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Effect of TiO_2 Filler Loading on Physico-Mechanical Properties and Abrasion of Jute Fabric Reinforced Epoxy Composites

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Abstract

Mechanical properties and abrasive wear behaviour of bi-directional jute fabric reinforced epoxy (J/Ep) with micron sized TiO_2 particles at different wt% (2.5, 5, 7.5 and 10) were investigated. The tribo-potential of combined effect of TiO_2 and jute fiber in epoxy (J/Ep) for enhancing the abrasion resistance has not been studied so far. Hence, the present work aims to explore the possibility of using TiO_2 filler and jute fiber to reinforce the epoxy and thus open a new way to implement inexpensive reinforcements and produce new candidate tribo-material for industrial applications. Silane treated TiO_2 filled J/Ep composites were prepared by hand lay-up method. Selected mechanical properties and three-body abrasive wear tests were evaluated as per ASTM standards. Results indicate an enhancement in the J/Ep composite mechanical properties due to addition of TiO_2 particles up to 7.5 wt% of loading. Highest tensile and flexural properties were found at 7.5 wt% TiO_2 loading. Results of abrasion tests show resistance to abrasion at 5 wt% TiO_2 filled J/Ep composite. Scanning electron micrographs evidenced that the fiber and filler have fairly good bonding with matrix. Finally, this investigation confirms the applicability of TiO_2 as secondary reinforcement in J/Ep composite.

Keywords

TiO_2 Filled J/Ep, Mechanical Properties, Abrasion, Scanning Electron Microscopy

1. Introduction

In recent years, attempts have been made to reduce the use of expensive fibers glass, aramid or carbon and also lighten considerably the automotive parts by taking advantage of the lower mass density and cost that majority natural fibers provide. In that sense, renewable fibers as load-bearing materials were vastly used in the composites of interior parts for a number of passenger and commercial vehicles [1]-[3]. Natural fiber/particulate reinforced polymer matrix composites (PMCs) have emerged as a potential environmentally-friendly and cost-effective choice to synthetic fiber reinforced PMCs. The availability of natural fibers and ease of extraction and manufacturing have tempted researchers to try locally available inexpensive fibers and to study their feasibility of effective reinforcement with engineering polymers for tribological applications [4]. Despite the interest and environmental appeal of natural fibers, their use has been limited to non-bearing applications due to their poor strength and stiffness compared with synthetic fiber/filler reinforced PMCs [5]. The stiffness and strength shortcomings of bio-composites can be overcome by structural configurations especially by chemical treatment and modified fabric architecture for highest strength performance.

With the advance of science and technology, high-molecular weight polymeric materials now become one of most attractive materials in recent years. Among thermosetting matrix resins used in composites manufacturing, epoxy resins are the most widely used for high performance applications [6] [7]. Epoxy matrixes exhibit excellent mechanical and thermal properties, low shrinkage upon curing, very good chemical and corrosion resistance properties and good process ability under variable working conditions. However, epoxy or epoxy-based materials have very poor impact resistance and wear properties. To improve the impact/wear resistance, several solutions have so far been proposed [8] [9]. The incorporation of inorganic fillers is one of the most common ones that soften rigid thermoset matrices [10] [11].

During the recent years, the interest in using natural fibres as reinforcement in polymers has increased. The attractive features of natural fibers like jute, sisal, silk, coir, banana, have been their low cost, light weight, high specific modulus, renewability and biodegrability. Since the interfacial bonding between the reinforcing fillers/fibers and polymer matrix is an important element in realizing the mechanical properties of the bio-based polymer composites. Several authors have focussed the studies on the treatment of fillers to improve the bonding with resin matrix.

The very fine micron-sized particles cause the particles to attract each other due to van der Waals forces and to form agglomerates. It is reported that a considerable amount of improvement in mechanical properties can be achieved using micron-sized filler loadings. Moloney *et al.* and other researchers [12]-[15] have reported that by selecting higher modulus filler and increasing the volume fraction, the modulus of filler filled epoxy can be increased. These reports prompted us to consider the exciting possibility of incorporating the fine micron-sized TiO_2 particles in a composite consisting of jute fabric reinforced epoxy to study their effects on the mechanical properties and abrasive wear behaviour of the composites. Siddhartha *et al.* [16] have investigated titanium dioxide (TiO_2) reinforced epoxy functionally graded composites. They concluded that addition of TiO_2 particles into epoxy has a dramatic effect on the flexural strength, tensile modulus, and interlaminar strength in comparison to homogeneous composites.

Shi *et al*. [17] studied the effects of filler crystal structure and shape on the friction and wear properties of potassium titanate whisker ($K_2Ti_4O_9$ whisker, $K_2Ti_6O_{13}$ whisker) and TiO_2 particles filled PTFE composites. They reported that the friction coefficients of various PTFE based composites are weakly dependent on filler shape, but they are more strongly dependent on filler crystal structure.

Swain *et al*. [18] have studied the physico-mechanical properties of alumina filled jute fiber reinforced epoxy hybrid composites. Jute and alumina as hybrid reinforcement in epoxy, they have concluded that hardness, strength, flexural and tensile modulus increased with increase in the fiber and filler loading. Alavudeen *et al*. [19] have investigated the mechanical properties of woven banana fiber, kenaf fiber and banana/kenaf hybrid fiber composites. Mechanical properties such as tensile, flexural and impact strengths of woven banana/kenaf fiber hybrid composites increased due to the hybridization of kenaf with banana fibers. Mantry *et al*. [20] have studied the tensile properties of unfilled and SiC particles filled jute/epoxy hybrid composites. They found that the tensile strength of unfilled jute/epoxy composite increased with increase in fiber loading. On the other hand the strength of SiC filled jute/epoxy composites decreased with increase in SiC loading. Osmani [21] has investigated the mechanical properties of silicon dioxide filled glass/epoxy composites and reported that tensile and shear strengths decreased with increase in silicon dioxide content and flexural strength and modulus were increased with increase in filler loading.

