Studies on Mechanical Characterisation of Bio-Fibre Reinforced Polymer Composites

N. B. Karthik Babu, V. Vignesh, N. Nagaprasad, K. Palanikumar, and A. Pugazhenthi

Abstract Polymer Matrix Composite (PMC) is a potential candidate material for structural, automotive and aerospace applications due to its high strength to weight ratio, non-corrosive and affordable. Because of these reasons, PMC's are widely used as an alternate material for both load bearing and non-load bearing applications. However, synthetic fibre usage in PMC fabrication limits its application in various sectors due to increased environmental awareness like non-degradability, land-filling and so on. This forced research community to develop eco-friendly material associated with equivalent mechanical properties and where bio-fibres are coming to picture here. Recently, an importance of bio-fibre reinforced PMC's have been realised and numerous studies were carried out to study various mechanical properties such as tensile, flexural, hardness and impact properties of bio-fibre reinforced PMC's. In this chapter, the effect of single bio-fibre, hybrid bio-fibre and synergistic effect of filler-fibre combination on mechanical properties are presented and reason/mechanism for properties improvement is analysed. This motivates novice researchers to understand failure mechanisms under mechanically loaded environment and lead to widen the way to carry out further research in bio-fibre composites.

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K. Palanikumar et al. (eds.), *Bio-Fiber Reinforced Composite Materials*, Composites Science and Technology,
https://doi.org/10.1007/978-981-16-8899-7_8

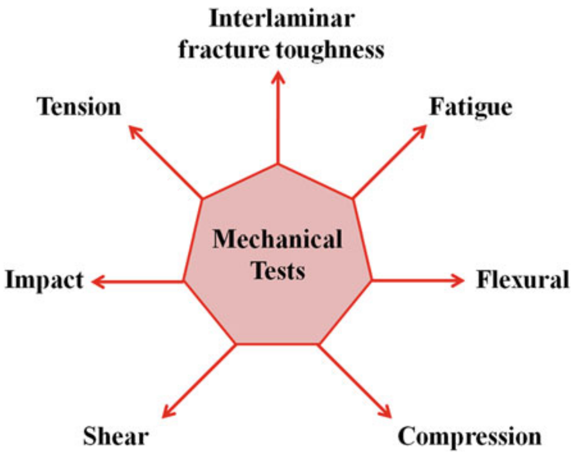
Keywords Polymer composites · Bio-fibres · Eco-friendly materials · Mechanical strength · Failure mechanisms

1 Introduction

Testing of any material or composite is essential to predict their strength and withstand-ability against mechanical load. These testing are helpful to avoid catastrophic failure of a material and severe damage too [1]. Under mechanical load, behaviour of a composite material is different when compared to pure metals therefore measurement of various basic mechanical properties of a polymer composite is mandatory. These behavioural differences of polymer composites are majorly due to its anisotropic nature of composites and they are composed of two or more constituents. Therefore, it can be realised that assessment of mechanical properties of any composite material is highly important and based on those test results it can be reveal that whether a proposed composite material is fit for a particular application or not (Fig. 1).

Firstly, it is realised that testing of composite materials is important, and then the following questions would come in to picture. What type of test or load? (Whether it is tensile or compressive or shear, etc.), what would be the test environment? (Whether it is room temperature or elevated temperature), what will be the test parameter? (Whether it may be sudden load or gradual load or long-term load) and so on. The answer for these questions is depends on end use of the proposed composite materials. Hence, it should be screwed-up those properties requisite of a composite material is highly depends on end application i.e. where a composite material is going to use? Based on these a designer can perform design process (of any component used in structural, automotive, aeronautics, and other applications) with the help of tests data.

Fig. 1 Most common tests for a composite material



2 Mechanical Characterisation of Composite Materials

2.1 Tensile Test

Tensile properties of a material can be assessed the most common test known as tensile test and this test is simple test where two opposite collinear tensile forces are applied along the longitudinal direction (as shown in Fig. 2). The applied force is gradually increased till specimen fracture and a stress–strain curve is plotted simultaneously during the test. In general, one can able to get following properties from tensile test (i.e.) tensile strength (in MPa), elongation at break (%), poisons ratio, Young’s modulus. Among these, the tensile strength is the most fundamental property of a material can be defined as an ability of that material against a force that tends to pull/stretch it. For newly any developed composite material, measurement of tensile properties is essential and outputs of this test are highly useful to predict suitability of a material for selected application. In order to assess the abovementioned properties composite samples should be designed with ASTM standards or any other suitable standards. Most commonly used standard is ASTM D3039 for determining the tensile properties of a polymer matrix composite [2].

