

Physical, Mechanical and Water Absorption Behaviour of Coir Fiber Reinforced Epoxy Composites Filled With Al₂O₃ Particulates

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Abstract: The objective of the present work is to study the physical, mechanical and water absorption behaviour of coir fiber reinforced epoxy composites filled with Al₂O₃ particulates. Composites with different compositions were prepared by varying the length of the fiber and content of fiber using hand lay-up technique. The experimental investigation reveals that the properties of composite increases with the incorporation of Al₂O₃ particulates. It is observed that the density of composites increases with increase in fiber content, while a decrease in density is observed with increase in fiber length. The strength properties of the composites increases with the increase in fiber content up to 15 wt.% and 12mm fiber length, however further increase in fiber length and fiber content the value decreases. The maximum tensile strength of 25.71MPa, flexural strength of 29.75MPa and impact strength of 14.76kJ/m² is obtained for composites with 12 mm fiber length and 15 wt.% of fiber content. The hardness and tensile modulus, on the other hand, increases with increase in fiber length and fiber content. The maximum hardness value of 19.52H_v and tensile modulus of 3.412GPa is obtained for composites with 15mm fiber length and 20 wt.% of fiber content. Finally, morphological analysis is also carried out using scanning electron microscope (SEM) to study the fracture behaviour of the composite samples.

Keywords: Coir fiber, Epoxy, Al₂O₃ particulate, fiber content, fiber length, mechanical properties.

1. Introduction

Over the past two decades, natural fibres have been receiving considerable attention as substitutes for synthetic fibre reinforcements like glass and carbon. Unlike the traditional synthetic fibres these lignocellulosic fibres are able to impart certain benefits to the composites such as low density, low cost, high stiffness, biodegradability, renewability and high degree of flexibility during processing. A great deal of work has been done on the mechanical properties of various natural fibres and how these fibres interact with various thermosets and thermoplastics. Among the different natural fibers, coir is seems to be a promising fiber due to its low cost, high availability, low density, easy production and friendly to environment. Coir consists of cellulosic fibers with hemi-cellulose and lignin as the



bonding materials for the fibers. The lignin content in coir fiber is quite high, so the fiber becomes stiffer, tougher and more long-lasting when compared to other natural fibers. Generally, coir is a waste of natural resources and a cause of environment pollution. Hence, research and development efforts have been going on to find out the new areas for coir, along with utilization of coir as reinforcement in polymer composites. Junior et al. [1] studied the tensile behaviour of coir fiber reinforced polyester composites. Monteiro et al. [2] studied the mechanical performance of coir fiber/polyester composites. The mechanical behaviour of coir fiber/polyester composites which revealed the lack of an efficient reinforcement by coir fibers is attributed to their low modulus of elasticity, in comparison with the neat polyester resin. Slate [3] investigated the mechanical properties of coir fiber reinforced cement sand mortar. Ayrlimis et al. [4] studied on coir fiber reinforced polypropylene composite panel for automotive interior applications. This study reported that the coir fiber is a potential reinforcement for thermoplastic composites, specifically for partial replacement of high cost and heavier glass fibers. Mazan et al. [5] studied the viability of coir fiber reinforced composites in sound absorption panel. Among different parameters fiber length and fiber content are the most important factors significantly influencing the properties of composites. Sumaila et al. [6] studied the effect of fiber length on the physical and mechanical properties of random oriented, nonwoven short banana fiber reinforced epoxy composites and concluded that the tensile strength, tensile modulus and percent elongation had their highest values at 15mm fiber length. Jutarat et al. [7] studied the effect of cotton fiber contents and lengths on properties of thermoplastic starch composites prepared from rice and waxy rice starches. Maged et al. [8] investigated the effect of fiber length and concentration on the physical properties of wheat husk fibers rubber composites.

Major constituents in fiber reinforced polymer composite are the reinforcing fibers and a matrix. In addition, particulate fillers can also be used with some polymeric matrices primarily to reduce cost and improve the properties. Hard particulate fillers consisting of ceramic or metal particles are being used to significantly improve the properties of many composite materials. The improved performance of polymers and their composites in industrial and structural applications by the addition of particulate fillers has shown a great promise and so has lately been a subject of considerable interest. Aluminium oxide (Al_2O_3) commonly referred to as alumina, is the most cost effective and widely used material in the family of engineering ceramics and has the potential to be used as filler in various polymer matrices. It is hard, wear-resistant, high strength and stiffness, has excellent dielectric properties, resistance to strong acid and alkali attack at elevated temperatures. With an excellent combination of properties and a reasonable price, it is no surprise that fine grain technical grade alumina has a very wide range of applications.

