Tribological behavior and mechanical properties of Bio-waste reinforced polymer matrix composites

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Abstract : An experimental study was conducted to investigate the erosive and abrasive wear behavior of coir dust filled epoxy resin matrix composites. The effect of coir dust concentration ,different impingement angles(30°,45°,60°,75°,and 90°),and various impact velocities(34,48,60,78,and 92m/sec) on the erosion rate of composite has been analyzed. The erodent used here is dry silica sand having the size range 200-600μm. However, it is found that the composite shows brittle type failure and maximum erosion rate is observed at 90° impingement angle. Erosion wear rate is decreased with increasing the coir dust amount.The abrasive wear property of the composite is examined on a pin-on-disc machine against 400μm grit size abrasive paper with test speed of 0.540 m/sec and at normal loads 5,10,15,20, and 25N. The effect of coir dust concentration and sliding distance on the weight loss of composites has been analyzed. Abrasive wear resistance decreases with increase in normal load and increases with increasing fiber content. Further, the erodent and abrasive worn surface morphology is examined by using scanning electron microscope (SEM), and possible wear mechanisms are discussed. The hardness and flexural strength of the composite also evaluated.

Keywords : Coir dust, Epoxy resin, Erosion wear, Abrasive wear, Impingement angle, SEM.

INTRODUCTION

Cellulosic fibers, like sisal, henequen, jute, oil palm, bamboo, wood paper in their natural condition, as well as, several waste cellulosic products such as shell flour, wood flour and pulp have been used as reinforcement agents of different thermosetting and thermo plastic resins[1-8]. During leaf defibration of henequen fibers and also during the transformation of the raw fibers into cordage, approximately 10 % of waste fibers are produced[9].These waste fibers could be profitably used in the manufacture of fiber polymer reinforced composites because they posses attractive physical and mechanical properties[10].Natural fibers having the unique properties such as bio degradability, environmental friendliness, low cost, low density, high specific strength and so forth have shifted the focus of researchers from synthetic to natural fiber-reinforced polymer matrix composites.

The interest in natural fiber reinforced polymer composite materials is rapidly growing in terms of their tribological, industrial applications and fundamental research[11].There are some possibilities where the composite may encounter impacts & abrasions from splinters of materials, sand and slurry of solid particles so consequently the material may failure due to erosion wear. Hence, the study of erosion behavior of natural fiber reinforced polymer composite is vital importance. The erosion wear of reinforced polymer composite is usually higher than unreinforced polymer matrix[12].The erosion resistance of polymer composite is low in comparison to monolithic materials[13].

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Abrasive wear of composites is strongly influenced by the filler loading and operating parameters. Hashmit *et. al.*[14] investigated the sliding wear behavior of cotton-polyester composites and obtained better wear properties on addition of cotton reinforcement. Tung *et. al.*[15] studied the abrasive wear behavior of bamboo and reported that the abrasive resistance of a bamboo stem is affected by the vascular bundle fiber orientation with respect to the abrading surface and the abrasive particle size. The different possible application areas of natural fiber reinforced polymer composites are consumer goods, windows, furniture, door paneling elements,designer office chairs, hand friendly Image products,wheels, impellers, seals, brakes gears, cams, artificial prosthetic joints and bearings etc.

In this paper, we have investigated the erosive and abrasive wear behavior of bio-waste (coir dust) reinforced polymer composite. Experiments are conducted to study the effects of coir dust content, impingement angle and impact velocity of the erodent particle on the erosive wear behavior and the effect of sliding distance and normal load on abrasive wear behavior of the composite material.

EXPERIMENTAL DETAILS

Epoxy LY556; chemically belonging to the 'epoxide' family is used as the Matrix Material. The hardener with IUPAC name NN0 (2-amineethylethane-1, 2- diamin) used with the epoxy has the designation HY-951.The epoxy resin and the hardener were supplied by Ciba Geigy India Ltd. Resin and hardener are mixed in a ratio of 8:1 by weight as recommended. Density of the epoxy resin system is 1.28 g/cm^3.

Coir dust was mixed with the epoxy resin by stirring at room temperature and cut in sheet form of dimensions (300x300x 5) mm applying uniaxial pressing at 2.00 ton load. Five samples i.e. sample A (pure epoxy), sample B (epoxy+10 wt% of coir dust), sample C (epoxy+20 wt% of coir dust), sample D (epoxy+40wt% of coir dust), and sample E (epoxy+60 wt% of coir dust) are prepared. Test specimens of suitable dimensions are cut from the composite sheets for erosion wear test. For abrasive wear test, composite pins of length 30 mm and diameter of 10 mm are prepared by using cylindrical moulds.

The bulk density and void fraction of the composite materials be obtained from following equations by using archemidus principle.

$$\text{Density} = \frac{\text{Dry weight}}{(\text{soaked weight - suspended weight})}$$

$$\text{Apparent porosity} = \frac{(\text{Soaked Weight - Dry Weight})}{(\text{Soaked Weight - Suspended Weight})} \times 100$$

To evaluate the value of flexural strength (FS), the short beam shear (SBS) tests (generally it is a3-point bend test) are performed on the samples at room temperature. The SBS test is conducted as per ASTM D2344-84 using the Instron 1195 UTM.The FS of any composite is calculated by using the following formula

$$FS = \frac{3FL}{2bt^2}$$

Where F- is the applied load, L- span length, t and b are the thickness and width of the specimen respectively.