Among all the natural fibers, jute is more promising as it is relatively inexpensive and commercially available in various forms. Jute fiber has many inherent advantages like luster, low extensibility, high tensile strength, moderate fire and heat resistance and long staple lengths.

The effect of abrasion is particularly evident in the industrial areas of agriculture, mining, mineral processing, earth moving and essentially where ever dirt, rock, and minerals are handled. In three-body abrasive wear the grits are free to roll as well as slide over the surface, since they are not held rigidly. Tribology focuses on wear, friction and lubrication of interacting surfaces in relative motion. It was assessed that the total wear of machine element can be recognized as 80% - 90% in the form of abrasion and 8% as in the form of fatigue wear [22].

For effective performance of PMCs, abrasive wear is to be minimised. The fiber in plain weave woven form as reinforcement in polymer matrix improves the load bearing capability [23]. Among the different types of synthetic fibers used (carbon, aramid and glass) the wear rate of epoxy reinforced with carbon fibers is less than that of glass fibers [24]. Furthermore, woven fabric reinforced PMCs yield better wear characteristics [5] [25] [26]. Modi *et al*. [27] have found that there is an increase in wear resistance of carbon fabric reinforced composites and the same is attributed to their balanced properties due to the simultaneous existence of parallel and anti-parallel fibers. Agrawal *et al*. [28] concluded that specific wear rate decreases with increase in sliding velocity up to 40 wt% fiber reinforced and then further decreases, whereas specific wear rate increases with the increase in applied normal load for long and short glass reinforced epoxy composites.

Interestingly, natural fibers like coir, coconut coir sheath, bamboo, sugar cane, waste silk, oil palm, ipomoea carnea and banana have proved to be good and effective reinforcement in the thermoset matrices for abrasion resistance applications [29]-[35]. Some researchers reported that, natural fibers need to be chemically treated first to make them more compatible with thermoset polymers to improve the mechanical properties of the composites. Surprisingly, research articles concerning the tribological behaviour of natural fibres reinforced polymers are rare in the tribology literature. Furthermore, few research articles were focused on the study of abrasive wear behaviour of natural fibers in woven form without fillers [36]-[38].

The present work aims to investigate the role of TiO_2 as secondary filler in the plain weave woven from jute fabric reinforced epoxy hybrid composites on mechanical and three-body abrasive behaviour of such hybrid composites. Tensile and flexural properties at rupture were measured for both unfilled and TiO_2 filled jute/epoxy (J/Ep) composites. Also, unfilled and TiO_2 filled J/Ep composite specimens were subjected to three-body abrasion tests using Rubber Wheel Abrasion Tester with dry silica sand abrasives. Results of mechanical properties and abrasive wear for unfilled and TiO_2 filled J/Ep composites at different loads/velocity and abrading distance are presented and discussed.

2. Materials and Testing Methods

2.1. Materials

In this study a bidirectional woven jute fabric with a density of 1.31 g/cm^3 (Calcutta supply agency, Bangalore) was used as reinforcement. The areal weight of the fabric used is approximately 320 g/m^2. The matrix material system selected is an epoxy resin (Bisphenol-A MY 740 with density 1.16 g/cm^3) supplied by Huntsman advanced materials, Bangalore, India. Araldite HY 918 and Anhydride DY 062 were used as hardener and accelerator. The commercially available titanium dioxide microfiller were obtained from Srivathsa enterprises, Bangalore. Its particle size ranged from 30 - 50 μm was used as filler material.

2.2. Composite Fabrication

The composite samples were fabricated by hand lay-up method followed by compression using a hot press. Plain weave jute fabric, which is compatible to epoxy resin, is used as the reinforcement. The mixture of epoxy resin and hardener is mixed in the ratio 100:12 by weight. The stacking procedure consists of placing the fabric one above the other with the resin mix well spread between the fabrics. A porous Teflon film is placed on the completed stack. To ensure uniform thickness of the sample a spacer of size 3 mm is used. The mould plates have a release agent smeared on it. The whole assembly is pressed in a hydraulic press (0.5 MPa) and allowed to cure for a day at room temperature. After molding, post curing was done at 100˚C for 2 h using an air circulated oven. The laminate so prepared has a size 250 mm × 250 mm × 3 mm. To prepare the titanium dioxide (TiO_2) filled J/Ep composites, filler TiO_2 is mixed with a known amount of epoxy resin. The details of the composites prepared are listed in Table 1. Specimens were cut to the ASTM standards using water jet machining.

2.3. Physico-Mechanical Tests

2.3.1. Density

Density was measured in accordance with ASTM D-792 method using METTLER AE 200 densitometer. The specimen is weighed in air, and then weighed after immersion in distilled water at 23˚C using a sinker and a wire to hold the specimen which was completely submerged.

2.3.2. Tensile Properties

The tensile strength and the tensile modulus of glass-epoxy composite with and without fillers were determined according to ASTM D638-14. The tensile test was carried out with the dog-bone-shaped specimens using universal test machine at room temperature. A crosshead speed of 2 mm/min was applied. The data reported were averages of at least five measurements for each composition. Tensile modulus was evaluated from the stress-strain diagram.