Although a great deal of work has been done on the coir fiber based polymer composites, however the study on the effect of filler and the fiber parameters such as fiber content and length on the physical, mechanical and water absorption behaviour is limited. To this end, the objective of the present work is to study the effect of fiber content and fiber length on the physical, mechanical and water absorption behaviour of coir fiber reinforced epoxy composites filled with Al_2O_3 particulate.

2. Experimental details

2.1. Composite fabrication

Short coir fiber and Al_2O_3 filler is taken as reinforcement and epoxy as matrix material. The coir fiber is collected from local sources and Al_2O_3 filler is obtained from NICE Ltd., Kolkata, India. The epoxy resin and corresponding hardener is supplied by Ciba Geigy India Ltd. The fabrication of the composite slabs is done by using conventional hand-lay-up technique. The Al_2O_3 filler has average particle size of 80-100 micron and their density is 3.69gm/cm^3 . The mould having dimension of $180 \times 180 \times 40 \text{ mm}^3$ is used for composite fabrication. Composites of various compositions were prepared by varying the content of fiber (5wt.%, 10wt.%, 15wt.% and 20wt.%) and length of the fiber (3mm, 6mm, 9mm, 12mm and 15mm) at constant filler loading (10wt%). The cast of each composite material is cured under a load of about 50kg for 24 h before it removed from the mould. Then,

specimens of suitable dimension are cut using a diamond cutter for various testing. The designation and composition of composites are listed in the Table1. Fig. 1, 2 and 3 shows the coir fiber, Al_2O_3 filler and the fabricated composite, respectively.



Fig. 1:- Coir fiber

Fig. 2:- Al_2O_3 filler

Fig. 3:- Fabricated composites

Table 1: Designation and detailed composition of the composites

Designation	Compositions
S1	Epoxy (85wt%) + Coir Fiber (3mm) (5wt%) + Al_2O_3 (10wt%)
S2	Epoxy (85wt%) + Coir Fiber (6mm) (5wt%) + Al_2O_3 (10wt%)
S3	Epoxy (85wt%) + Coir Fiber (9mm) (5wt%) + Al_2O_3 (10wt%)
S4	Epoxy (85wt%) + Coir Fiber(12mm) (5wt%) + Al_2O_3 (10wt%)
S5	Epoxy (85wt%) + Coir Fiber (15mm) (5wt%) + Al_2O_3 (10wt%)
S6	Epoxy (80wt%) + Coir Fiber (3mm) (10wt%) + Al_2O_3 (10wt%)
S7	Epoxy (80wt%) + Coir Fiber (6mm) (10wt%) + Al_2O_3 (10wt%)
S8	Epoxy (80wt%) + Coir Fiber (9mm) (10wt%) + Al_2O_3 (10wt%)
S9	Epoxy (80wt%) + Coir Fiber (12mm) (10wt%) + Al_2O_3 (10wt%)
S10	Epoxy (80wt%) + Coir Fiber (15mm) (10wt%) + Al_2O_3 (10wt%)
S11	Epoxy (75wt%) + Coir Fiber (3mm) (15wt%) + Al_2O_3 (10wt%)
S12	Epoxy (75wt%) + Coir Fiber (6mm) (15wt%) + Al_2O_3 (10wt%)
S13	Epoxy (75wt%) + Coir Fiber (9mm) (15wt%) + Al_2O_3 (10wt%)
S14	Epoxy (75wt%) + Coir Fiber (12mm) (15wt%) + Al_2O_3 (10wt%)
S15	Epoxy (75wt%) + Coir Fiber (15mm) (15wt%) + Al_2O_3 (10wt%)
S16	Epoxy (70wt%) + Coir Fiber (3mm) (20wt%) + Al_2O_3 (10wt%)
S17	Epoxy (70wt%) + Coir Fiber (6mm) (20wt%) + Al_2O_3 (10wt%)
S18	Epoxy (70wt%) + Coir Fiber (9mm) (20wt%) + Al_2O_3 (10wt%)
S19	Epoxy (70wt%) + Coir Fiber (12mm) (20wt%) + Al_2O_3 (10wt%)
S20	Epoxy (70wt%) + Coir Fiber (15mm) (20wt%)+ Al_2O_3 (10wt%)