Leitz Micro -hardness tester was used for Hardness measurement this tester had a diamond indentater ,in the form a right pyramid with a square base and an angle 136° between opposite faces, is forced in to the material under a load F. After removal of the load the two diagonals X and Y of the indentation left on the surface of the material are measured and their arithmetic L is calculated.

In this present study we considered the load F= 0.3 Kgf and Vickers hardness number is calculated by using the following formula.

$$Hv = 0.1889 \ F/L^2$$
$$L = (X+Y)/2$$

Where F - is the applied load, L- is the diagonal of square impression (mm), X- is the horizontal length (mm), and Y- is the vertical length (mm).

The solid particle erosion wear tests were carried out as per ASTM G76 standard on the erosion test rig. It consists of an air compressor, an air particle mixing chamber and accelerating chamber. Dry compressed air is mixed with the erodent particles, which are fed at constant rate from a sand flow control knob through the nozzle tube and then accelerated by passing the mixture through a convergent brass nozzle of 3mm internal diameter. These particles impact the specimen, which can be held at different angles with respect to the direction of erodent flow using a swivel and an adjustable sample clip.

The wear rate was expressed in terms of $\Delta w_1 / \Delta w_2$

Where Δw_1 - is the loss in weight of the composite.

Δw_2 - is the total weight of the erodent used.

The experimental details are given in Table 1.

Table 1 : Erosion Test Experimental Details

Impingement angle	30°, 45°, 60°, 75°, 90°
Impact velocity	34, 48, 60, 78, 92 m/sec
Erodent particle size	200, 300, 400, 500, 600 μm
Duration of erosion	25 min
Flux rate	0.650 g/min

Abrasive wear tests are carried out on a pin-on-disc type wear testing machine. Abrasive paper of 400μm grit size is used for experimentation .The specimen was held stationary and the disc is rotated while a normal force is applied through a lever mechanism. A series of tests are conducted for sliding distances i.e. 20,40,60,80, and 100 m under different normal loadings i.e. of 5,10,15,20, and 25N .The material loss from the composite surface is measured by using a precision electronic balance and then the specific wear rate(mm³/N-m) is expressed on volume loss basis as;

$$W=\Delta m/\rho tVF \ (mm^3/N\text{-}m)$$

Where Δm is the mass loss (in gm), ρ is the density of the composite (g/cm³), t is the test duration (sec), V is the sliding velocity (m/sec), and F is the applied load (N).

The worn surfaces of the pure epoxy and the composites were examined with scanning electron microscope JEOL JSM-64800LV.

RESULTS AND DISCUSSION

Fig. 1 gives the changes in the density and void fraction of the composite material with variation of the amount of coir dust. From the figure it was clear that with increasing coir dust amount the density of the material was decreases. This is due to presents of high air content (from 24% to 89% by volume)[16]. With addition of coir dust in epoxy resin the volume fraction of voids was increased.

(a)   (b)
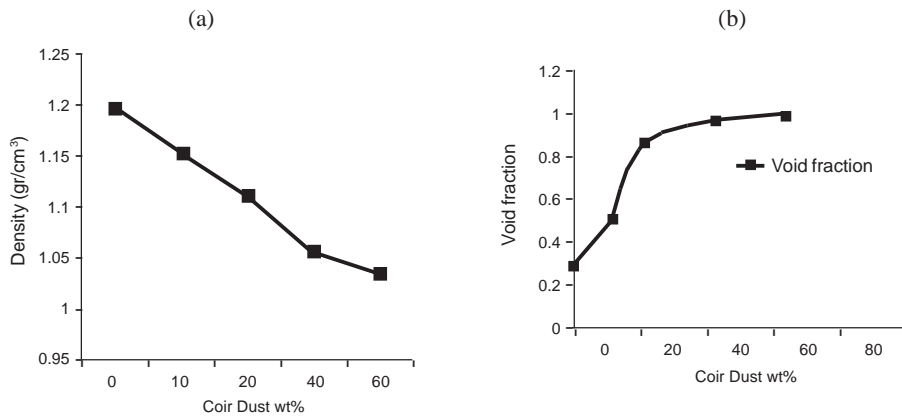
Fig. 1 : Variation of the (a) density ,and (b) void fraction with wt% of the coir dust.