2.3.3. Flexural Properties

Bending test was applied to J/Ep composite with and without TiO_2 filler in order to determine the flexural properties. ASTM D790-10 was followed to determine the bending strength and the modulus unfilled and TiO_2 filled J/Ep composites. Test Method 1 of ASTM D790-10 was used in which a three-point loading system-utilizing centre loading on a simply supported beam was employed. Specimens were machined from a laminate and tested at a crosshead speed of 1.5 mm/min. The test specimen had dimensions of 90 mm × 12 mm × 3 mm. Five specimens from each composition were tested and flexural strength and modulus were evaluated from the load-deflection curves.

The tensile and bending tests were carried out on a fully automated Kalpak-100 kN universal testing machine connected to a computer, which was aided by KALPAK software. A 50-kN/10 kN load cell was used and load versus deflection data were collected for all measurements. The loading was of displacement-controlled type. The load

Table 1. Composites selected for the present study.

Composite's composition	Designation	Jute fiber (wt%)	Epoxy (wt%)	TiO_2 filler (wt%)
Jute fabric reinforced epoxy	J/Ep	55	45	0
Titanium dioxide filled Jute fabric reinforced epoxy	J/Ep-2.5 TiO_2	55	42.5	2.5
Titanium dioxide filled Jute fabric reinforced epoxy	J/Ep-5 TiO_2	55	40	5
Titanium dioxide filled Jute fabric reinforced epoxy	J/Ep-7.5 TiO_2	55	37.5	7.5
Titanium dioxide filled Jute fabric reinforced epoxy	J/Ep-10 TiO_2	55	35	10

versus deflection curves obtained from the tests was transformed into stress versus strain curves.

2.3.4. Abrasive Wear Test

The three-body abrasive wear tests were conducted using a dry sand/rubber wheel abrasion tester as per ASTM G-65. The dimensions of the samples measuring 75 mm × 27 mm × 3 mm was cleaned with acetone and dried. The experiments were carried out for two different loads (23.5 and 47 N) under different abrading distances (125 m to 500 m). Densities of the composites were determined using a high precision electronic weighing balance following Archimedes's principle. The tests were conducted at a rotational speed of 200 rpm. The wear was measured by the loss in weight, which was then converted into wear volume using the measured density data. After the wear test, the sample was again cleaned. The specific wear rate (K_s) was calculated from the equation:

$$K_s = \frac{\Delta V}{L \times D} \quad \text{m}^3/\text{N}\cdot\text{m} \tag{1}$$

where ΔV is the volume loss, L is the load and D is the abrading distance.

2.3.5. Scanning Electron Microscopy

Tensile and flexural fractured surfaces of test specimens were examined by using Model JEOL JSM-6480LV scanning electron microscopy with an acceleration voltage of 20 kV. Before the examinations, a thin gold film was coated on the fractured surface by sputtering to achieve a conducting layer.

3. Results and Discussion

The measured density, tensile and flexural properties of the TiO_2 filled J/Ep composites are tabulated in Table 2. All measurements of the mechanical properties reported here show that the TiO_2 filled J/Ep samples are significantly stronger than the unfilled J/Ep composite samples.

3.1. Effect of Filler Loading on Density

The measured densities of the unfilled and TiO_2 filled J/Ep composite samples are listed in Table 2. As indicated in Table 2, the density variation of TiO_2 filled J/Ep composites

Table 2. Physico-mechanical properties JE and TiO_2 filled JE composites.

Sample code	J/Ep	J/Ep-2.5 TiO_2	J/Ep-5 TiO_2	J/Ep-7.5 TiO_2	J/Ep-10 TiO_2
Density, ρ (g/cm^3)	1.20	1.29	1.36	1.40	1.44
Tensile strength, σ (MPa)	25.9	33.07	34.09	40.02	29.05
Tensile modulus, E (GPa)	1.32	1.68	1.78	1.95	1.25
Flexural strength, σ_f (MPa)	64.2	93.74	95.27	99.34	74.95
Flexural modulus, E (GPa)	2.51	3.17	3.49	3.62	3.03

are significant. It is observed that as the TiO_2 filler loading increases, the bulk density of J/Ep composite also increases. At the same time, density of TiO_2 is 4.1 g/cm^3 which is higher that the J/Ep composite. Further, in can be seen the 10 wt% TiO_2 filled J/Ep is 1.44 g/cm^3, which is highest when compared to other compositions of J/Ep composites.

3.2. Mechanical Properties of Composites

The importance of mechanical properties is to quantify the role of fiber and filler in PMCs. Further, mechanical properties can also provide information on interfacial behaviour in composites, because the interaction between the fiber and/filler with the polymer matrix has a great effect on the mechanical properties. The mechanical properties such as tensile/flexural strength, modulus and deformation were reported in Table 2 and in Figures 1-4.

The typical load-displacement curves of unfilled and TiO_2 filled J/Ep composites are shown in Figure 1 and the measured mechanical test results are listed in Table 2. Referring to the tensile and flexural test results listed in Table 2, it can be seen that both modulus and strength increases up to 7.5 wt% TiO_2 filler loading. When the loading is above 7.5 wt%, it was found that the strength as well as modulus decreased rapidly. This could be due to more particles get agglomerated and poor interaction between TiO_2 particles and J/Ep composite.

It is observed from that the tensile strength of TiO_2 filled J/Ep composites is higher than that of unfilled J/Ep composite. The variation in the elongation at break, strength and modulus of unfilled and TiO_2 filled J/Ep composites are given in Figure 1 and Figure 2 respectively.