2.2. Physical and mechanical tests

The composites under this study consists of three components namely matrix, fiber and particulate filler. The actual density (ρ_{ce}) of the composite is determined experimentally by simple water immersion technique. However, the theoretical density of composite materials in terms of weight fraction is calculated using the following equation [9]:

$$\rho_{ct} = \frac{1}{\left(\frac{W_f}{\rho_f}\right) + \left(\frac{W_m}{\rho_m}\right) + \left(\frac{W_p}{\rho_p}\right)} \quad (1)$$

Where, W and ρ represent the weight fraction and density respectively. The suffix f , m , p and ct stand for the fiber, matrix, particulate filler and the composite materials respectively. The volume fraction of voids (V_v) in the composites is calculated using the following equation:

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \quad (2)$$

Micro-hardness measurement is done using a Leitz micro-hardness tester. The tensile test is performed in the universal testing machine Instron 1195 as per ASTM D 3039-76. The three point bend test is conducted on all the composite samples in the universal testing machine Instron 1195. Span length of 40 mm and the cross head speed of 2mm/min are maintained. Impact strength of the composites is evaluated by a low velocity impact tests conducted in an impact tester as per ASTM D 256 test standards. The fractured surfaces after tensile testing are examined using scanning electron microscope (SEM) JEOL JSM-6480LV.

2.3. Water absorption test

The water absorption tests of coir fiber reinforced epoxy composites were done as per ASTM 570 by immersion in distilled water at room temperature. The samples were taken out periodically and after wiping out the water from the surface of the sample weighted immediately using a precise balance machine to find out the content of water absorbed. The specimens were weighed regularly at 24, 48, 72, 96, 120, 144, 168, 192, 216, 240, 264, 288, 312, 336, 360, 384, 408, 432, 456 and 480 hours. The water absorption is calculated by the weight difference. The percentage weight gain of the samples is measured at different time intervals by using the following equation.

$$\text{Water absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad (3)$$

Where, W_1 and W_2 are the weight of the dry and wet samples.

3. Results and discussion

3.1. Density

Density is one of the most important factors in determining the properties of composites of a composite material. It mainly depends on the relative proportion of reinforcement and matrix. The void content of composites is the difference between the experimental density and the theoretically density values of composites. Fig. 4 shows the effect of fiber parameters on the density of composites. It is clearly observed from the figure that the density of composites decreases as the fiber length increases from 3mm to 15mm. This is mainly due to the inclusion of long fibers into the composites decreases the packing, which leads to the disruption of fiber distribution and resulting in high void spaces. Apparently, greater void contents yield low density composite. However, the density of composites increases with increase in fiber content. Fig. 5 shows the variation of void content with fiber parameters. It is evident from the figure that the void content in the composites increases with the increase in fiber content. Presence of large amounts of the hydroxyl group in natural fibers makes them polar and hydrophilic in nature. This polar nature also results in high moisture absorption in natural fiber based polymer composites, leading to fiber swelling and voids in the fiber-matrix interface [10].

