Friction and Wear Properties of Polymeric Composite Materials for Bearing Applications

N.Hariprasad[1], M.S.Yogeswaran[2], K.Girirajan[3], V.Raviraj[4]
[1,2,3] *Department of Mechanical Engineering, Sri Sairam Engineering College, Chennai*
[4] *Associate Professor, Sri Sairam Engineering College, Chennai*

Abstract- **This paper presents a study of the tribological properties of two locally developed polymeric composite materials for bearing applications. Unidirectional reinforcements by linen and jute fibres are used, each in turn, in unsaturated polyester resin. Friction and wear tests are carried out, in dry conditions, on a pin-on-disc machine. The experimental results, backed by scanning electron microscope examination, revealed that the reinforcement volume fraction as well as orientation has considerable effect on the friction and wear of polyester composites. An increase of fibre volume fraction to 33% increased the coefficient of friction of the tested material by about 14% and decreased its wear rate by about 95% at both low and high values of pressure velocity product (PV limit) when the fibres were oriented normal to the specimen surface. The same increase in volume fraction of the fibres when oriented in the longitudinal and transverse directions resulted in almost the same increase in the coefficient of friction (16%) while the wear rate decreased only by 65% at low PV value. For the same orientations at high PV value, the results showed no significant effect on the coefficient of friction while the wear rate decreased by 72%.**

Index terms- **Friction and wear; Tribological properties; Polymeric composites; Bearing applications**

.I INTRODUCTION

Recent reports on the shortage of metals have encouraged many scientists to look for new and alternative non-conventional materials [l-3]. Among these, composites and fibre reinforced polymeric materials were the most attractive. One advantage which encouraged research workers to focus on composites is the diverse range of mechanical and tribological properties that can be obtained using different types of reinforcements in different orientations with different volume fractions.

In bearing applications several polymer-based fibre-reinforced composite materials are now in use. However, the ease of manufacturing has always tempted scientists in different parts of the world to try locally available inexpensive fibres. The attempts to utilize composite materials always raise the question “why shouldn’t it be locally manufactured. This leads to another question concerning the suitability of locally available fibres for reinforcement purposes and to what extent they satisfy the specifications of good reinforced-plastic bearing material. The present work represents an attempt to produce and evaluate the characteristics of an alternative material using locally available textile fibres in Egypt, for sliding bearing applications

II. EXPERIMENTAL DETAILS

A. Materials

Unsaturated polyester, resin type Eterset 2504 APTS, manufactured by Eternal Chemical Co. Ltd. is used as a matrix material. It has, among other advantages, low pressure moulding capabilities which make it particularly valuable for large component manufacture at relatively low cost compared with other thermosetting resins. Methyl ethyl ketone peroxide (55% concentration) is used as a catalyst with 1 wt. % Peroximon Kl hardener. Two types of fibres, locally produced and commercially available, namely linen and jute, are used as fibrous reinforcement to develop the linen fibre-polyester composite (LF-PC) and the jute fibre-polyester composite (JF-PC).

The reinforced polyester composite specimens are fabricated by the open moulding (casting) process following the main principles adapted by Abdel-Aziz [17] and Aggag [18]. In order to ensure the reliability and reproducibility of the results obtained, it is necessary to fabricate all specimens under the same conditions. For this reason, a long rod was fabricated in each cast to get various types of specimens from the same rod. Details of the mould used and the method to set a certain volume fraction are given by Aggag [18]. Fibre volume fraction percentages used are 5, 12, 21 and 33% for linen and 13 and 15% for jute.