From the measured elongation of various J/Ep composites in Figure 1, the elongation was found to be higher in the case of unfilled J/Ep composite, while this value is lower in the of TiO_2 filled J/Ep composites. Regarding the elongation values of particulate

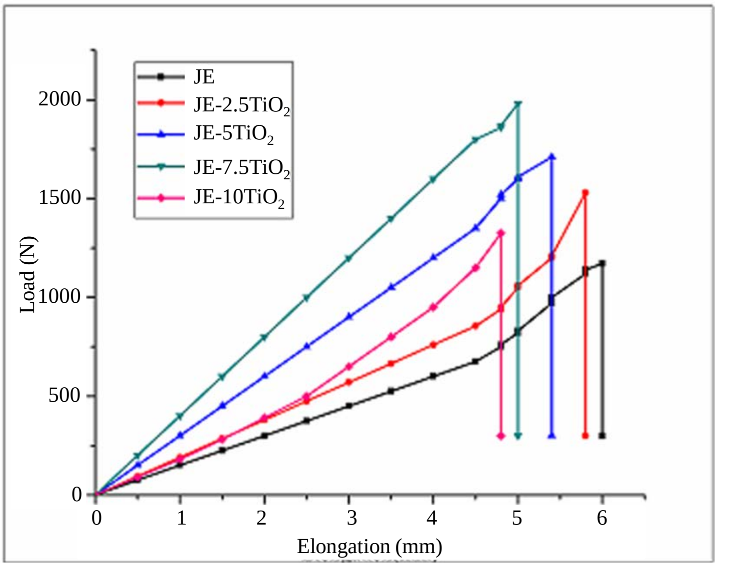


Figure 1. Load vs Elongation at break for TiO_2 filled J/Ep composites.

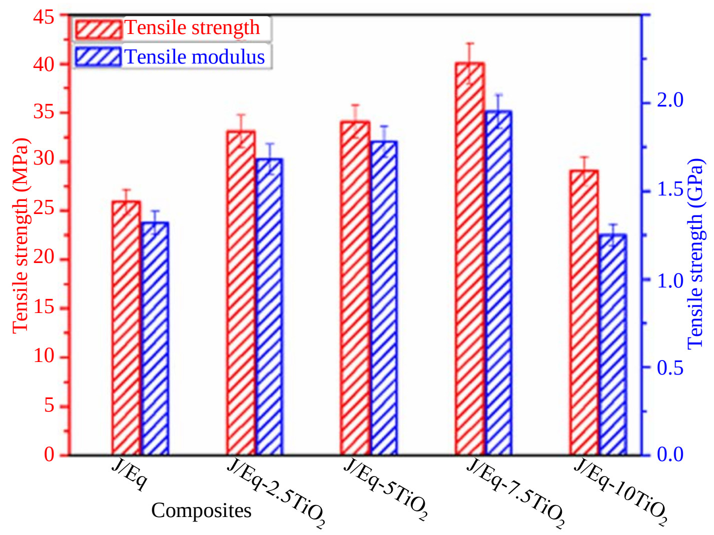


Figure 2. Tensile strength and modulus of TiO_2 filled J/Ep composites.

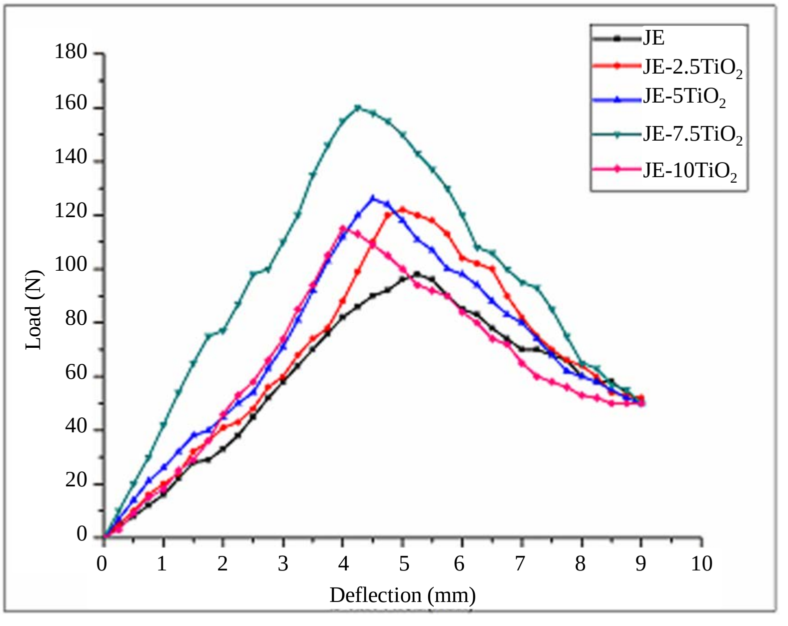


Figure 3. Load vs deflection for TiO_2 filled J/Ep composites.

filled fiber reinforced PMCs, structural parameters of fiber/filler shape, ductility, strength, stiffness, and aspect ratio play an important role. These values are dominated by the fiber/filler breakage and matrix cracking. The ductile nature of jute fiber provides strain compatibility between fiber and matrix. The strain compatibility get reduced when TiO_2 filler is hybridized with jute fiber, elongation is decreased. In general, factors such as the extent of bonding of the filler to the epoxy matrix and the distribution of the filler in the epoxy matrix as well as the shape, size and content of the particulate fillers have been found to affect mechanical properties of the epoxy matrix composite. In the present work, it seems that there is a relation between the particles

