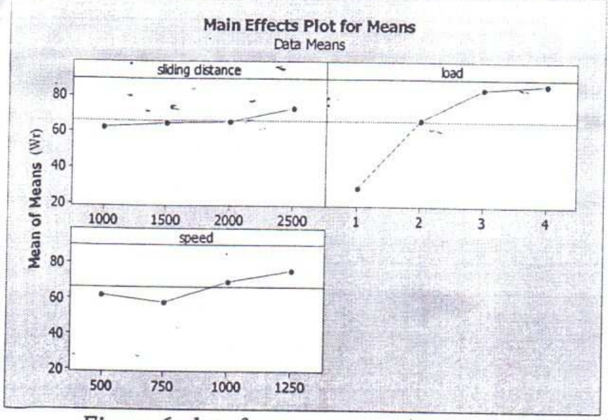

*Figure 6 plots for parameter v/s wear (w$_r$)*

wear rate with normal load for GFEC are shown in Fig. 5. This figure indicates that wear rate increases with the increase in normal load up to 30N. The shear force and frictional thrust are increased with the increase in applied load and these increments accelerate the wear rate at initial stage then wear rate decrease. At higher load it shows less specific wear rate. Hence these composites have good wear properties at higher loads. Here in figure 5 wear in microns are increasing with increasing load and speed.

At low load, frictional heat generation is low resulting in less extent of back transfer polymer film into the composite pin. In Fig. 5 shows that at higher load larger frictional heat generation resulted in large extent of back transfer patches of polymer film, which were intermittently spread over the surface and shield the composite surface from further damage. This may explain the improvement in wear resistance at higher load. Secondly, at higher load the relatively soft non-abrasive GF were exposed to a larger extent of transfer film of polymer on the metal counterface. Thus, the increasing wear resistance with increasing the load could be possibly due to formation of a fibre-rich surface.

It is also noticed that under dry sliding condition the specific wear rate increase with increase in sliding speed shown in figure 5. At high speed fatigue effects and frictional heating are intensified causing a strong surface damage in the form of fibre pull-outs and matrix fracture, resulting in very high wear rate. High rotation speeds also intensify the debris removal by centrifugal forces avoiding the formation of protective layers in open tribological systems. At lower sliding speeds there are minimum value in specific wear rates. It is highly dependent on the film generated on the counterface. If the film transfer is smooth and adhered well on the counterface, the steady state can be achieved. Meanwhile, if the film transfer is rougher than the counterface and/or not adhered well on the counterface then increase in the material removal can be noticed at longer sliding distance. These findings are in agreement with the findings of Mimaroglu [16].

*Table 6 Response table for signal to noise ratios*

| Level | SD | L | N |
|---|---|---|---|
| 1 | -6.42 | -1.66 | 11.04 |
| 2 | 2.21 | -0.20 | 0.26 |
| 3 | 0.71 | -8.50 | -5.09 |
| 4 | -3.19 | -3.64 | -13.01 |
| Delta | 8.68 | 12.15 | 24.07 |
| Rank | 3 | 2 | 1 |

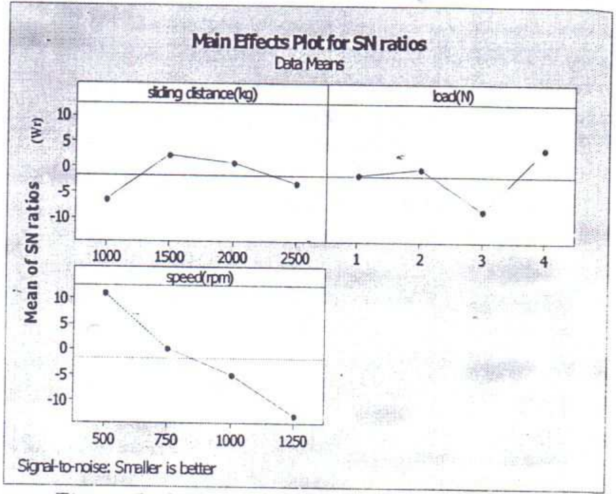

*Figure 7 plots for parameter v/s wear rate (W$_r$)*

Table 6 shows The S/N ratio response, from which concluded that among all the factors, sliding speed is most significant factor affecting the wear rate of GFEC. Figure 7 shows s/n cure for wear rate, analysis of the results also conclude that factor combination of SD (1500m), L (4kg) and N (500rpm) gives minimum specific wear rate.

## *6.* Conclusions

From the experiment, it is concluded that increase, decrease or stabilization of co-efficient of friction and wear, depends on formation of thin polymer film during process.

