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RESEARCH ARTICLE

Effect of fiber loading on abrasive wear behaviour of *Ipomoea carnea* reinforced epoxy composite

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Abstract Natural fibers are emerging as promising reinforcement material for fiber reinforced polymer (FRP) composites. Numerous possible material combinations, unique self-lubrication capabilities and low operating noise make the FRP composites a potentially better material over conventional metallic materials for tribological applications In this paper, an experimental study has been conducted to determine the abrasive wear behaviour of Ipomoea carnea particulate reinforced epoxy composite. Studies were done by varying the load (5, 7.5,10 and 15 N) on 10 %, and 20 30 and 40 % weight fraction of fibers at different velocities. The worn surface morphology of the eroded surfaces wear examined using scanning electron microscopy (SEM).

Keyword Natural fiber · Ipomoea carnea · Abrasive wear · Pin-on-disc machine · SEM

Introduction

Industries today are under tremendous pressure to design ecologically friendly material for their products. This is because of growing environmental awareness and new rules and regulations that are binding on industries. The use of natural fibers for the reinforcement of composites has lately received increasing attention both from academia and by industries [1]. The promising application of natural fibers in composite applications are packaging, decking, interior panels and furniture. Due to high specific strength and modulus [2] natural fibers are emerging as promising reinforcement material for fiber reinforced polymer (FRP) composites. Numerous possible material combinations, unique self-lubrication capabilities and low operating noise make the FRP composites a potentially better material over conventional metallic materials for tribological applications [3–5]. Natural fiber reinforced plastic composites due to their

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inherent biodegradability, low density, low cost, a range of mechanical properties; less abrasiveness and so on are preferred over synthetic fiber [6–10]. Besides the inherent characteristics of natural cellulose fibers is that they can be more easily modified than the relatively inert carbon, aramid and glass fiber. There are basically two types of filler produced from wood, flour and fibers; with wood flour (WF) being most commonly used material in wood plastic composite (WPC) manufacturing. The geometrical aspect ratio of a WF particle which generally gives optimum results typically lies between 1 and 5 [11]. This low aspect ratio however leads to weak interfacial potential of wood fiber but compensated by its low cost and easy processing. Various researchers [12–14] have studied the effect of WF size on the tensile, flexural properties of a composite and have reported that WF length and structure have a substantial impact on the physical and mechanical properties of a composite but the particle size has no significant effect on the mechanical properties. As per the literature available researchers worldwide have tried and proved that sisal, jute coir, oil palm, bamboo, sugarcane, wheat, flax straw, waste silk and banana can effectively use as reinforcement material in thermoset and thermoplastic matrices [15–24].

In the pursuit of visualising the influence of natural fiber reinforced polymer composites in tribological applications, extensive research work has already been published on various types of polymers and fibers. EI-Tayeb [25], Mishra and Acharya [26], Deo and Acharya [27] have reported the tribo potential of sugarcane and *Lantana camara* fiber reinforcement in thermoset polymers for enhancing adhesive wear resistance. Recently Bajpai et al. [28] studied the tribological behaviour of nettle, grewiaoptiva and sisal fiber in PLA composite and reported that the specific wear rate of the developed composite was more than 70 % lower than the maximum wear rate of neat PLA.

There are many potential natural resources which India has in abundance. Most of them come from forest and agriculture. Observing the tremendous advantages and opportunity of natural fibers there is a need to further explore the possibility of new fibers to be used as reinforcement in polymer composites for tribological applications. *Ipomoeacarnea*, locally called as "Amari" in Odisha is one such natural resource found abundantly in many parts of India, whose potential as fiber reinforcement in polymer composite has not been explored till date. Although it was native of South America, it was introduced in India as an ornamental plant. It is described to have narcotic effect on central nervous system and stimulatory allopathic effects [29]. This species is renowned as a weed all over the world and it happens to dominate the accompanying species [30]. Throughout history scientist and researcher have striven hard to find ways of destroying these weeds. But this weed has continued to challenge researchers by defying destruction and control. The main chemical constituents of this fiber are cellulose (57.73 %), lignin (16.59 %), pentosan(17.30 %), ash(6.45 %), and silica(0.16 %) [31], which indicates that it is a fibrous material and can be used as a filler for making light weight polymer composite.

Hence the present work aims to explore the possibility of using *Ipomoea carnea* fibers as reinforcement in polymer matrix and to study its tribological behaviour.