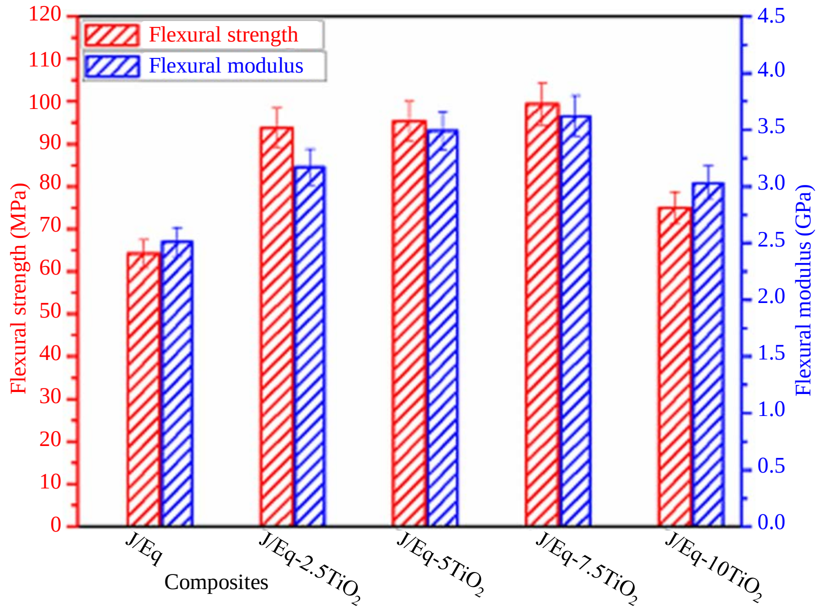


Figure 4. Flexural strength and modulus of TiO_2 filled J/Ep composites.

loading producing elongation, as the loading increases the elongation at break decreases.

Figure 2 shows the tensile strength and modulus as a function of TiO_2 filler loading for the J/Ep composite specimens manufactured by hand lay-up followed by compression moulding. It can be seen that the tensile strength and tensile modulus of all J/Ep composites increased with increasing TiO_2 content; which showed that an increase in the rigidity of TiO_2 filled J/Ep composites would result in more resistance to higher load at low elongation. In TiO_2 filled J/Ep composite samples the higher strength and modulus indicates there was better filler-matrix bonding combined with the fact that the rigid TiO_2 filler was stronger than the jute fiber. The tensile strength is increased with increasing TiO_2 up to 7.5 wt%, because of the uniform dispersion of TiO_2 filler in J/Ep (**Figure 2**). However, the increase in tensile strength is marginal beyond 7.5 wt% of TiO_2 filler loading. This could be attributed to a slight agglomeration of TiO_2 particles in J/Ep. The improvement in the J/Ep composite tensile properties by using small amount of TiO_2 filler may be attributed to the improvement of the interfacial interaction. TiO_2 particles have higher rigidity than epoxy and sufficient particle/matrix adhesion as well as good bonding between fiber and matrix should be attributed for the interfacial interaction improvement. This investigation is mainly focused on TiO_2 filler loading rather than unfilled J/Ep composite, taking the 7.5 wt% TiO_2 loading into J/Ep there is about 23% increase in the tensile strength.

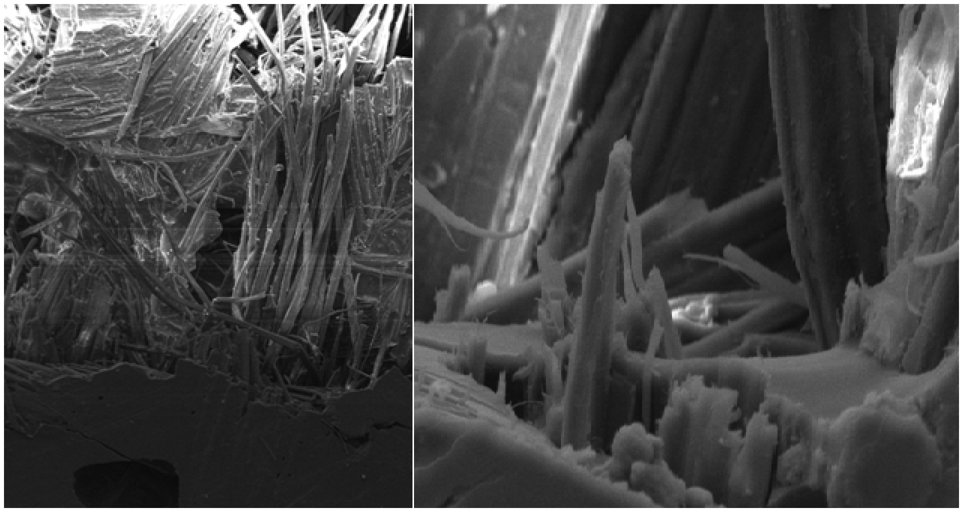
Elastic modulus is mainly dependent on the matrix deformation of the composite and increases as the slope of the load-deformation curve at the initial stage and is practically not much influenced by the interfacial strength between fiber and matrix. Generally, the addition of TiO_2 filler and jute fiber reduces the elongation at break because of the lower elongation at break values of TiO_2 filler and jute fiber compared to that of epoxy matrix at the filler loading 0 - 10 wt%. Comparing the results, it can be seen that TiO_2 filled J/Ep samples show improved mechanical properties, confirming the effect of TiO_2 filler inclusion. The addition of TiO_2 particles causes a dispersion of these particles in the matrix which impede to the propagation of failure along the loading direction. Thus the failure would propagate easily in those directions where the dispersed concentration is less leading to increased tensile strength, modulus and lower elongation. Fuqua and Ulven studied the role of MAPP on tensile properties of corn chaff fiber reinforced polypropylene composite materials [39]. They also studied the effect of different silane treatments on corn chaff fiber and distilled dried grains reinforced PP composite materials. It was concluded that 5 wt% MAPP yielded the optimum tensile and modulus properties for the PP composites. They also concluded that the strength reduction in higher MAPP loading was due to poor interaction between the compatibilizer and the fiber/matrix system. Similar observations were also found from our present investigation for TiO_2 filled J/Ep composites.