B. Test specimens

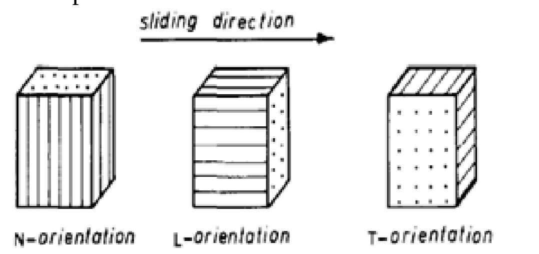


Fig.1 Test specimens with three fibre orientations

Test specimens are prepared from the two fabricated composite materials. For each percentage of fibre volume fraction three types of test specimens are prepared to satisfy the three orientations illustrated in Fig. 1. All specimens are cut from their corresponding rods and sized in cuboidal geometry by polishing using emery papers, with water as a coolant, to eliminate possible heat effects on specimen structure. The final size is 3 mm X 5 mm X 15 mm.

C. Instrumentation

Friction and wear tests were carried out using a conventional pin-on-disc machine [19]. The design ensures two salient features, namely the provision of wide range of sliding velocities encountered in practice and the precise measurement of the tangential frictional force during the tests. The first is achieved through the use of a variable speed DC motor. The disc rotating speed could be controlled within ±2 rev/min in a speed range of 200-500 rev/min, hence the sliding velocity, using a feedback control unit to guarantee constant speed irrespective of torque variations. The second feature is ensured by using a high precision force measuring system which consists of a strain gauge load-cell of nominal maximum capacity of 0.2 KN and a digital strain indicator set to read with a resolution of 0.02 N. The load cell is calibrated against a secondary standard force transducer.

D. Test procedure

Wear and friction tests are carried out using a counter face disc machined from a 57 HRC steel plate to an outer diameter of 150 mm and a thickness of 19 mm. The disc is polished resulting in a surface roughness of 0.15 pm (CLA). On average, a running-in period of about 20 min was observed before the steady state value of the coefficient of friction corresponding to the specific volume fraction/fibre orientation under consideration was reached and the reading was recorded. Each recorded value is the average result of at least five tests on the same volume fraction/fibre orientation. Tests are carried out on specimens of the two composite systems developed, in dry conditions, at low and high energy values (pressure-velocity (PV) product) [20]. This limit (Fig.2) in a given environment enables the designer to determine the limiting operating conditions, i.e. the applied load, sliding speed and temperature. Two values for PV are chosen, namely 0.61 MPa m/s (low PV) and 1.65 MPa m/s (high PV) and plotted in Fig. 2 relative to the curve representing the PV limit of polyester.

III. PROPERTIES AT LOW AND HIGH PV-VALUE

A. LF-PC friction coefficient at low PV value

Shows the variation of the coefficient of friction U with the volume fraction V_f of the LF-PC tested at low PV value in the three fibre orientation directions.

The standard deviation of each one of the plotted values varied between 0.020 and 0.039. In the case of normal orientation (N) the figure shows a slight increase of coefficient of friction (UN) as the fibre volume fraction (V_f) increases. This increase may be accounted for by the assumption that the adhesion junctions formed on the surface require higher frictional force for shearing since the fibres are deeply embedded in the matrix material.

In the longitudinal orientation (L), UL decreases steadily as V_f increases up to a value of about 12.5% then it reaches almost a constant value indicating that this is a threshold value of UL. The decrease in VL at lower values of V_f may be due to the relative ease of detachment of the outer layer of the fibres from the matrix when compared with the UN, since the fibres in this case are parallel to the sliding direction and sliding surface.

The coefficient of friction UT in the transverse direction also exhibits a similar behaviour to that in the L-orientation case. The decrease in UT at the beginning can also be attributed to the ease of detachment of the fibres from the matrix. The initial decrease of the friction coefficient UT, at the lower values of Vf is almost equal to the decrease in UL. This may be explained as follows; when the fibre-rich surface increases in the contacting area, the friction coefficient may decrease. This is shown clearly in the figure, where UN is greater than UL and UT. Similar results were previously obtained with cotton-polyester composites [1l] and with Kevlar-epoxy composites [5].

B. LF-PC wear rate at low PV value

The standard deviation of each of the plotted values varied between 0.48 X l0-8 and 7.65 X l0-8 g cm-1. The figure indicates a clear tendency of wear rate to decrease with the increase in fibre volume fraction in the three cases of fibre orientations.