Friction coefficient increases with increasing load and speed (rpm). For sliding distance it increase up to 30N, then friction co-efficient decrease. This may be due to formation thin film.

Wear rate also increasing with increasing speed and sliding distance. Also observed that at higher load GFEC provides good wear resistance.

The current trends of these experimental and analytical results can be used in future to design different tribological and mechanical components. The researchers can use these results to innovate some design strategies for improving different concerned mechanical processes. It is expected that the research findings of tribological behaviour of polymer and composites discussed in this paper will also be used for future research and development.

### Nomenclature

| Parameter | Particulars | Units |
|---|---|---|
| W | Wear | µm |
| $w_r$ | Wear rate | $mm^3/Nm$ |
| $f_f$ | Friction force | N |
| µ | Co-efficienf of friction | - |
| SD | Sliding distance | m |
| L | Load | kg |
| D | Track diameter | mm |
| N | Speed | rpm |
| T | Time | sec |

## 7. References

[1] Bhushan B. and Gupta B.K. "Handbook of Tribology: Materials, Coatings and Surface Treatments" McGraw-Hill, New York (1991); Reprinted with corrections, Krieger Publishing Co., Malabar, Florida.1997

[2] Yousif B.F, Nirmal U, Wong K.J., "Three-body abrasion on wear and frictionalperformance of treated betelnut fibre reinforced epoxy (T-BFRE) composite" Material and Design 2010;31(9):4514–4521.

[3] Ben Difallah, "Mechanical and Tribologicai Response of ABS Polymer Matrix Filled with Graphite Powder" Material and Design 2012;34:782–787.

[4] El-Tayeb N.S.M, Yousif B.F, Yap T.C, "An investigation on worn surfaces of chopped glass fibre reinforced polyester through SEM observations" Tribology International 2008; 41(5):331–340.

[5] Bansal D.G, Streator J.L, "Corrigendum to a method for obtaining the temperature distribution at the interface of sliding bodies"Wear 2011. http://dx.doi.org10.1016/j.wear.2008.08.019 [Wear, 2009; 266: 721–732].

[6] Narish S, Yousif B.F, Rilling D, "Adhesive wear of thermoplastic composite based on kenaf fibres" Proc Institute of Mechanical Enginering J: J English Tribology 2011;225(2):101–9.

[7] Xue Q, wang Q, "Wear mechanisms of polyetheretherketone composites filled with various kinds of SiC." Wear, Vol. 213,1997, pp. 54-58

[8] Zhang, S. W, "State-of-the-art of polymer tribology"Tribology International,1998; 31 (1–3): 49–60.

[9] Tanaka K., "Transfer of semicrystalline polymers sliding against smooth steel surface"Wear 1982; 75: 183 – 199.

[10] Bahadur S. and Tabor D., "Role of fillers in the friction and wear behavior of highdensitypolyethylene" In: Lee LH, editor. Polymer wear and its control. ACS Symposium Series, Washington DC 1985: 287: 253–268.

[11] Kendall K.N., Rudd C.D., Owen, M.J. and Middleton, V., "Characterisation of the resin transfer moulding process" Composites Manufacturing 3(2),1992, 235–249,.

[12] El-Tayeb N. S. M., Yousif B. F., and Yap T. C. "Tribological studies of polyester reinforced with CSM 450-R-glass fiber sliding against smooth stainless steel counterface" Wear, 2006; 261:443-452.

[13] Pihtili H. and Tosun N., "Investigation of the wear behavior of a glass fiber-reinforced composite and plain polyester resin" Composites Science and Technology, 2002; 62:367-370.

[14] Anderson J.C., "The wear and friction of commercial polymers and composites,"In: Friction and wear and polymer composites. Friedrich K,editor. Composite materials series, vol. 1. Amsterdam: Elsevier 1986; 329–362.

[15] Stuart B. H., "Tribological studies of poly(ether ether ketone) blends" Tribology International 1998; 31(11): 647–651.

[16] Mimaroglu A., Unal H., and Arda T., "Friction and wear performance of pure and glass fiber reinforced Poly-Ether-Imide on polymer and steel counterface materials" Wear 2007; 262: 1407 – 1413.

[17] Glen S.P., "Taguchi methods: a hand on approach" Addison-Wesley: NY. 1993.

[18] Nuruzzaman D.M., Chowdhury M.A., and Rahaman M.L., "Effect of Duration of Rubbing and Normal Load on Friction Coefficient for Polymer and Composite Materials" Industrial Lubrication. and Tribology 2011; 63: 320 – 326.