PMCs used in structures are likely to fail in bending and therefore the development of new fiber and particulate filled PMCs with improved flexural characteristics is necessary. Flexural mechanical test was performed to evaluate the strength, modulus and deflection of the unfilled and TiO_2 filled J/Ep composites.

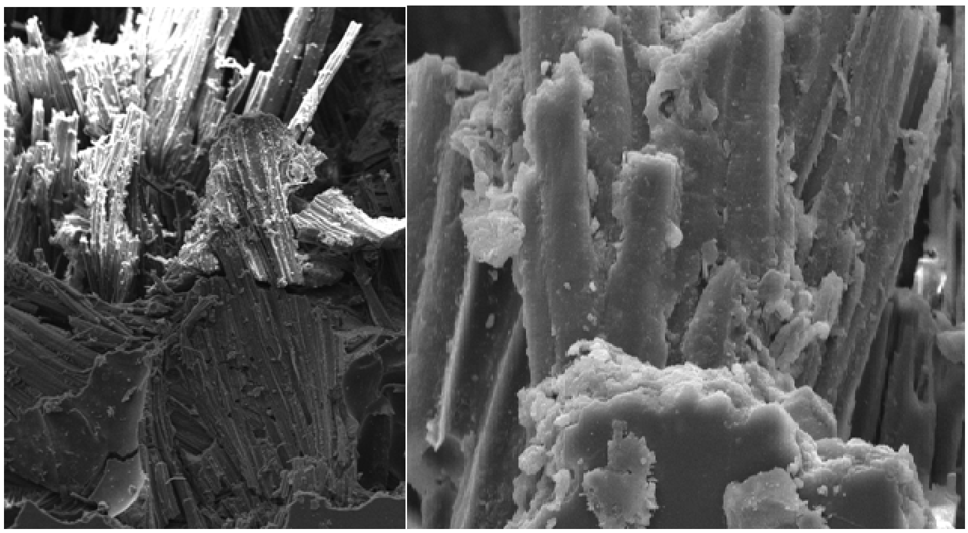
The flexural properties of these composites are shown in **Table 2** and the typical load-deformation curves are shown in **Figure 3**. Flexural properties like strength and modulus of unfilled and TiO_2 filled J/Ep composites are shown in **Figure 4**. The flexural strength of unfilled J/Ep composite is 64.2 MPa and increases with increase in TiO_2 filler loading. Modifying the J/Ep composite with different TiO_2 loading improved both flexural strength and modulus. In the case of 7.5 wt%, TiO_2 particles caused a maximum increase in the flexural strength (64.2 to 99.34 MPa) as well as modulus (3.17 to 3.62 GPa). The maximum flexural strength and modulus increase is about 55% and 14 5 respectively, when compared to unfilled J/Ep.

As discussed earlier, the fiber and filler interface in PMCs plays a major role in the improvement of the mechanical properties. Stresses transfer and elastic deformation from the matrix to the fiber and fillers are governed by the interface quality. Due to the higher rigidity of TiO_2 particles compared to epoxy, the deformation comes from the polymer. Up to 7.5 wt%, the TiO_2 particles are able to induce further mechanisms of failure without blocking matrix deformation. On the other hand, when filler loading exceed 7.5 wt%, large number of particles get agglomerated and reduced the matrix deformation. These results indicate that there is no significance of increasing the filler loading beyond 7.5 wt%.

SEM micrographs of fracture surfaces of unfilled and TiO_2 filled J/Ep composites are shown in **Figure 5(a)** and **Figure 5(b)**. **Figure 5(a)** shows the unfilled J/Ep composite after tensile testing in which a smooth fracture surface as well as cracks in different planes of matrix (**Figure 5(a)**), more fiber breakage in the loading direction, pull-out of fibers in the transverse direction (**Figure 5(a)**) can be seen. This is an indication of a brittle fracture of the J/Ep composite. It can be observed that the fibers were cut



(a)



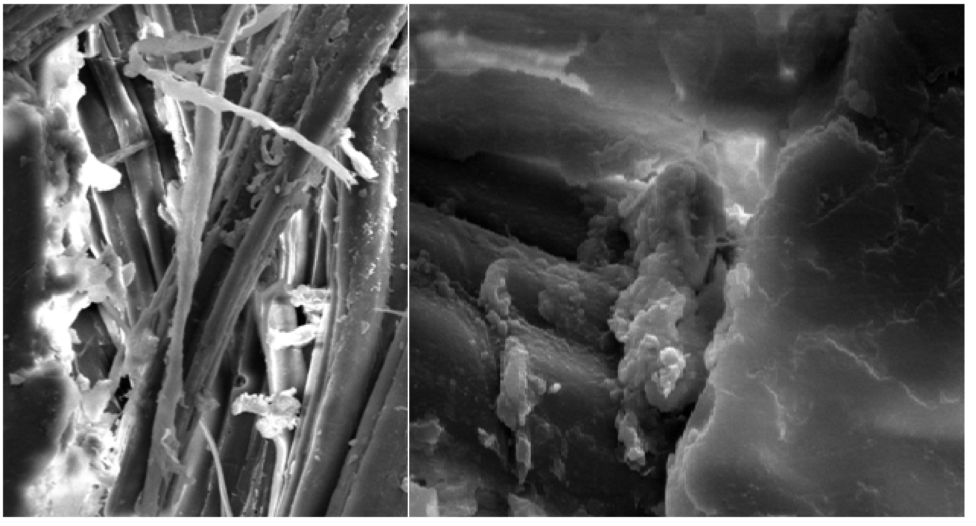
(b)

Figure 5. Fractographs of tensile failed samples (a) unfilled J/Ep and (b) 7.5 wt% TiO_2 J/Ep composites.