During bio-fibre reinforced polymer composites fabrication, a manufacturer must concern about matrix/fibre interface, compatibility between fibre and matrix,

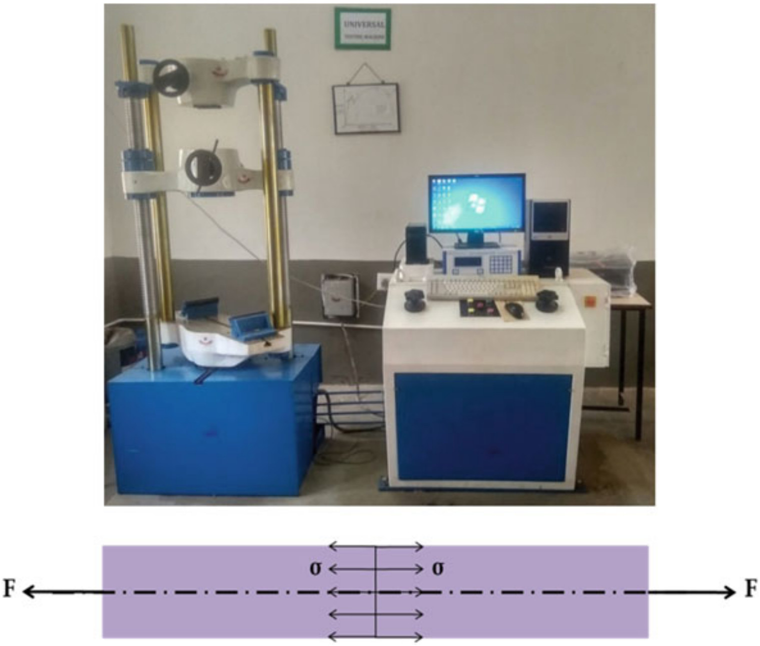


Fig. 2 Tensile test machine and its stress distribution

porosity, distribution of fibre, and so on. The abovementioned parameters have enormous influence on tensile strength and other properties of a composite material (Fig. 2).

2.2 Flexural Test

Flexural properties of a material can be found through 3-point or 4-ponit bending test (also called as flexural test) and the properties obtained such as flexural strength, flexural modulus, elongation, etc. using this test are equally important to disclose flexural strength of a material when a specimen is subjected to bending load. During flexural test, a load is applied normal to the axis of specimen and subjected to bending till the failure of a specimen (as shown in Fig. 3). Like tensile test, a stress–strain curve is plotted simultaneously during the flexural test and aforesaid properties were also recorded. Both tensile and flexural tests are regularly used techniques to assess the fracture strengths of materials (Fig. 3).