The results of the hardness and flexural strength of the composites were shown in Fig. 2(a) and 2(b). It was observed that the hardness and flexural strength of the composite has decreased with increasing the coir dust concentration due to the softness of the coir dust compare with the matrix material and the increased coir dust acted as filler, not as reinforcement[17].
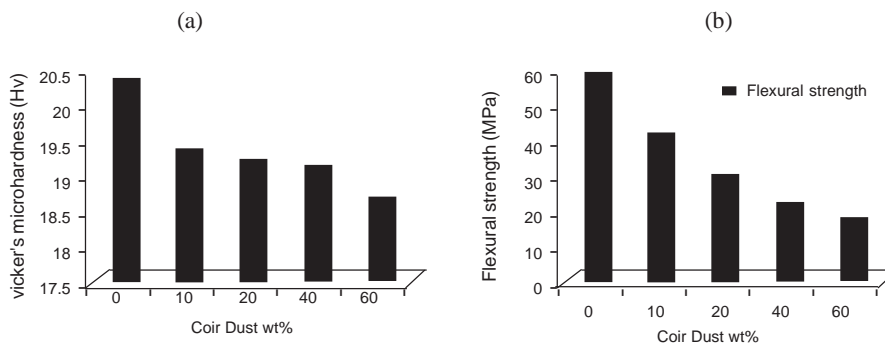
(a)   (b)

Fig. 2 : Variation of (a) hardness and (b) Flexural strength of the composite with coir dust concentration

The influence of the coir dust concentration on the erosion wear behavior of composite material had shown in Fig. 3. It was observed that with increasing the coir dust erosion rate is decreases, this is beacuse with increasing coir dust content fiber-matrix interfacial bonding increases and erosive mechanism dominated by the fiber content which is soft compare with the matrix material.
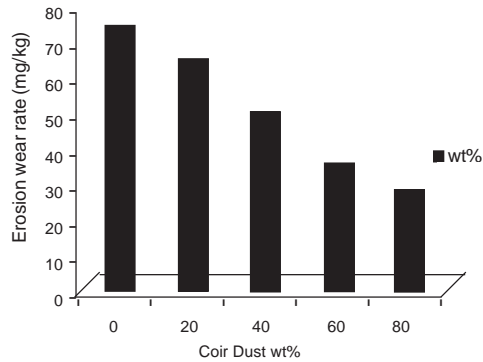

Fig, 3 : Coir dust content dependence of the erosion wear rate.