In the case of N-orientation fibres, the wear rate (WN) decreases as Vf increases. The decrease in WN is considerable up to a value for fibre volume fraction Vf of about 12.5% after which WN remains nearly constant. The difficulty of extracting the long fibres from the bulk material in the N-orientation seems to be the main reason for the decrease of the wear rate. The fibres with this orientation are clearly in the best position to resist detachment from the bulk materials [21].

The delamination theory of wear proposed by Suh [22] could also explain this fact where, generally, the harder asperities of the mating surface exert surface traction on the softer surface, causing plastic shear deformation which accumulates with repeated loading. Cracks are initiated, and then propagate by further loading, and finally long and thin sheared wear sheets delaminate. In the case when fibres are oriented normal to the sliding surface and the sliding direction, the fibres diminish the crack propagation process under loading, and this could well be a reason for the wear rate diminishing by this considerable amount [5]. In addition, the possible formation of a fibre-rich surface protects the contacting surface and diminishes the wear rate of the matrix.

In the present experiments, the fibres do not instantaneously break, owing to their flexibility, but bend and become inclined to the direction of the sliding while still attached to the bulk. This process results in a fibre-rich surface at the sliding interface. Moreover, polyester, which is more brittle, breaks when friction forces are applied. This causes an increase in the percentage of fibres on the contact surface, and consequently a decrease in the overall wear rate. Scanning electron microscope (SEM) results support such explanation. SEM photographs of the worn surface of normal oriented specimens with different Vf are shown in Figs. 5 and 6.

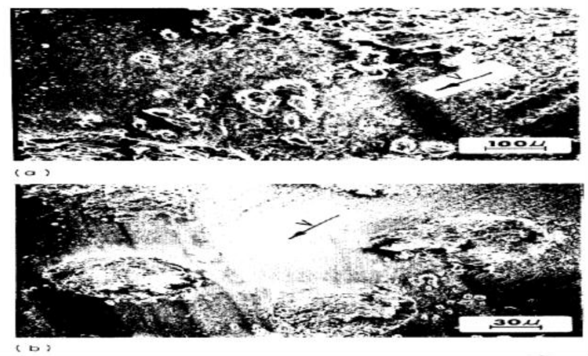


Fig.2 SEM micrograph of worn surface of 12% LF-PC (N-oriented) at low PV value

A fibre-rich surface is shown to be formed in both cases. Fig.5 shows the wear tracks ploughed by the hard asperities of the mating surface and fibre shearing.

Fig. 6 shows also wear tracks and the plastically deformed matrix. The particles of wear formed, shown in Fig. 2, are larger than those in Fig.6. This observation is consistent with the results above where wear rate decreases with increasing Vf. The figure also shows a clear ovality of the cross-section of the fibre end, with the major diameter being oriented in the direction of sliding.

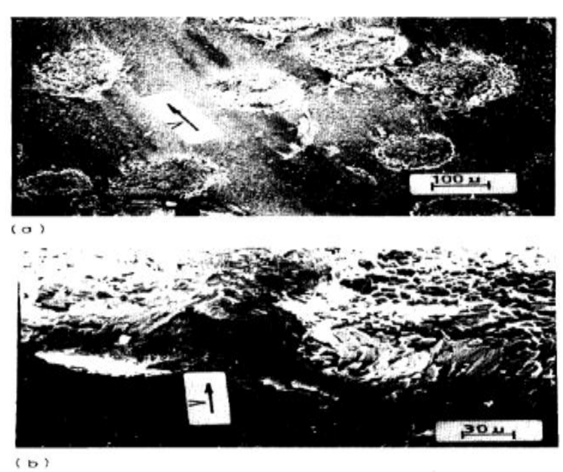
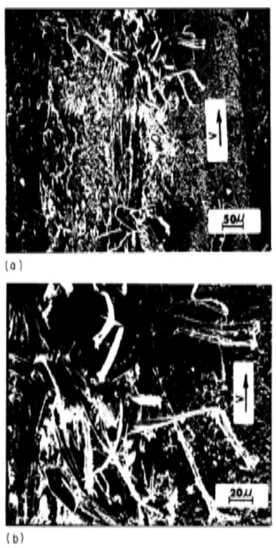