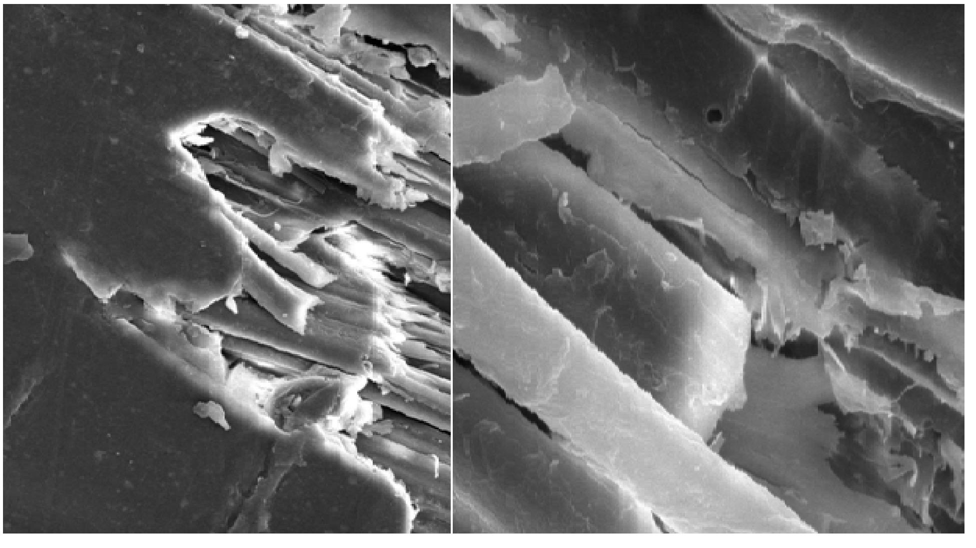
perpendicular to fiber axis (bottom portion of micrograph, **Figure 5(a)**), few fibers damaged in the length direction and also relatively poor bonding with the epoxy matrix. This indicates that a relatively small amount of energy was consumed to fracture the J/Ep samples.

Figure 5(b) shows lower and higher magnified SEM images of J/Ep composite after tensile testing for 7.5 wt% of TiO_2 filler loading, respectively. When TiO_2 introduced into J/Ep, the fracture morphology is different from that of unfilled J/Ep. From **Figure 5(a)**, it can be observed that the matrix surface is rough, more cracks in different planes, good bonding between fiber/filler and matrix as well as less fiber breakage (**Figure 5(b)**). This result indicates the resistance of the material and emphasizes that the ultimate strength is at 7.5 wt% of TiO_2 in J/Ep composite.

SEM micrographs of bending test failed fractographs of TiO_2 filled and unfilled hybrid composites were shown in Figure 6(a) and Figure 6(b). Figure 6(a) and Figure 6(b) shows SEM pictures of flexural fractured surfaces of JE and JE-7.5TiO_2 samples at 50x and 500x magnifications respectively. From Figure 6(a), it can be clearly observed the jute fiber pull out and debonding between the reinforcement and matrix material. The lack of adhesion between the pulled out fibers and the resin is also visible from the Figure 6(b). The agglomeration is the collective stacking or collection of fibers together in the matrix which reduces the strength by non-uniform stress transfer. The fiber-matrix adhesion, dispersion and orientation of fibers, fiber agglomeration, and presence of air voids these are the influential factors for reduction of strength of the fiber reinforced composite.



(a)

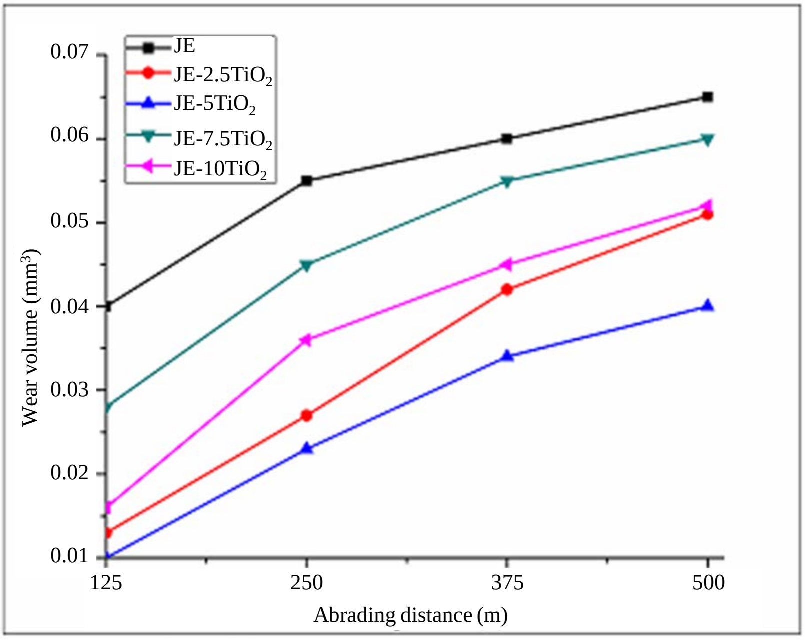


(b)