Experimental details

Materials

The epoxy resin used in the present investigation is Araldite LY556. Its common name is Bisphenol-A-Biglycidyl ether and it chemically belongs to epoxide family. The hardener used was HY951 with IUPAC name NNO-bis (2aminoethylethane-1,2diamin). *Ipomoea carnea* stem was obtained locally. The outer skin layer was removed without damaging the fiber surface (Fig. 1a). Then it was split into two halves revealing its hollow structure. The spongy material inside the hollow structure was removed and allowed to dry for 24 h (Fig. 1b). The stem was then chopped into short pieces (Fig. 1c) and dried in oven at 60 °C for 4 h. The chopped pieces were made to particulate form (100 microns) with the help of a ball mill (Fig. 1d).

Fabrication of composite

For different weight fraction of fibers, a calculated amount of epoxy resin and hardener (ratio of 10:1 by weight) was thoroughly mixed with gentle stirring to minimize air entrapment. Different doses of particulates (10, 20, 30 and 40 wt %) were added separately in the above mixture and stirred with a mechanical stirrer for 12 min. The mixture was then poured into a designed cylindrical mould (Fig. 2a, b, c) and fixed properly. During fixing some of polymer mix

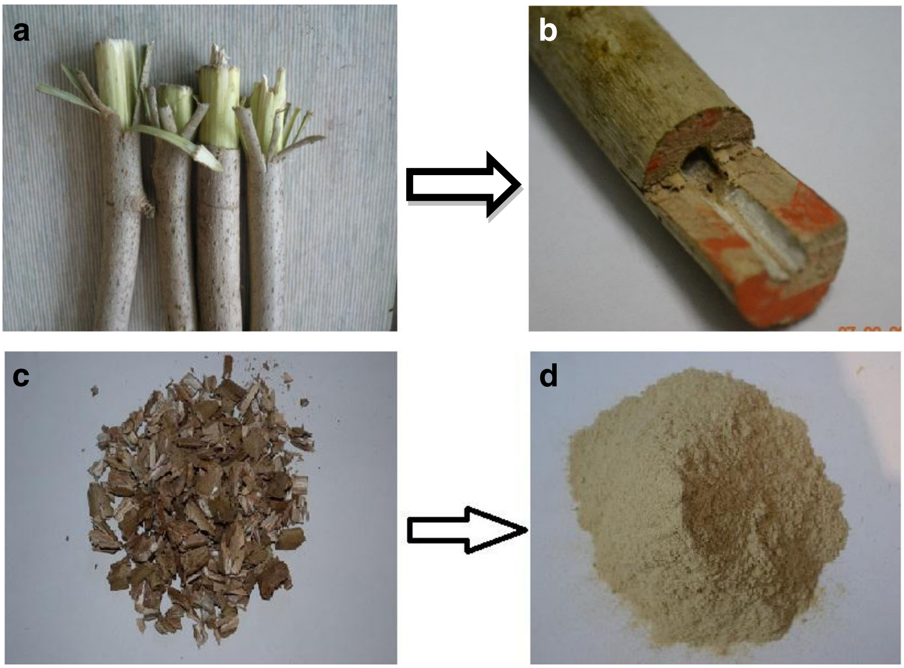

Fig. 1 (**a**) Outer skin removed from stem (**b**) Stem showing the hollow structure (**c**) Short pieces made from stem (**d**) Particulates of 100 micron size