Fig.3 SEM micrograph of worn surface of 21% LF-PC(N-oriented) at low PV value

In the case of the L-orientation fibres, a decrease in wear rate occurs as V, increases. The fibres in this case are oriented parallel to the sliding surface and also to the sliding direction. In this position the fibre can be easily detached from the matrix; hence it is observed that the decrease in wear rate in this case is much smaller than that observed in the case where sliding is in the N-orientation.

Fig.4 shows SEM photographs of the worn surfaces of such specimens. The photographs show the wear tracks on the surface where the worn surfaces also exhibit plastically deformed matrix and fibre bulking from matrix.



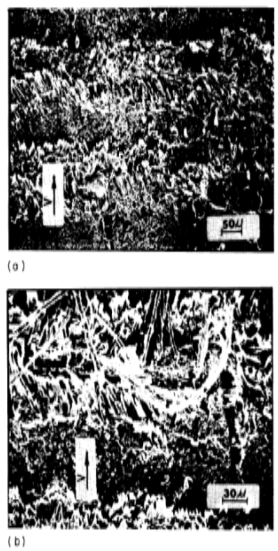


Fig.4 SEM micrograph of worn surface of 33% LF-PC (L-oriented) at low PV value

Fig.5 SEM micrograph of worn surface of 33% LF-PC (T-oriented) at low PV value

In the case of the T-orientation fibres, a decrease in the wear rate also occurs by increasing Vf, in which wear rate becomes nearly constant at Vf > 12.5%.The observed decrease in wear rate is smaller than that observed in both the N-orientation and the L-orientation cases. These results agree well with those obtained by Sung and Suh [5] on graphite fibre-epoxy composites. Fig. 8 shows SEM micrograph of the worn surface of LF-PC specimen tested in the T-orientation at low PV value. The photographs show the wear tracks on the surface. The worn surfaces also exhibit plastically deformed matrix and fibre failure resulting in freely protruding bulked parts.

In the present experiments a fibre-rich surface is observed in the three orientations; a larger fibre-rich surface is observed in the N-orientation whereas a smaller fibre-rich surface is observed in both the T- and the L-orientation. Such observation is consistent with the wear rate results obtained experimentally and further confirmed by SEM photographs (Figs.6-8). Tanaka [23] showed that the wear of fibre-filled polymers is less if the fibres composing the fibre-rich surface have good wear resistance. Similar results were also obtained by Cirion et al. [8] on Aramid fibre-polyetherketone composites. On increasing V, the Aramid fibre created an effective transfer film on the surface of the steel counter-part which further enhanced the wear resistance of the respective composite system.

C. LF-PC friction coefficient at high PV value

Fig. 9 shows that UN increases as Vf increases. However, comparison of Fig. 3 with Fig. 6 indicates that the friction coefficient of pure polyester at high PV value is less than that observed at low PV value. This decrease is due to the softening of the surface matrix which takes place in the case of sliding at high PV value.

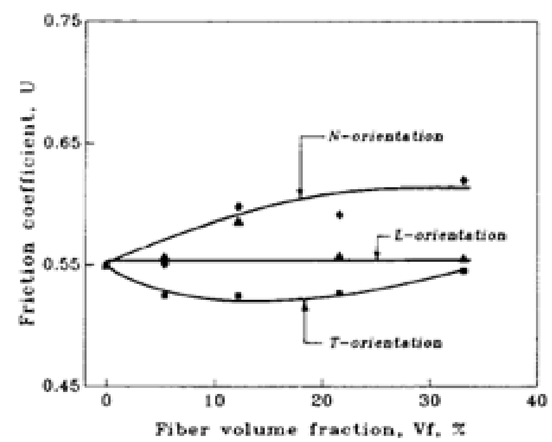


Fig.6 Coefficient of friction vs V_f of LF-PC at high PV value

Hence, the friction coefficient decreases because of the ease of matrix material detachment from the bulk. On the other hand the increase of UN as Vf increases may occur because the fibres in this case are embedded in the matrix, which prevents easy detachment of softened polyester from the matrix.