Generally erosion behaviour of the composites depends on the impingement angle. Brittle behavoiur is characterized by maximum erosion rate at normal incidence (90°), and the ductile behaviour was characterized by the maximum erosion wear rate at 15-30° impingement angle. Fig. 4 shows the Impingement angle dependence of erosion wear rate at different time intervals for all samples. From the figure it was clear that with increasing the impingement angle erosion rate of the composite was increased, and attains a peak value at impinge angle 90°, it means that the material shows the brittle type failure.
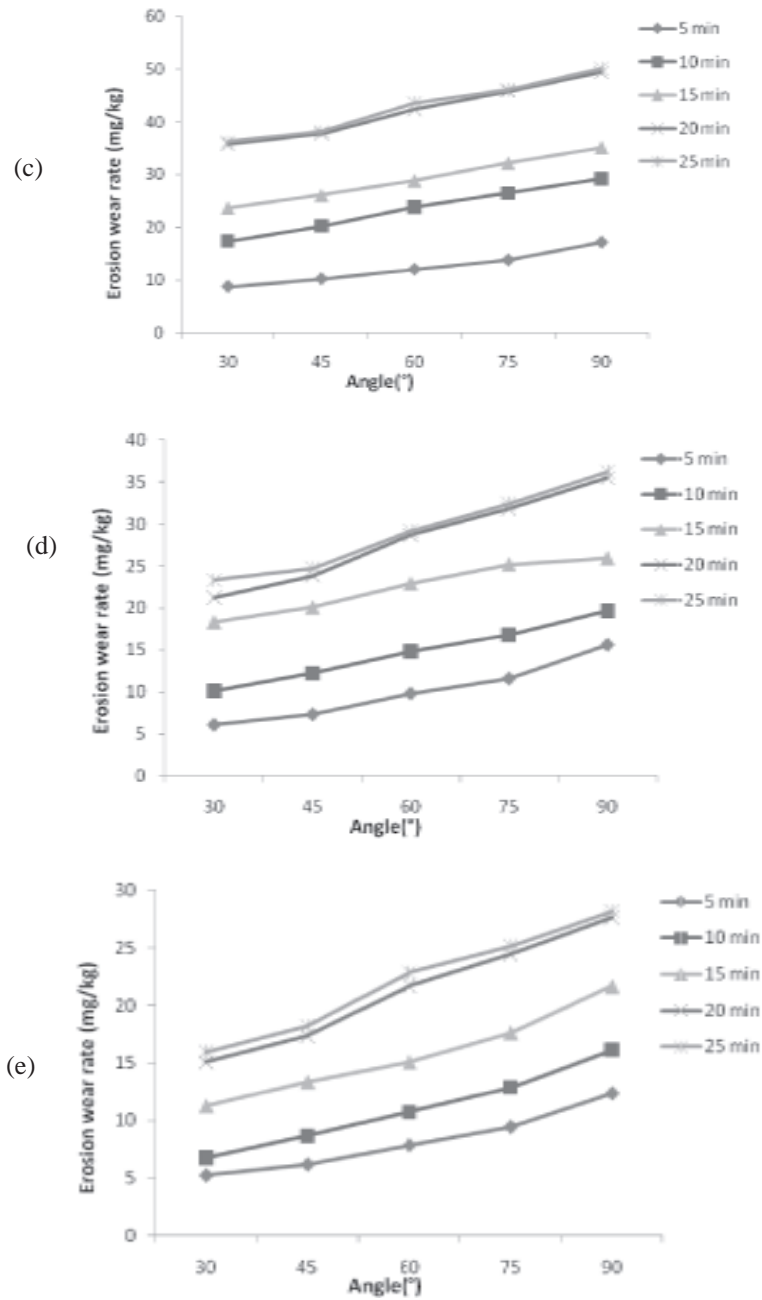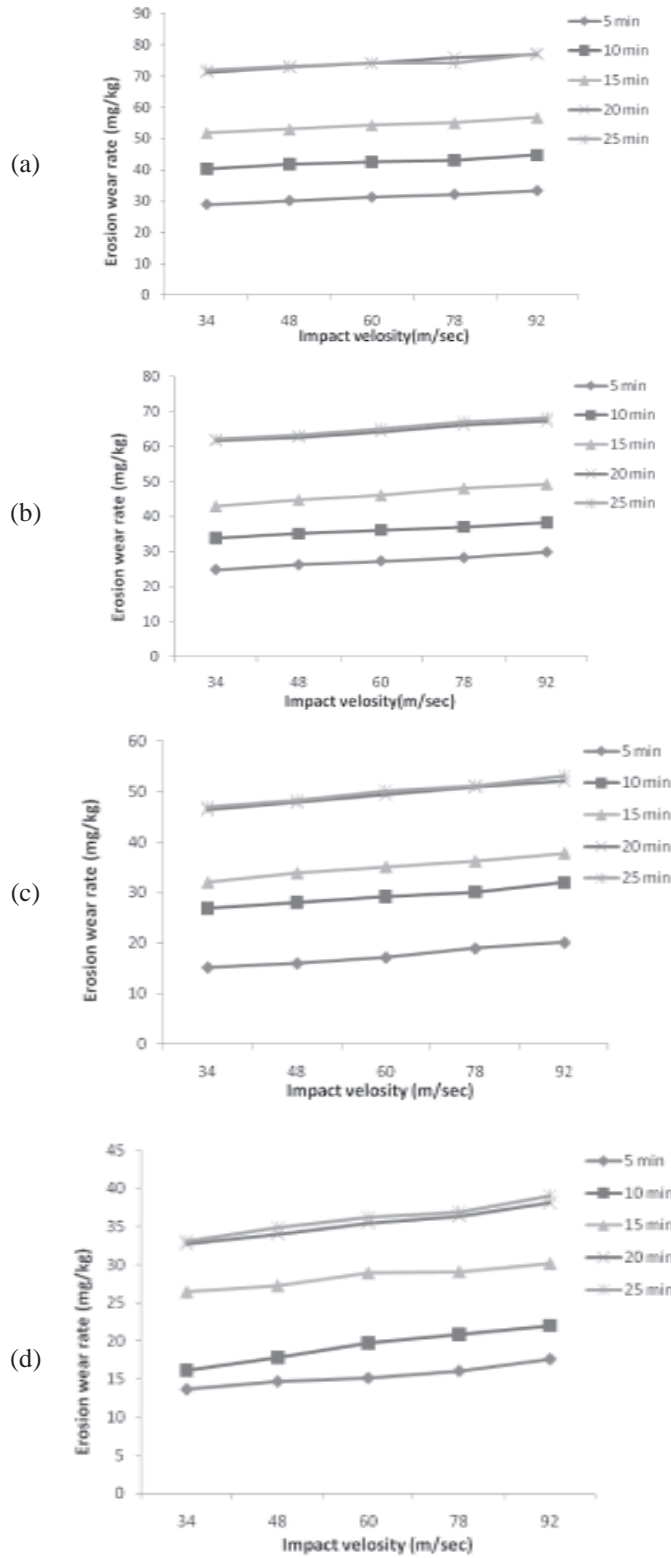
(c)

(d)