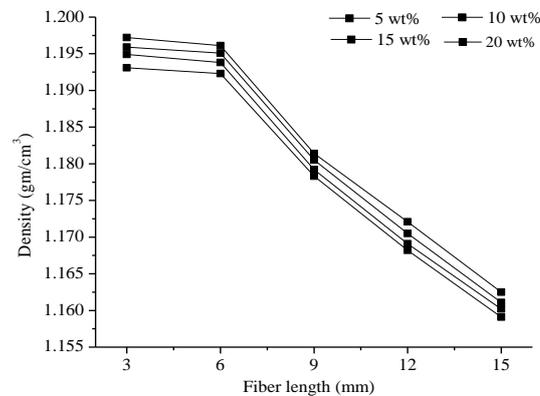


Fig. 4:- Effect of fiber content and length on density of composites

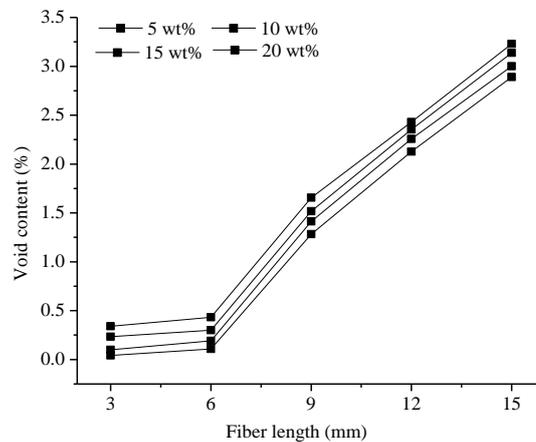


Fig. 5:- Effect of fiber content and length on void of composites

3.2. Tensile strength

The tensile strength of Al_2O_3 filled coir fiber composites is presented in Fig. 6. The tensile strength of composites increases with increase in the fiber content up to 15 wt.%. However, further increase in fiber content the strength decreases. This decrease may be due to the improper adhesion hinders the increase of tensile strength. As the fiber content increases, instead of dispersion the gathering of fibers takes place and the resin cannot wet the fibers due to non-entrance of resin in-between the two adjacent fibers. It is also observed that as the fiber length increases, the tensile strength of composites increases and then decreases irrespective of fiber content. In case of small fiber length, tensile strength is less due to the fact that length may not be sufficient enough for proper load distribution. On the other hand, for the composites of longer fiber length, tensile strength decreases. The reason may be due to the fact that longer fiber may not become compatible with the matrix properly.

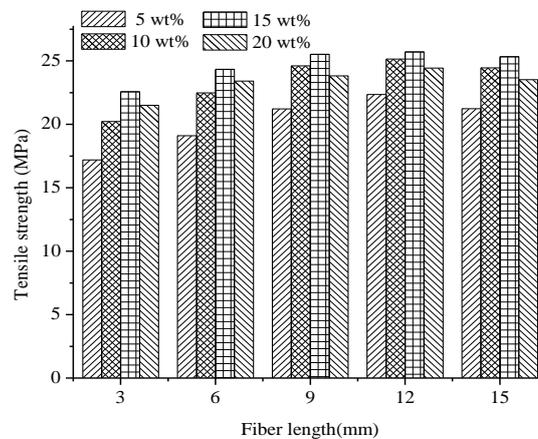


Fig. 6:- Effect of fiber content and length on tensile strength of composites

3.3. Tensile modulus

The effect of fiber parameters on the on the tensile modulus of composites is shown in Fig. 7. It is evident from the figure that the tensile modulus increases with the increase in fiber content. The increase in fiber content results in increased brittleness of the composites; thus stress/strain curve becomes steeper. Thus, as the fiber content increases, the degree of hindrance increases, which in turn increases the stiffness. On the other hand as the fiber length increases, the tensile modulus of the composites also increases.

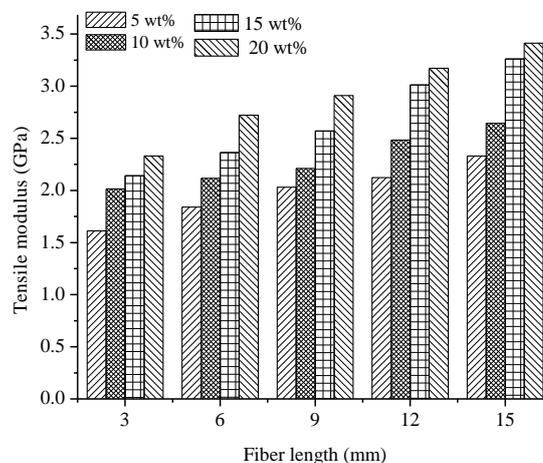


Fig. 7:- Effect of fiber content and length on tensile modulus of composites

3.4. Flexural strength

The effect of fiber content and length on the flexural strength of composites is shown in Fig. 8. It is evident from the figure that the flexural strength increases with increase in fiber content up to 15 wt.%, and then it decreases. It follows the similar trend as tensile behaviour. The reasons for the lower flexural properties at higher fiber content are probably due to the weak fiber-to-fiber interaction, void and poor dispersion of fiber in the matrix. Generally, Al_2O_3 filler offer greater resistance to crack initiation and propagation in the composite. Due to which there is an increase flexural strength of composites with Al_2O_3 filler as compared to without filler.