The friction coefficient is found to be almost unchanged as Vf increases in the L- orientation case. The fact that the fibres in this orientation could easily be pulled out of the softened matrix may explain such a result. The figure also shows that UT exhibits similar behavior to that of U in the L-orientation but with slightly higher values.

D. LF-PC wear rate at high PV Value

The wear rate at high PV value is found to be 200-300% greater than that at low PV value for the same volume fraction percentages and orientation direction as indicated by the comparison between Fig.4 and Fig.7.This result is expected because of the thermal softening of pure polyester.

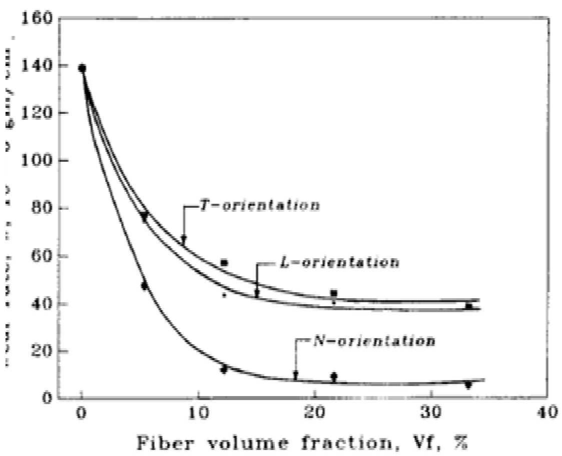


Fig.7 Wear rate vs V_f of LF-PC at high PV value

The figure shows that for the N-oriented fibres, the high value of WN, due to softening of polyester, decreases as V_f increases. This is attributed to the fact that the long fibres embedded in the matrix prevent the catastrophic failure of the softened polyester at the sliding surface. The fibres with this orientation are in the best position to prevent the detachment from the matrix. When the fibres are oriented in the L-orientation a decrease in the wear rate is also observed as V_f increases as shown in the Fig.7.However the observed decrease in the wear rate is smaller than that observed in N-orientation case. In this position the fibre can easily be detached from the matrix.

In the case T-orientation a decrease in the wear rate also occurs as V_f increases. The observed decrease is still smaller than that observed in the case of N-orientation but more or less equals that observed in the case of L-orientation (Fig.10).It is expected that, when fibres are oriented normal to the sliding surface, debonding will occur at the surface and will propagate down along the length of the fibre to a finite distance; the stronger the fibre the longer the resulting de- bonding distance. For weaker fibres, the fibre break occurs before debonding propagation. This is illustrated schematically in Fig.11.

Wear of fibres occurs because of the shear force component (Fs) whereas debonding of the fibre depends on the tensile force component(Ft).It is expected that, When V_f decreases, the force carried by each fibre which leads to increased wear rate. This may apply with no appreciable difference between transverse and longitudinal orientation. However, the debonding tendency occurs more in the transverse case which agrees with the results obtained.

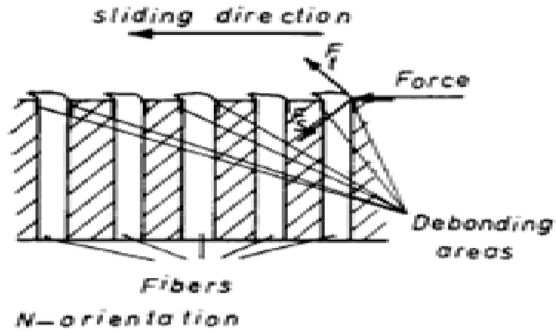


Fig.8 Schematic representation of failure mode in unidirectional continuous fibre-reinforced composite