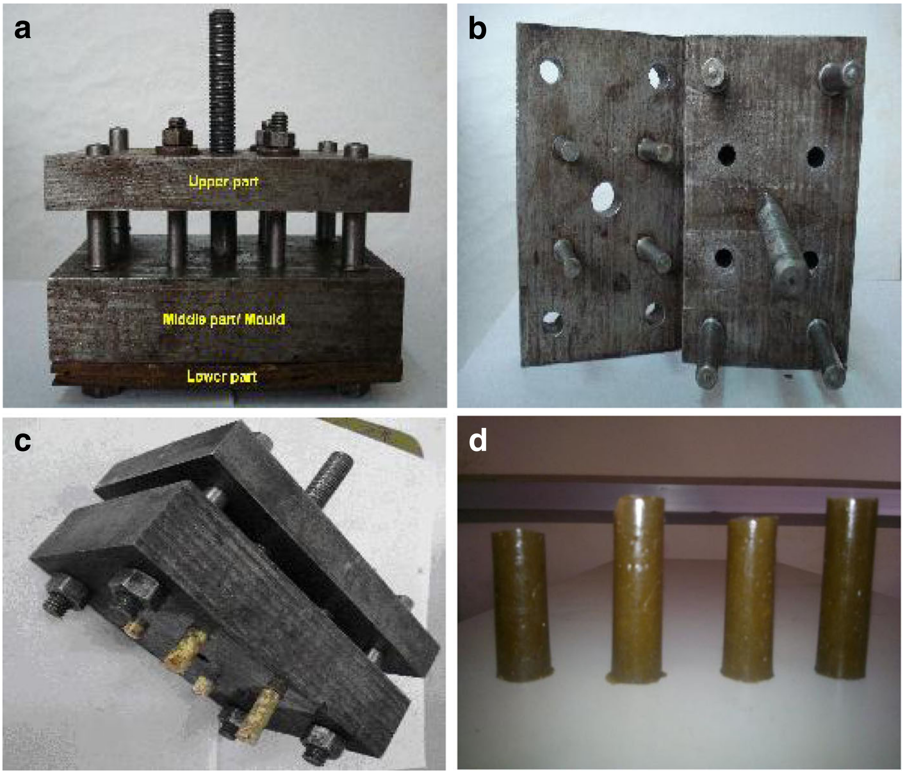

Fig. 2 Steel Mould and prepared pin type composite samples; (**a**) Mould used for preparing samples, (**b**) Two halves of the mould, (**c**) Mould with Pin types composite samples, (**d**) Fabricated composite pins

was squeezed out. Care was taken for this during pouring and fixing to make composite pins of length of 35 mm and diameter of 10 mm (Fig. 2d). Before removing the pins from the mould they were kept in the mould for 24 h at room temperature. The pins were also subjected to a post curing in hot air cven at 80 °C for 4 h to ensure complete curing. Cured samples after removal were kept in a desiccator for further experiment.

Abrasive wear test set-up

Dry sliding wear test has been carried out under multi-pass condition on a pin-on-disc type wear testing machine (As per ASTM G-99 standard) supplied by Magnum Engineers, Bangalore. Abrasive paper of 400 grade (grit-23 μm) has been pasted on a rotating disc (EN 31 Steel disc) of 120 mm diameter using double-sided adhesive tape. The setup used for the test is shown in Fig. 3a. The specimens under tests were fixed to the sample holder. The holder along with the specimen (Pin) was positioned at a particular track diameter. A track radius of 40 mm was selected for this experiment and was kept constant for the entire investigation. For each test new abrasive paper was used and the sample was abraded for a total time of 30 min.

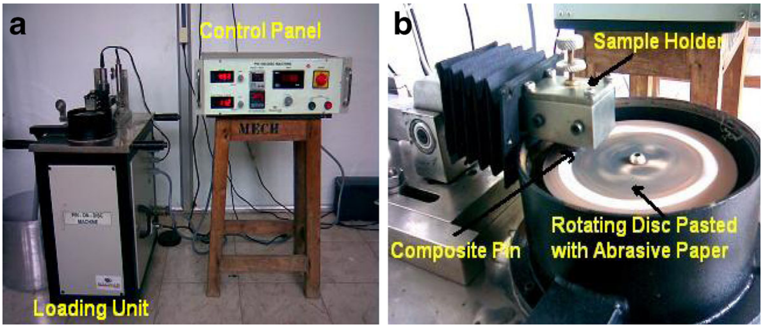

Fig. 3 **a** Pin on disc abrasive wear testing machine **b** Pin in loading position along with the track

Experimental procedure

The sample pin was abraded under different loads for six intervals of 5 min where each time interval corresponded to a sliding distance of 376.98 m. The effect of various loads (5, 7.5 10, 15 N) and sliding velocity of 1.2566 m/sin track radius of 40 mm were studied. The samples were cleaned with acetone to remove any debris that adhered to the sample before and after each run. The weight loss in the specimen after each test was recorded by weighing the pin to an accuracy of 1×10^{-3} mg using an electronic balance. The specific wear rate k_0 calculated using Eq. (1)

$$k_0 = \frac{\Delta w}{(\rho \times S_d \times F)} \tag{1}$$

Where 'k_0' is the specific wear rate in m^3/Nm, 'Δw' is the weight loss in grams, 'ρ' is the density of the sample, 'S_d' is the sliding distance in meter, and 'F' is the applied load in Newton.