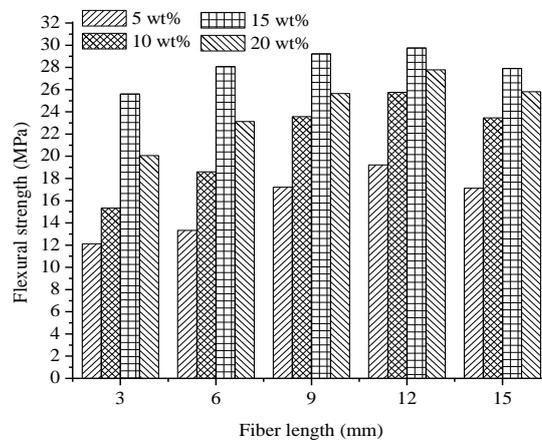


Fig. 8:- Effect of fiber content and length on flexural strength of composites

3.5. Micro-hardness

Fig. 9 shows the effect of fiber content and fiber length on the micro-hardness of composites. It is observed from the figure that as the weight percentage of fiber in the composite increases, the hardness of composite also increases. Similarly, as the fiber length increases, the hardness of the composite also increases. Similar trend of increase in hardness of the composites with increase in fiber length has also been reported by the researchers [11].

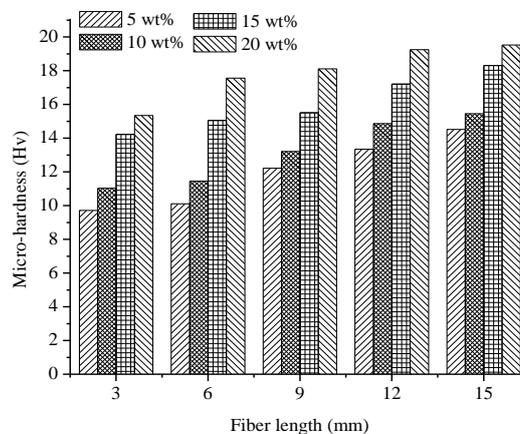


Fig. 9:- Effect of fiber content and length on micro-hardness of composites

3.6. Impact strength

Fig. 10 shows the effect of fiber content and fiber length on the impact strength of composites. It is observed that the impact strength increases with the increase in fiber content up to 15 wt.% and further it decreases. It has been reported that high fiber content increases the probability of fiber agglomeration and it stress concentration requiring less energy for crack propagation. The impact strength of all composites increased with fiber content up to 15 wt.%. The reasons are that the fiber is capable of absorbing energy and compression pressure which removes the voids contents in the composites because of appreciative mix-up fiber and matrix. The maximum impact strength of 14.76 kJ/m² is obtained for composites with 12 mm fiber length and 15 wt.% fiber content.

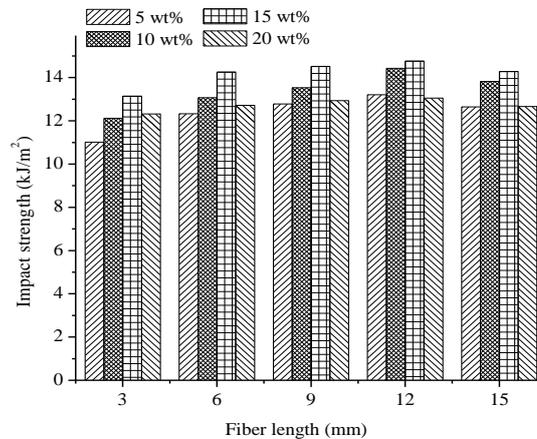


Fig. 10:- Effect of fiber content and length on impact strength of composites

3.7. Water absorption

Fig. 11 shows the effect of fiber parameters on the water absorption of composites with increase in immersion time. It is observed from the figure that the water absorption process is sharp at the beginning and levelled off for some length of time where it approaches to equilibrium. Generally, the rate of water absorption is greatly affected by the composite's density and void content. Longer the fiber, the higher is the water absorption. Similarly, it is also evident from the figure that the rate of water absorption increases with increase in fiber content. Composites with 20 wt.% coir fiber content shows more water absorption rate as compared to 5 wt.% fiber content. The reason may be due to the coir fibers contain more polar hydroxide groups, which result in a high moisture absorption level of natural fiber based polymer composites.