(e)
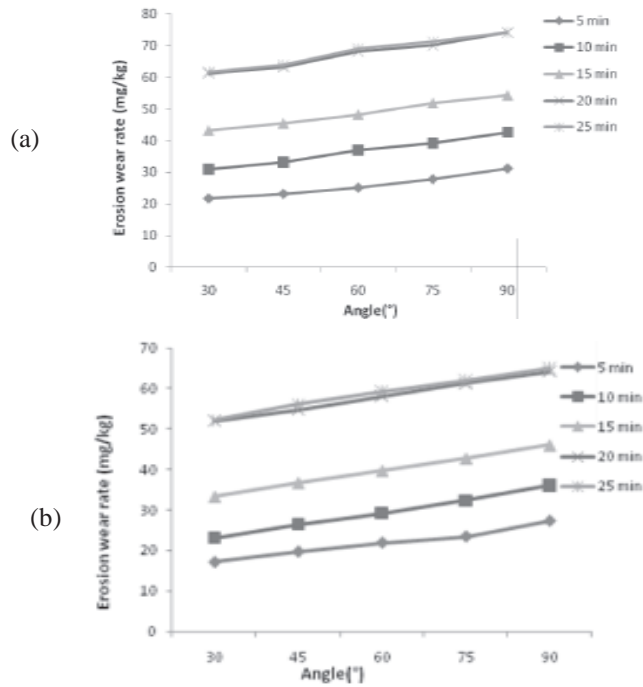
Fig. 4 : Impingement angle dependence of erosion wear rate at different time intervals for (a)sample A,(b)sample B, (c) sample C, (d)sample D, and (e)sample E.
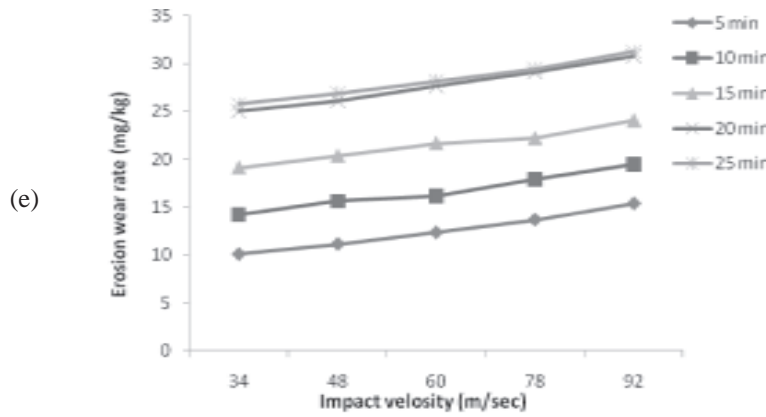
Fig. 5 shows Impact velocity dependence of erosion wear rate at different time intervals for (a) sample A, (b) sample B, (c) sample C, (d) sample D, and (e) sample E. From the graphs we can observe that with increasing impact velocity erosion rate of the composite is increasing. This is because; with increasing erodent particle velocity the tangential component of the impact force which is cause for the erosion increases.

(a)

(b)

(c)

(d)

(e)

Fig. 5 : Impact velocity dependence of erosion wear rate at different time intervals for (a)sample A,(b)sample B, (c) sample C, (d)sample D, and (e)sample E.

The SEM micro graphs of surfaces eroded 6(a) at 30° 6(b) at 60°, and 6(c) at 90° impingement angle for sample C with impact velocity 48 m/sec is shown in Fig. 6. From Fig. 6(a) we can observe that the intensive debonding of the composite due to the breakage of the fibers, Fig. 6(b) shows the increament in the pulverization process with increasing the impingement angle , leading to the higher erosive wear of the composite material. Fig. 6(c) shows the brittle fracture of the composite. As the impingement angle increased, the extent of fiber damage (initiated at fiber-matrix interface followed by the microcracking, microcutting, pulverization, and removal from the surface leaving behind weakened surface of cavity of appropriate size) also increased.
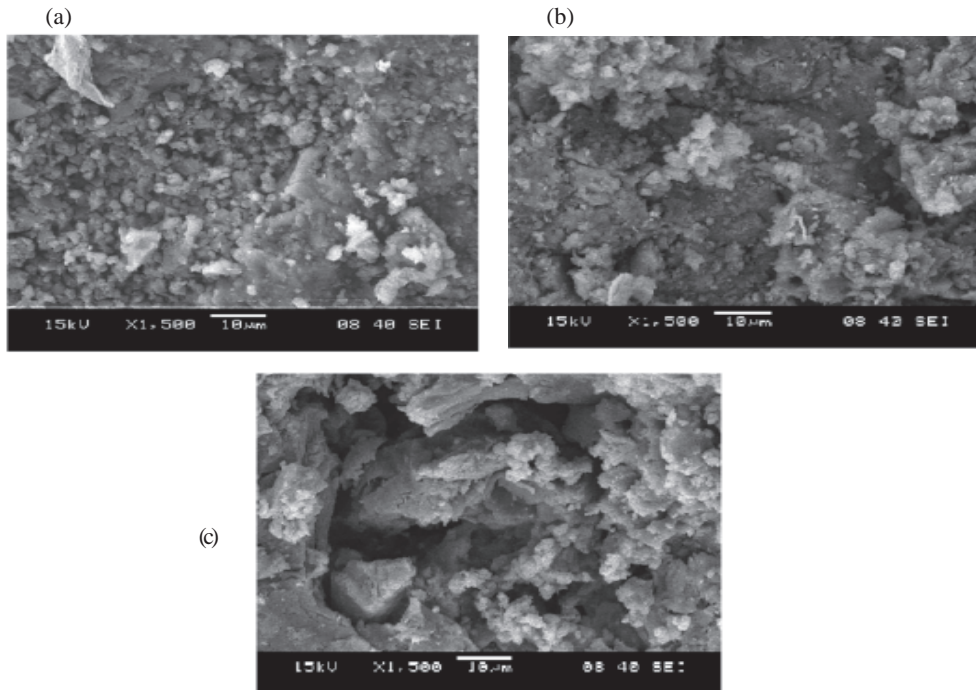
(a)   (b)

(c)

Fig. 6 : Scanning electron microscope microphoto of surfaces eroded (a) at 30° (b) at 60° and (c) at 90° impingement angle for sample C with impact velocity 48 m/sec.