Density

The actual density (ρ_{act}) of the developed composite was measured experimentally by the water immersion method. The theoretical density (ρ_{th}) of the developed composite was calculated using the following relationship between weight fraction and density [24].

$$\frac{1}{\rho_{th}} = \left(\frac{w_f}{\rho_f}\right) + \left(\frac{w_m}{\rho_m}\right) \tag{2}$$

Where, 'w_m' is the weight fraction of matrix, 'w_f' is the weight fraction of reinforcement, 'ρ_f' is the density of reinforcement, and 'ρ_m' is the density of matrix.

The percentage volume fraction of voids present in the composites was calculated using the following relation:

$$v_{void} = \left(\frac{\rho_{th} - \rho_{act}}{\rho_{th}}\right) \times 100 \tag{3}$$

Table 1 Density and volume of voids of different samples

Fiber (%)	Theoretical density (gm/cc)	Actual density (gm/cc)	Void fraction (%)
10	1.023	1.013	0.977
20	0.946	0.938	0.845
30	0.869	0.862	0.718
40	0.792	0.787	0.631

Examination of worn surfaces

The worn surfaces of the specimen are examined directly by a scanning electron microscopy (SEM; JEOL JSM-6480LV).

Results and discussion

The theoretical and measured densities of the composite along with the corresponding volume fractions of voids are presented in Table 1. It may be noted that there is difference between actual and theoretical densities of the composites as observed from the table. This difference is a measure of voids and pores present in the composite. It is clearly seen that with the increase in fiber content there is a decrease in the void fraction and in all the composites the volume fraction of voids are reasonably small (<1.00 %). This attributed to the packing characteristics of the composite with different volume fraction of particulates.

Figure 4 shows the influence of load on the abrasive wear of unreinforced and reinforced composites at a sliding velocity of 1.2566 m/s. The weight loss increases with the normal load. Weight loss was relatively lowat lower load (5 N) because of lower penetration and because less numbers of abrasive particles were in action with the rubbing surface. Abrasion wear was greatly

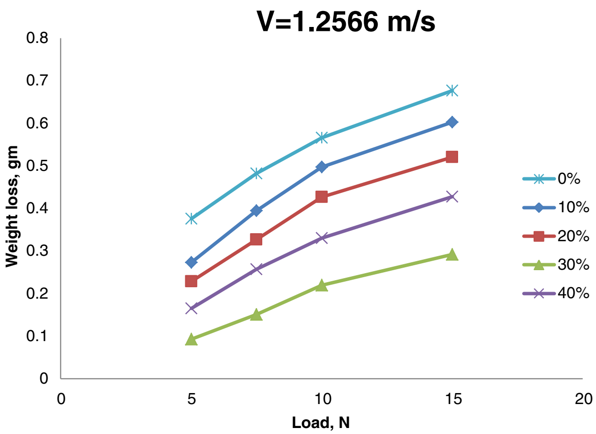

Fig. 4 Weight loss at various loads at 300 rpm

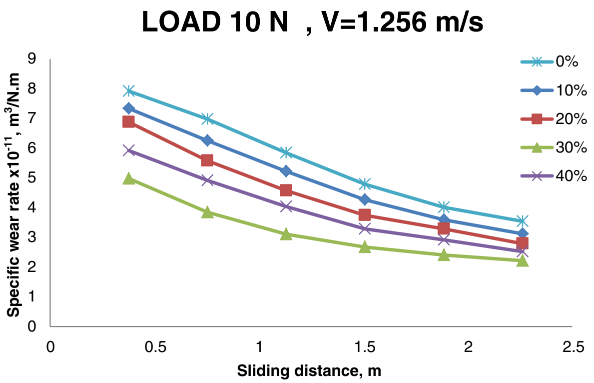

Fig. 5 Specific wear rate against sliding distance for 10 N load at sliding velocity 1.2566 m/s

increased at higher load because most of the abrasive particles penetrated into the surface and created more grooves, resulting in more material removal by ploughing. The weight loss decreases with the addition of *Ipomoea carnea* particulate up to 30 wt %. It means that *Ipomoea carnea* is very effective in improving the tribological performance of epoxy, especially for its wear resistance. However, at 40 % of reinforcement the wear rate suddenly increases. This might be due to agglomeration of particulates, which leads to poor interfacial adhesion at higher fibre content. The same type of behaviour is reported by Wu and Cheng [32] while studding the tribological properties of Kevlar pulp-reinforced epoxy composites.