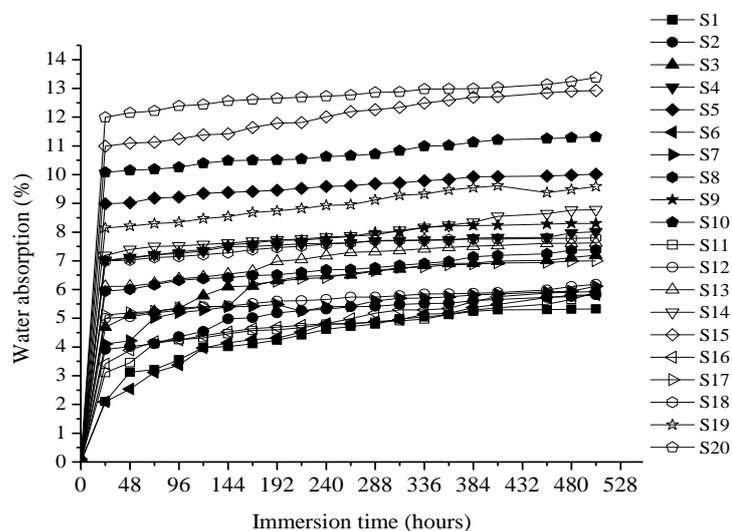


Fig.11:- Effect of fiber content and length on water absorption behaviour of composites

3.8. Surface Morphology

The fracture surfaces study of composite after tensile test is shown in Fig. 12 (a) and (b). From Fig. 12 (a) it is clear that the fibers are detached from the resin surface due to poor interfacial bonding. Pulled-out fibers are clearly visible for composites with 5 wt.% fiber content and 3mm length. However, the composite with 15 wt.% fiber and 12 mm length shows good matrix/fiber adhesion. Only very small fiber pull-out which coated with matrix material is observed as shown in Fig. 12 (b).

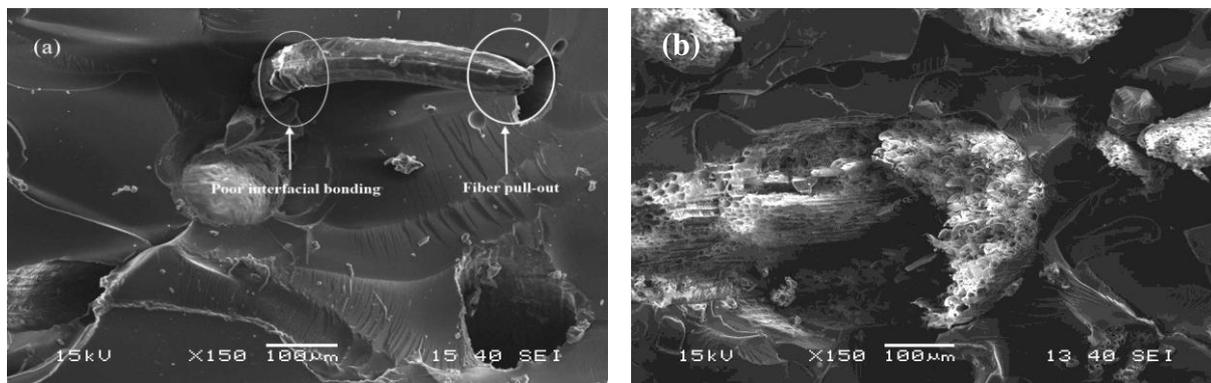


Fig. 12:- SEM micrographs of fractured surface of composites after tensile tests

4. Conclusion

The properties of the coir fiber reinforced epoxy composites filled with Al_2O_3 filler are significantly influenced by the filler and fiber parameters. The void content of the composites increases with the increase in both fiber content and fiber length. The strength properties of composite increases with increase in the fiber content up to 15 wt.% and then decreases. Therefore, the optimum fiber content is found to be 15 wt.% for better mechanical properties. Similarly, 12 mm fiber length is found to be effective in increasing the strength properties of composites. On the other hand, the hardness and tensile modulus of composites increases with increase in both fiber content and fiber length. The improvement in mechanical properties of composites with Al_2O_3 filler is observed as compared to unfilled one. The minimum water absorption is observed for composites with 5 wt.% fiber content at 3 mm fiber length. Fiber pull-out is clearly observed for composites with 5 wt.% fiber content and 3mm length from the SEM micrographs. On the other hand composite with 15 wt.% fiber and 12 mm length shows better matrix/fiber adhesion.

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