Fig.7 shows the effect of coir dust content on the specific wear rate (SWR) of the composite.It is observed that with increasing coir dust concentration specific wear rate is decreasing. At higher coir dust loading wear mechanism is dominated by coir dust, which is less brittle than the epoxy resin matrix , hence decrement in the specific wear rate.
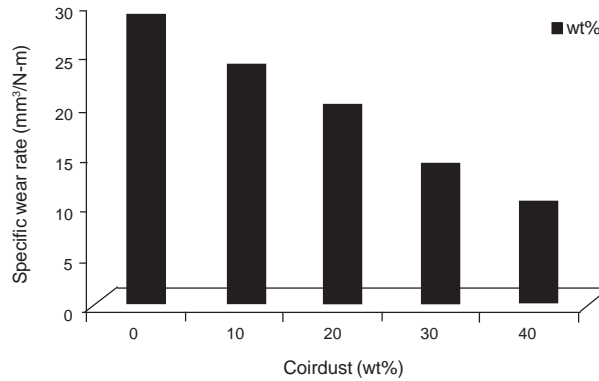

Fig. 7 : Variation of Specific wear rate with fiber content

The influence of sliding distance on specific wear rate (SWR) for different composites at different normal loads is shown in Fig. 8. The SWR was decreasing with increasing sliding distance for all the samples. Initially high SWR