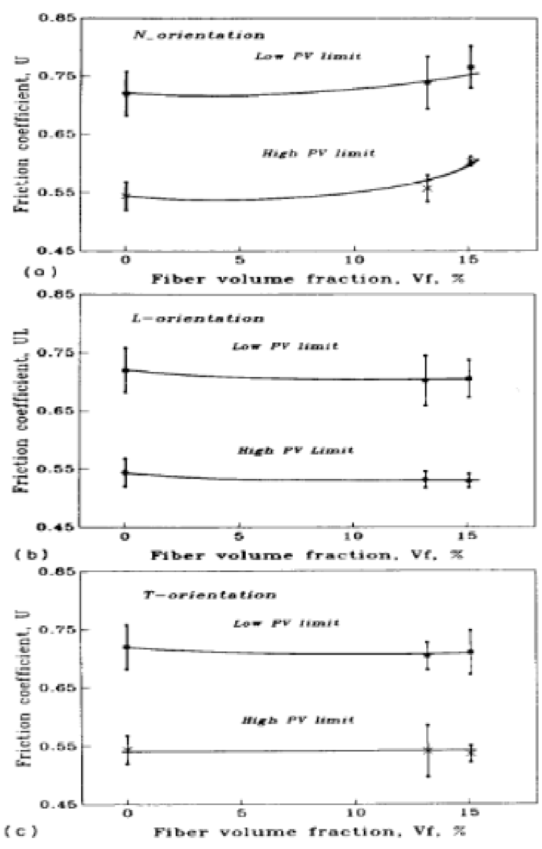


Fig.9 Coefficient of friction vs V_f of JF-PC at high PV values

IV.EFFECT OF JUTE REINFORCEMENT ON FRICTION AND WEAR

Figs 12 and 13 show the preliminary results obtained of friction and wear tests on jute fibre-polyester composite (JFPC) at low and high PV values. The variation of U and W with the three fibre orientations with respect to sliding direction for all tests is plotted.

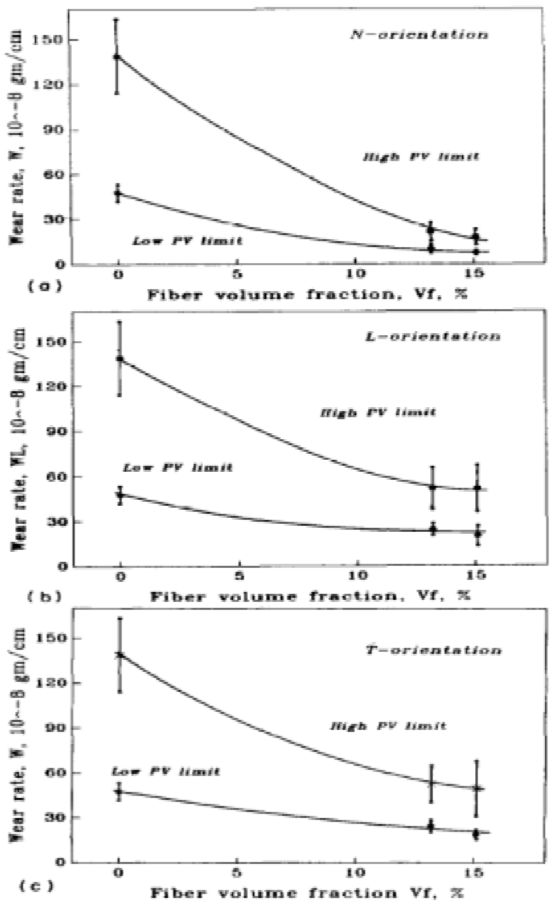


Fig.10 Wear rate vs V_f of JF-PC at low and high PV values

Comparing Fig. 9.with Figs. 3 and 6 and Fig. 10 with Figs. 4 and 10 both indicate that the coefficient of friction and wear rate of JF-PC exhibit similar behaviour to that in the case of LF-PC when tested under the same conditions. Moreover, it can be shown from such comparison that the wear rate of the N-orientation of JF-PC is slightly higher than that obtained in the same orientation of LF-PC when tested under the same conditions. Such phenomena may be explained by viewing the SEM photographs for both cases.