Figure 5 shows the specific wear rate (k_0) at 10 N applied load in abrasive wear mode as a function of sliding distance for all the composites. The specific wear rate decreased with increasing sliding distance for all the samples. Initially, maximum wear rate was observed because abrasive paper was fresh. With consecutive runs, the wear rate decreased gradually because the abrasive grits become smooth and less effective. The wear debris filled the space between the abrasives, which reduced the depth of penetration in the sample. Also the steady state condition is probably due to the transfer film of polymer onto the counter abrasives [33–35].

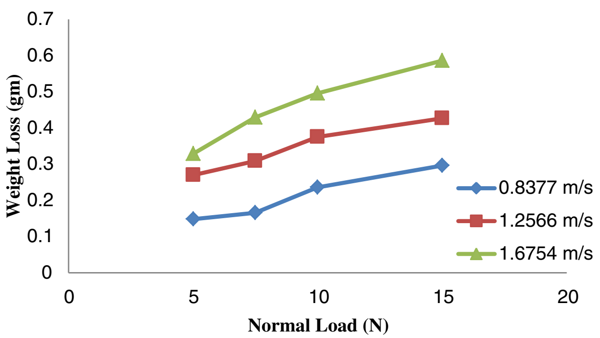

Fig. 6 Abrasive weight loss of 30 % *Ipomoea carnea* composites against normal load under different sliding velocities