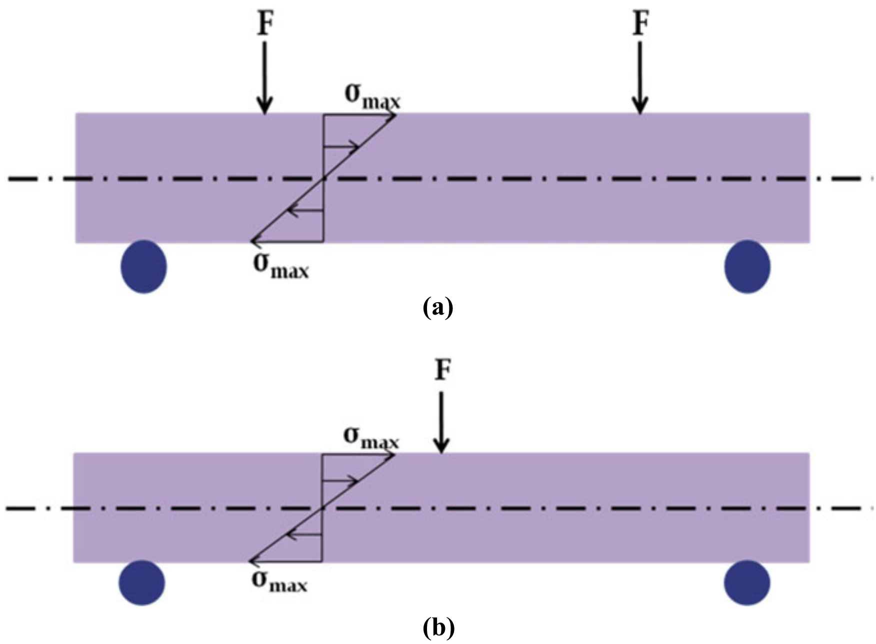


Fig. 3 **a**, **b** schematic of bending tests **a** 3-point and **b** 4-point and their stress distribution (where, F = applied load and σ = stress)

2.3 Impact Test

Before introduction of the carbon fibre reinforcement, a minimum interest was paid on study of impact response of glass fibre reinforced polymer composites (as shown in Fig. 4). However, concern on impact response of a polymer composite material was increased when carbon fibre reinforcement was used as reinforcement in polymers. This was due to the higher brittleness of carbon fibre compared to glass fibre and these glass fibre reinforced polymer composites exhibited better performance under impact load [3]. Since natural fibre reinforced composites are gradually replacing synthetic fibre reinforced polymer composites in structural and automotive applications, impact behaviour of these materials is likely to become increasingly important. The impact resistance of bio-fibre reinforced polymer composites has recently been tested using a variety of test methods. The capacity of a material to withstand a shock/sudden load or an applied stress at high speed is known as impact resistance. Impact strength is asignificant mechanical property of materials that are used for many potential engineering sectors such as automobiles, construction, aeronautics and many more. It is determined by a variety of factors, including strength, stiffness, Young's modulus, fibre span and orientation, and physical bond and compatibility between fibre and matrix, among others. In addition, it also depends on method of test used to assess the impact energy.

Fig. 4 Impact testing machine

2.4 Hardness

Hardness is the significant property of a material this displays the resistance against plastic deformation, typically by indentation. Polymers and their composites are relatively soft materials, and the hardness of these materials is usually determined using a shore hardness tester. Hard plastics are commonly graded on the shore D hardness scale, whereas soft rubbers are graded on the shore A hardness scale. The shore D hardness test is used to determine the hardness of polymer composites in the majority of studies. In general, the output of shore D hardness range between 0 and 100 and the higher value of the polymer indicates that the material's hardness increases. The samples should be cleaned with acetone before being measured, and the testing surface should be smooth. During the test, the sample is mounted on a flat surface, the test probe is pressed against the surface for 15 to 20 s, and the tester's measurement is taken. The test is repeated seven times per sample to improve the reliability of the results, and the average hardness of the samples can be taken into account. The portability, ease of measurement/handling, and reduced measurement time are all advantages of using the shore D hardness test. Figure 5 depicts a typical image of a shore D hardness tester.

Fig. 5 Shore D hardness tester

3 Mechanical Characterisation of Single Fibre Reinforced Polymer Composites

The polymer composites composed of long bio-fibres and polymeric resin could be useful for structural or civil engineering applications and their usage have been steadily increasing in the automotive and construction sectors due to their advantageous features like high specific strength and stiffness. Conversely, performance of various natural fibres reinforced polymer composites has been questioned due to high variability in mechanical properties for structural reliability analysis. The mechanical properties of a polymer composite can be studied through various tests. From those tests, the effect of natural fibre content on stress–strain relationship, ultimate tensile strength, Young's modulus, ductility, and toughness can be determined experimentally [3] (Fig. 6).

Intrinsically most polymers have less strength compared to metals. Hence, fibre reinforcement has become essential to strengthen raw polymers and withstand against mechanical load. In this way the synthetic and natural fibres are gained their importance in polymer composites and widened their use in different sectors. In general, natural fibre shows lower mechanical strength relative to synthetic fibres. Therefore, evaluation of mechanical properties of natural fibresis equally important before manufacturing polymer composites. Reddy et al. analysed the tensile properties of