Fig.11 SEM micrograph of worn surface of 15% LF-PC (N-oriented) at low PV value

Fig. 11, compared with Fig. 5, reveals that smaller areas of fibre-rich surface are present in the first photograph, relative to the second, indicating higher wear rate for the JF-PC.

V. CONCLUSIONS

Testing the composites in dry conditions below the PV limit of the pure matrix material revealed that the coefficient of friction improves considerably when linen or jute fibres are used as reinforcement (LF-PC and JF-PC) in the longitudinal and transverse orientation, with increasing V_f up to a percentage of 15% where improvement ceases. On the other hand, it is found that the fibres oriented in the normal direction increase the coefficient of friction in the case of linen as well as jute fibres. Moreover, the transverse and the longitudinal orientation of fibres in the LF-PC and JF-PC system yield lower wear rate than that of the matrix material and the normal orientation fibres give its lowest rate at a value of 15% V_f.

Testing the developed composites in dry conditions above the PV limit of the pure matrix material revealed that the coefficient of friction is not significantly improved using either linen or jute fibres for reinforcement in both the longitudinal and the transverse orientation cases. It increases in the case of normal orientation. On the contrary, the wear rate improves as the volume fraction increases in both composite systems. As in the low PV case, the normally oriented fibres give the lowest wear rate, but at 20% V_f.

The size of the resulting wear debris decreases as the fibre volume fraction increases. In all cases the polyester matrix is shown to fail by the formation of a wear plateau within a plastically deformed zone. The extent of such localized zones, however, depends on a fibre plucking-off mechanism in both longitudinal and transverse orientations and fibre debonding in normally oriented fibres.

REFERENCES

[1] NM.W. Pascoe, Plain and filled plastics materials in bearing; a review, Tribology, 6 (5) (1973) 184.
[2] J.K. Lancaster, Polymer based bearing materials; the role of fillers and reinforcement, Tribology, 5 (6) (1972) 249.
[3] B.J. Briscoe and D. Tabor, The sliding wear of polymers; A brief review, in N.P. Suh and K. Sako (eds.), Fundamentals of Tribology, MIT Press, Cambridge, MA, 1980, p. 733.
[4] J.K. Lancaster, Wear, 20 (1972) 335.
[5] N.H. Sung and N.P. Suh, Effect of fiber orientation on Friction and wear of fiber reinforced polymeric Composites, Wear, 53 (1979) 129.
[6] M. Cirino, K. Friedrich and R.B. Pipes, The effect of fiber orientation on the abrasive wear behavior of Polymer composite materials, Wear, 121 (1988) 127.
[7] K. Tanaka, Friction and wear of semi crystalline Polymers sliding against steel under water lubrication, J. Lubr. Techno L, 102 (1980) 526.
[8] C. Lhymn, Lubricated wear of fiber-reinforced polymer composites, Wear, 122 (1988) 13.
[9] C. Lhymn and A.L. Pulsifer, Tribological properties of Poly (butylenes terephthalate)-glass composites: abrasive wear, Mater. Sci. Eng., 79 (1986) 233.
[10] T. Ksukizoe and N. Ohmae, Wear mechanism of Unidirectionally oriented fiber-reinforced plastics, J. Lubr. Technol., 99 (4) (1977) 401.
[11] A.M. Eleiche and G.M. Amin, The effect of unidirectional cotton fiber reinforcement on the friction and wear characteristics of polyester, Wear112 (1986) 67.
[12] Ramesh and Kishore, Dry wear studies on glass-fiber-reinforced epoxy composites, Wear, 89 (1983)
[13] C. Lhymn and C. Light, Effect of sliding velocity on Wear rate of fibrous polymer composites, Wear, 116 (1987) 343.
[14] C. Lhymn, Tribological properties of poly (butylenes terephthalate)- glass composites: adhesive wear, Mater. Sci. Eng., 80 (1986) 93.