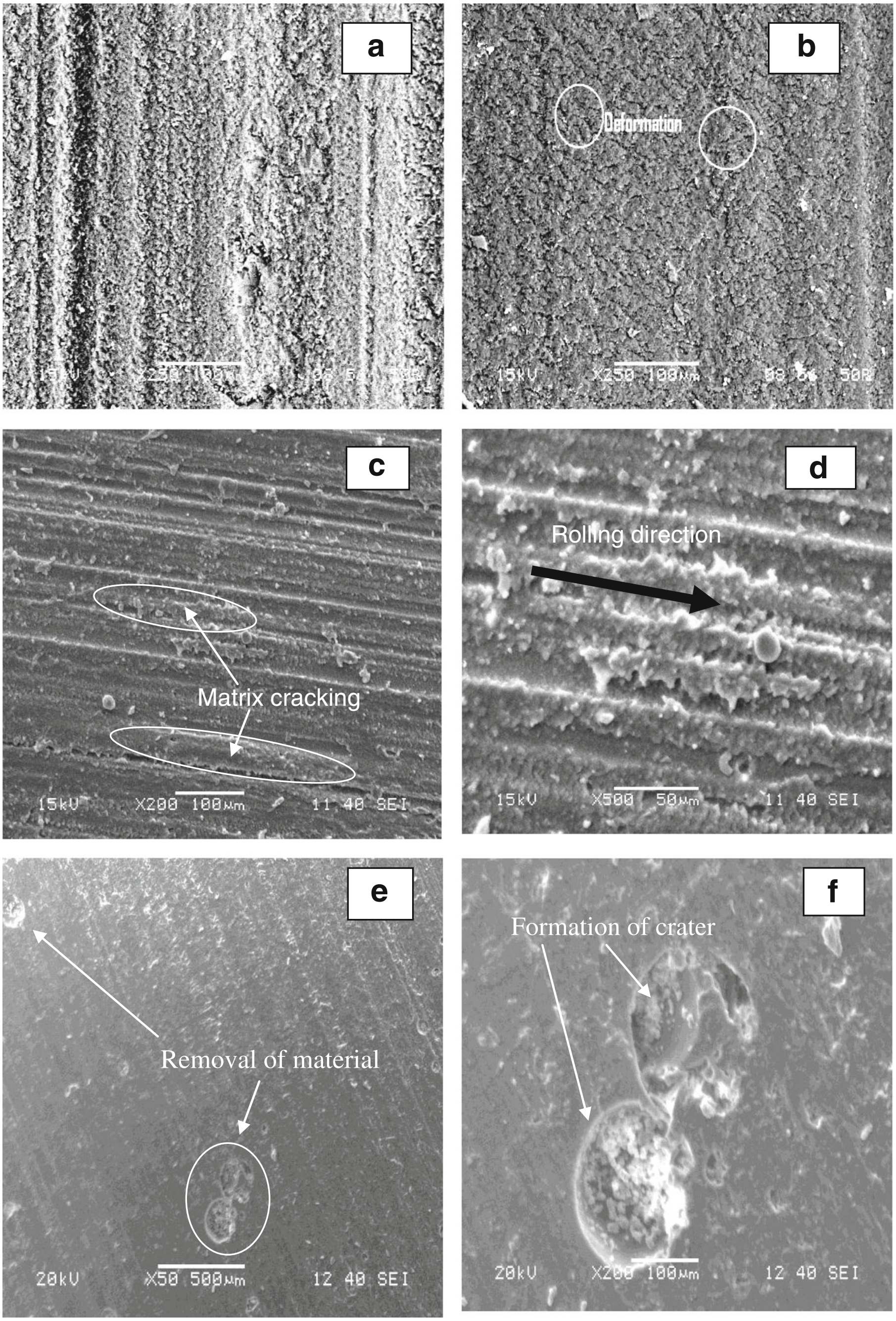

Fig. 7 Scanning electron micrograph of worn surface of tested composite samples; (**a**) Neat epoxy under 10 N load, (**b**) Neat epoxy under 15 N load, (**c**) 30 wt % *Ipomoea carnea* reinforced composite under 10 N load (**d**) 30 wt % *Ipomoea carnea* reinforced composite under 10 N load at higher magnification (**e**) 40 wt % *Ipomoea carnea* reinforced composite under 10 N load (**f**) 30 wt % *Ipomoea carnea* reinforced composite under 10 N load at higher magnification

Figure 6 shows the influence of normal load on the abrasive wear of 30 wt % fibre-reinforced composite under different sliding velocities (0.8377, 1.2566 and 1.6754 m/s). Abrasive wear increases linearly with increasing normal load at lower sliding velocity (0.8377 m/s). At higher sliding velocities (1.2566 and 1.6754 m/s) the abrasive weight loss increases largely up to 15 N load and then increases marginally up to 25 N load. It can be concluded that abrasive wear increases with increasing sliding velocity. It can also be concluded that the abrasive wear of *Ipomoea carnea* composite was significantly sensitive to normal load but less sensitive to variation of sliding velocity.

SEM observation

The worn surface morphologies of neat epoxy and its composites were examined by SEM. The worn surfaces of neat epoxy samples are shown in Fig. 7a and b. Brittleness of an epoxy sample exhibits poor resistance for abrasive wear. Removal of debris of brittle fragmented matrix forms in the wear tracks can be seen in Fig. 7a. In addition to this the worn surface of neat epoxy can also be characterized by plastic deformation and adherence (Fig. 7b) at higher normal load of 15 N. This might have happened due to the thermal softening effect because of the generation of high frictional heat at the sliding surface under higher normal load. The wear debris that formed due to abrasion filled the space between the abrasives with consecutive runs, which reduced the depth of penetration in the sample.

The surface morphology of 30 wt % fiber is shown in Fig. 7c. It is seen that the surface after the wear is not smooth. Matrix cracking is clearly visible however there is no sign of detachment of particles from the matrix which probably increase the wear resistance of the composite. Figure 7d shows the same view at higher magnification which indicates that due to higher loads particulates are seen to be elongated along the rolling direction but are still intact with the matrix. Figure 7d shows the morphology of the eroded surface for 40 wt % reinforcement. Removal of chunks of materials at some places is visible. Figure 7e shows the same surface at higher magnification. Formation of craters due to removal of materials is quite significant which are mainly responsible for lower wear rate at 40 wt % reinforcement.

Conclusions

The salient results of the present study are

1. The incorporation of *Ipomoea carnea* into epoxy can significantly reduce abrasive wear loss. The optimum wear resistance property was obtained at a particulate content of 30 weight fraction. However, excessive addition of fiber (40 wt %) results in pulling out of the particulates from the matrix resin during the test due to poor interfacial adhesion.
2. Abrasive wear is very sensitive to normal load compared to sliding velocity and increases marginally with increasing sliding velocity.

3. With increasing sliding distance, wear rate gradually decreases and attains an almost steady state in multi-pass condition.
4. The specific wear rate of the composite decreases with an increase in sliding distance because the space between the abrasive is filled by the debris, which reduces the depth of penetration of abrasive particles into the composite sample.

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