is observed because the abrasive paper was fresh with consecutive runs,wear loss was decreasing gradually,because the abrasive grits became less effective. The wear debris filled the space between the abrasives (SiC grits), which reduced the depth of penetration in the sample.
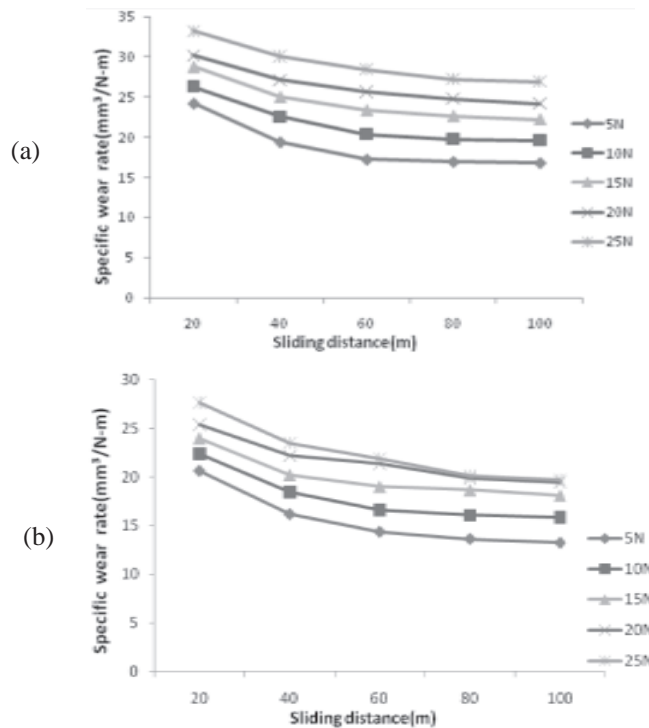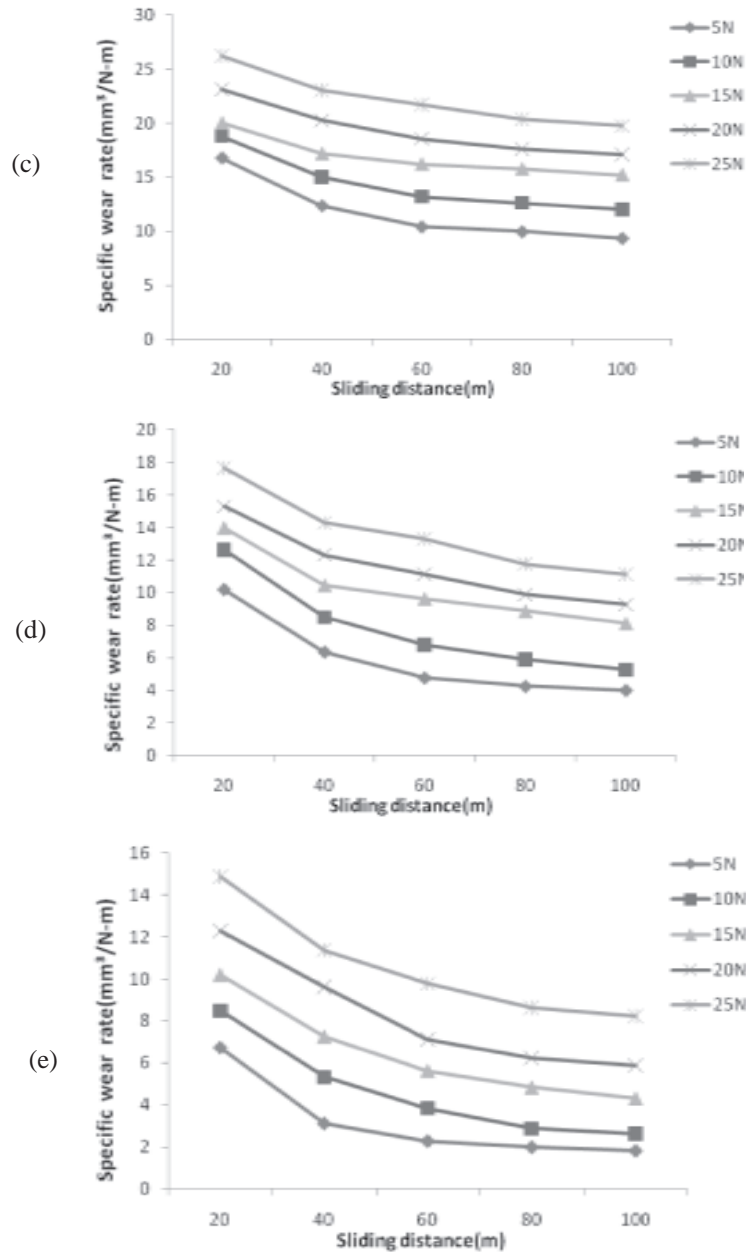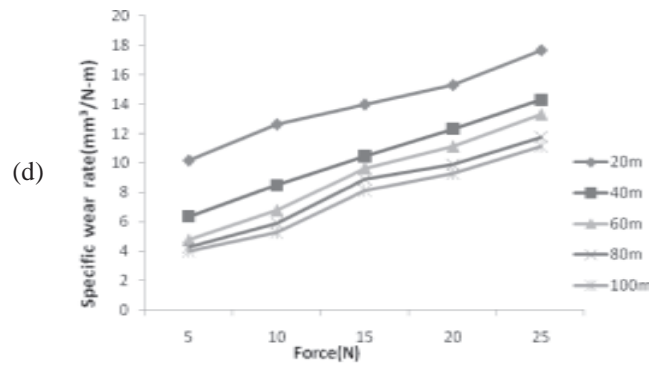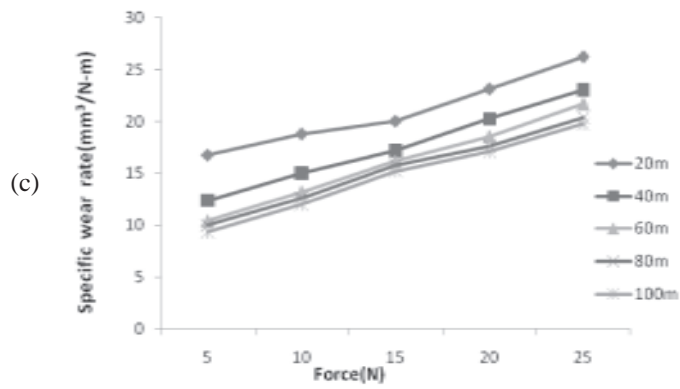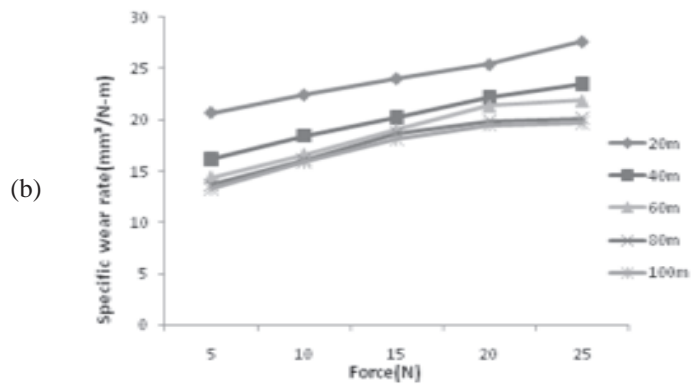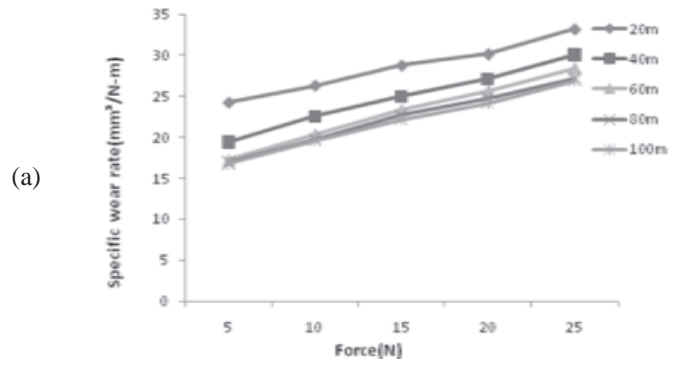
Fig. 8 : Sliding distance dependence of Specific wear rate at different normal loads for (a) sample A, (b) sample B, (c) sample C, (d) sample D, and (e) sample E.