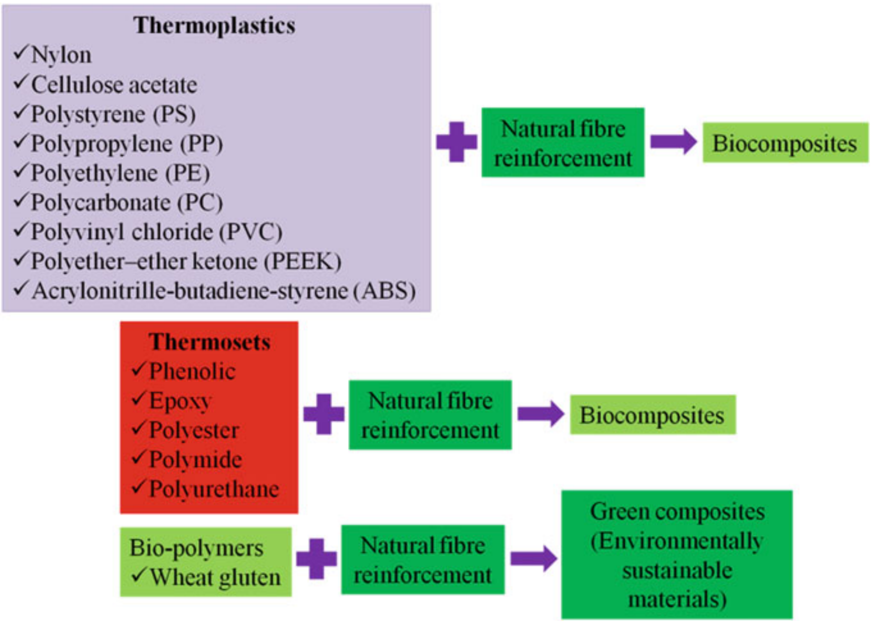


Fig. 6 Different combinations of polymer composites

borassus fine fibres and these properties of the fibres increased after 8 h of alkali treatment due to better fibre structure. Based on enhanced tensile properties, renewability and eco-friendly nature, borassus fine fibres was suggested as reinforcement in manufacturing of green composites [4]. The figure shows different polymer composites which is composed of both biocomposites and green composites. The Fig. 6 discusses natural fibre reinforcement in different category of polymers, in which a biocomposite have anyone compound (either matrix or reinforcement) as biodegradable material however, a term green composite is completely (all components) biodegradable material. The natural fibres reinforcements have significant drawbacks like low mechanical strength, poor thermal stability, low useful life span and soon. Kandola et al. used jute and sisal fibres as reinforcement and fabricated jute/PP, sisal/PP, jute/PLA, and sisal/PLA composites in this PP based composites are partially synthetic and PLA based composites are fully eco-friendly materials. The mechanical strength of prepared composites was assessed through tensile, flexural and impact test. The higher Young's modulus and flexural modulus were recorded in tensile and flexural tests respectively by the PLA-based composites and these values were higher than respective PP-based composites. In addition, sisal fibre reinforced composites exhibited higher Young's modulus and flexural modulus compared to jute fibre reinforced composites [5].