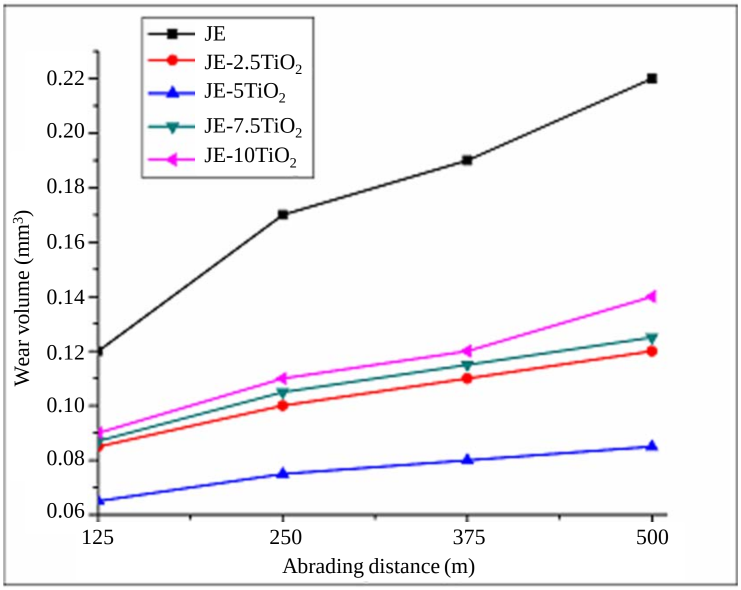
Figure 6. (a) Fractograph of bending failed sample of unfilled J/Ep composites; (b) Fractograph of bending failed sample of 7.5 wt% TiO_2 J/Ep composites.

3.3. Abrasive Wear Performance

Abrasive wear performance results are reported as wear volume loss of J/Ep composites; the greater the wear volume loss, the lower the abrasion resistance. The wear volume loss for the unfilled and TiO_2 filled jute fabric epoxy composites as a function of abrading distance at two different loads of 23.5 N and 47 N are shown in Figure 7(a) and Figure 7(b) respectively. It is clear that the abrasion resistance of all J/Ep composites



(a)



(b)

Figure 7. Wear volume of unfilled and TiO_2 filled J/Ep composites: (a) 23.5 N and (b) 47 N.

increased with increasing TiO_2 content; this is because of improved filler/matrix adhesion and good interaction between filler and matrix upto 5 wt% of TiO_2loading and beyond this loading, TiO_2 particles removed during three-body abrasion leading to increased wear volume loss. Further, it is observed that there is a near-linear trend of volume loss with an increasing abrading distance (Figure 7(a) and Figure 7(b)). The highest volume loss is seen with unfilled J/Ep composites while the lowest is seen for 5 wt% TiO_2 filled JE composite. The volume loss is higher in (7.5 and 10 wt%) TiO_2 filled J/Ep as compared to 5 wt% TiO_2 filled ones, indicating the good bonding between filler and fiber with the matrix. With the increase in filler loading, the wear volume loss of the composites also increases. Wear resistance is better in J/EP with 5 wt% TiO_2 and it could be due to the uniform dispersion of TiO_2 particles in the matrix. Higher filler loading >5 wt% in the epoxy matrix did not protect the fibers from damage and hence increased the wear volume loss.

The wear volume strongly depends on the applied load and abrading distance for all the composites. With an increase in applied load from 23.5 N to 47 N there is an increase in the wear volume, due to the fact that the apparent contact area is greatly increased at higher applied load of 47 N. This increase in contact area, allows a large number of sand particles to encounter the interface and share the stress. This, in turn, leads to increase in the wear volume. Among the composites studied, the better abrasion resistance was achieved at 5 wt% TiO_2 filled J/Ep composite. This is attributed to the fact that, in 5 wt% TiO_2 filled J/Ep composite, the dispersion of filler is more or less uniform and better adhesion due to surface modification of fillers and fairly good interaction between the matrix and fiber/filler.

4. Conclusions

Jute fabric reinforced epoxy composites filled with TiO_2 filler were tested for their physical, mechanical properties as well as three-body abrasive wear. The following findings were observed.

- Increasing TiO_2 content up to 7.5 wt% tended to increase the tensile and flexural modulus of J/Ep composites, but decreased the deformation at break.
- TiO_2 particles could be used as secondary reinforcing filler with jute fabric in epoxy matrix composites because of the dispersive enhancement of jute in the form of fabric in the epoxy matrix, as indicated by an increase in tensile and flexural strength.
- Compared with unfilled J/Ep composite, the mechanical properties of the 7.5 wt% TiO_2 filled JE composite show better tensile and flexural strength with an increase of 23.4% and 54.5% respectively. Tensile properties results show that both tensile strength and tensile modulus of J/Ep composites tend to increase with increase in TiO_2 filler loading, especially up to 7.5 wt%. Higher loading of TiO_2 beyond 7.5 wt%, the strength and modulus was found to decrease and is due to poor interaction between the filler and fiber/matrix system.
- TiO_2 filler addition to J/Ep composites has exceptionally improved the abrasive

wear performance. The maximum wear volume is observed for unfilled J/Ep composites. The wear volume is increased with increase in abrading distance and load and decreased with increase in TiO_2 loading up to 5 wt%.

- The fractographs of both tensile and flexural specimens show microcracks in the matrix, pull-out of fibers, debonding of fiber, bending of transverse fiber, better adhesion between filler and matrix.

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