Fig. 9 shows the plot for SWR as a function of normal loads for unreinforced and reinforced composites at different sliding distances (sliding velocity is 0.540 m/sec). The SWR increases with increasing of normal load. The SWR is relatively low at smalar loads because of less penetration and less number of abrasive particles were in action with sliding surface. The SWR is increased with increasing load because most of the abrasive particles were in action with the sliding surface and created more grooves, resulting high material removal from the surface.
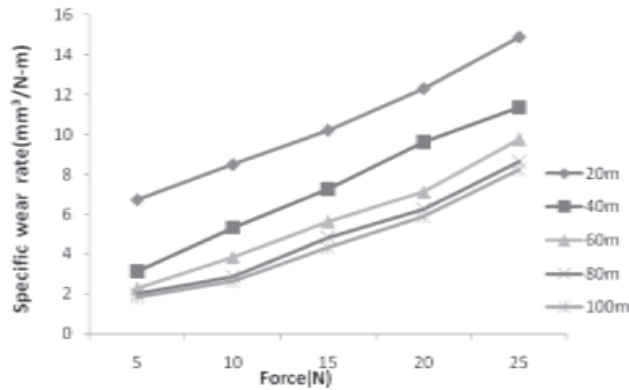
(a)

(b)

(c)

(d)

Fig. 9 : Normal load dependence of Specific wear rate at different Sliding distances for (a) sample A,(b) sample B, (c) sample C, (d) sample D, and (e) sample E.

The abraded surface morphologies of pure epoxy, 10wt% and 40wt% of coir dust composites after 100m sliding distance is shown in the Fig. 10(a), 10(b) and 10(c).Wear tracks are formed due to micro-cutting. From the worn microstructure , initially micro- cracks are formed around the coir dust paricles, and particles are removed under compression and shear. Increase of the coir dust content has increased the resistance to shear force, this may be due to its honeycomb like structure of the mesocarp.
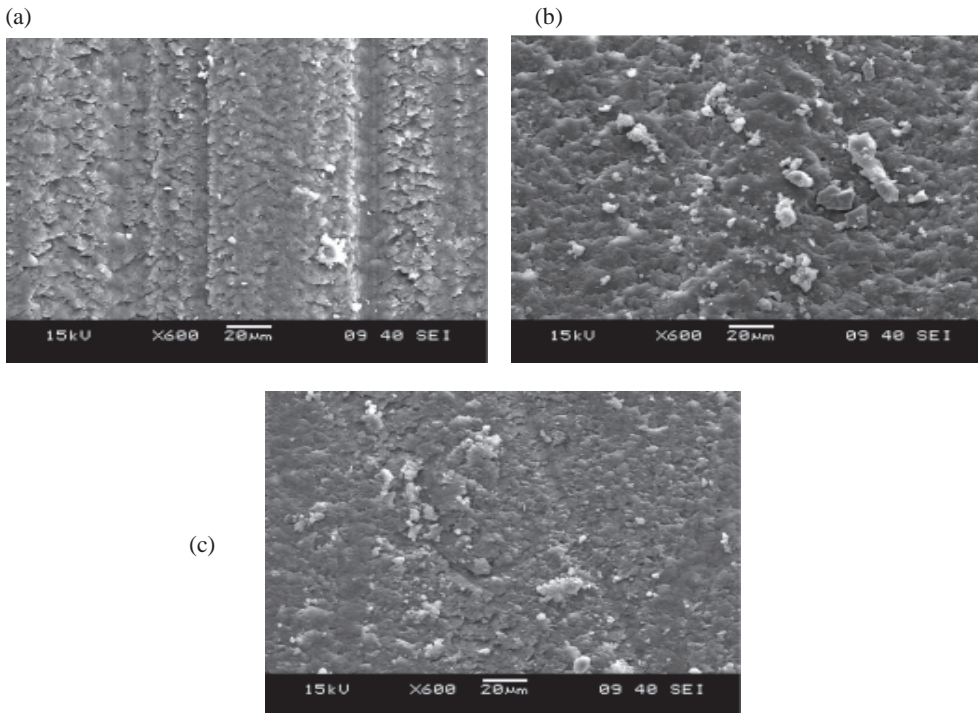
(a)

(b)

(c)

Fig. 10 : Scanning electron micrograph of (a) worn surface of pure epoxy, (b) worn surface of 10 wt% coir dust reinforced composite,and (c) worn surface of 40 wt% coir dust reinforced composite under 20 N normal load against 400?m grit size abrasive paper.

CONCLUSION

Based on the wear studies carried out on bio-waste coir dust reinforced Polymer composites in erosive and abrasive mode ,it is found that, coir dust loading influences the erosive and abrasive wear behaviour of the composite. The erosion wear resistance has increased with increasing volume fraction of the coir dust because of the softness of coir dust compare with the matrix material.The composite shownbrittle type failure. The SWR is found to be more sensitive to normal load and the SWR of composite decreases with increasing sliding distance. With increasing coir dust concentration the Hardness and flexural strength of the composite is decreasing.

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