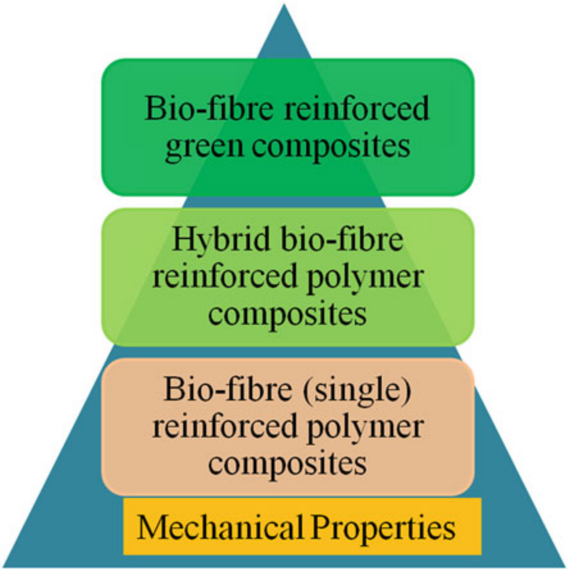
Since 1990s, natural fibre polymer composites have been potentially employed in automotive industries. For instance, major products such as interior door panels, trunks, roofs, seat backboards, dashboards and analogous partsproposed for automotives. Automotive parts made of bio-fibre reinforced polymer composites have been significantly grew-up by ca. 50% from 2000 to 2005. Similarly, in domestic, construction, musical instruments, and packaging materials are the few areas where natural fibre reinforced polymer composites are actively involved [6]. However, some of the typical factors like non-linear behaviour of natural fibre, properties decay over time, etc. are restricting their application in heavy load bearing sectors. In addition, bio-fibres have reduced thermal stability than synthetic glass fibres. Most natural fibres are partially/fully decay around 240 °C. Most importantly composition of natural fibres (cellulose, hemicelluloses, lignin, and extractives) significantly depend on cultivation place like geographic location where the plants are grown up and mechanical properties could vary when there is a change in these composition [7]. However, bio-fibres such as coir, flax, sisal, jute, banana, kenaf, and hemp show the advantages like minimum carbon footprint and biodegradable combined with a good specific strength and stiffness at an affordable cost. Dobah et al. explained the mechanics of jute/polyester composites using tensile and fatigue tests. The uni-axial and multi-axial loads were applied on 25 vol.% of jute fibre reinforced polyester composites and found that the composites showed 42 MPa of tensile strength and 7.5 N-m of torsion strength under uni-axial tensile and torsional loads respectively. On the other hand, these values were reduced to 22 MPa and 5 N-m in multi-axial static tests. Based on the test results, the authors suggested that the use of jute/polyester composite materials in sectors such as car and aircraft interiors could show effective performance with lower weight, cost and carbon footprints [8].Sivakumar et al. investigated randomly palmyra fibre reinforced composites with effect of potassium permanganate chemical treatment. The composite plate fabricated by hand lapup method and the results showed that treated plamyra fibre enhanced superior tensile and flexural properties than the untreated fibre [9]. Karthikeyan et al. studied the natural fibre as banana ribbon with polyester composites with effect fibre rope mat and random orientation. The above composites were fabricated by using compression moulding machine. From this study it has been asserted that by rope mat composites showed maximum mechanical properties that when compared to other composites [10]. Vijaya kumar et al. prepared a new natural fibre as caryota fibre to fabricate the composites plates with help of compression moulding machine. The optimum results were obtained at 40% of fibre content when compared other composites weight percentages and utilized the material in automobile and other related industries [11]. Vignesh etal introduced a new chopped indian mallow fibre with polyester composites and compression moulding technique is adopted for manufacturing the composite plate with different weight percent 10 to 50%. The result indicated that increasing the fibre content in composites plate show the ultimate mechanical and thermal properties of the composites [12]. Palanikumar et al. developed the mechanical and vibrational analysis of bio caryota reinforced polymer composite to decreases the environmental effect and light weight load carrying structures. Compression moulding machine is used for fabricating the composite laminates with varying weight % from 10 to 45%. The bio caryota fibre shows better properties than other natural fibre composites in the literatures [13].The short bio-fibres have been used for semi-structural or non-load bearing parts in the automotive sector where low weight vehicles imply minimum fuel consumption as well as low carbon emissions. However, structural or load bearing parts demand comparatively higher mechanical properties and this could be achieved when using long natural fibres as reinforcement.

4 Mechanical Characterisation of Hybrid Fibre Reinforced Polymer Composites

Versatile ways to improve a material strength is given in Fig. 7. From long year ago, the natural fibres have been reinforced to improve the strength of polymer composites and recognised as successful reinforcement for polymer composites. Over the time, hybrid fibres have been used in polymer composites manufacturing and hybrid fibres exhibited higher mechanical strength compared to single fibre reinforced polymer composites because of synergistic effect of two fibres [14].

Currently, large number of researchers from engineering and science background has been introducing new natural fibres due to increased environmental awareness between researchers. This could be a bright chance to develop and analyse properties of hybrid natural fibre reinforced composites and leads to new material development. In addition, researchers have been motivated towards the development of green composites i.e. fully biodegradable material and there are huge opportunity

Fig. 7 Evolution of biocomposites



for such green composites development and only countable works have been carried out in this fully biodegradable hybrid composites.

Hybridization two or more fibres can enhance mechanical properties because of (i) the variation in diameter of two fibres is possible in hybridization, this leads to effective settling of fibres within the matrix with increased surface area contact and leads to effective stress transformation [9]. (ii) During mechanical tests, a fibre with low elongation take applied load initially and break first; followed to this applied load is taken by fibre with high elongation which could reduce the sudden failure of matrix and leads to improved stress transfer from matrix to fibres and consequential enhancement of mechanical properties [14]. Many researchers have been reported the synergistic effect of synthetic and natural fibres reinforcement on mechanical properties hybrid fibre reinforced polymer composites and achieved good improvement in mechanical properties. A composite contains hybrid fibres reinforcement balances their properties deficiency by one another fibre(s) during mechanical loading.

Srinivasan et al. prepared hybrid epoxy composites in which the reinforcements used were banana fibre, flax fibre and glass fibre. It was concluded that the hybrid epoxy composite has better mechanical properties compared to single glass fibre reinforced composite (GFRP)when subjected to impact and flexural loads. Also, it is noticed that the hybrid composite exhibited better mechanical strength compared to single fibre composites [15]. In another work, Alavudeen et al. developed banana/polyester, kenaf/polyester and banana/kenaf/polyester composites and analysed their mechanical properties using tensile, flexural and impact tests. Among aforesaid composites, the woven banana/kenaf fibre added hybrid composites showed higher mechanical strength and this was due to hybridization effect of kenaf with banana fibres [16].

Ramesh et al. analyzed the mixing of sisal—jute—glass fibre reinforced polyester composites to find increasing of various applications. The mechanical characteristics of hybrid composites were tested through ASTM standards. Sisal–jute- GFRP fibre composites showed best performance in terms of mechanical properties and morphology studies of fractured specimen provides the internal cracks, internal structures and internal fractured of composites while various mechanical loading[17]. Palani kumar et al. investigated green hybrid polymer composites to evaluate the mechanical properties of the composites. The result indicated better tensile, flexural and impact strength due to hybridization of composites with low pollution effects. The SEM analysis proved the fibre breakage, void and failure of resin packages were found in after testing of composites specimen [18]. Stalin et al. studied the hybrid vetiver fibre matvinyl ester composites to evaluate the tensile, flexural, hardness and impact properties. The composites plate fabricated by compression moulding with various combination at 45° and 90° direction.The hybrid double-layer fibre mat composites indicates ultimate tensile and flexural properties and it is found that vetiver double-layer fibre mat composites at 90° direction, indicating high impact strength than a banana and other hybrid fibre mat composites[19]. Vignesh et al. focused effects of their wood sawdust filler on hybrid and twisted hybrid indian mallow/ roselle fibre composite. The ten combination of hybrid and twisted hybrid plates were fabricated by compression molding machine and composite specimen were tested both warp and weft direction as per ASTM standards. Twisted hybrid double layer composites yarn mat and wood sawdust filler sample recorded significantly greater improvement on the mechanical properties at warp direction, when compared other reported hybrid composite materials. Above composites were recommended to fabricate the automobile and electronics industries applications [20]. Stalin et al. carried out to evaluate the mechanical properties of hybrid Typha angustata mat reinforced vinyl ester composites. The Typha angustata/Banana mat composites exhibited better impact strength and hardness due to the exchange the properties between the two natural fibres and sufarce morphology of fracture specimen such as fibre fracture, matrix fracture, delamination of fibre, fibre bending and fibre pull out were found by SEM analysis [21] (Fig. 7).

In short, the hybrid fibres reinforcement is an effective technique to achieve better mechanical strength. Moreover the growth of scientific techniques and new fibre establishment would allows us to develop new hybrid composites that could be a good alternate for conventional single fibre added composites.

5 Summary

In short the natural fibre reinforcements are gaining their importance in polymer composites development because of its availability, affordability, renewable and importantly low carbon footprint on the environment after useful life.

As natural fibre is used as reinforcement in the manufacturing of polymer composites, mechanical properties such as tensile strength and modulus, flexural strength and modulus, and so on can be effectively altered (or) changed.

The reinforcement of natural fibres in naturally derived polymers together forms a green composite and such composites have been needed to be developed since these green materials are biodegradable in nature and leads to sustainable development. Introduction of new natural fibre opened door to next level research in polymer composites and analyse of mechanical properties. More importantly, hybrid natural fibres reinforcement need more focus since hybrid polymer composites shows superior mechanical properties than to single fibre reinforced composites.

Hybrid surface modified fibre reinforced polymer composites are still more likely to develop and evaluate their effect on mechanical properties of polymer composites. With appropriate chemical treatment, the surface of the natural fibre can be changed.

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