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Mechanical Properties of Hybrid Composites with Date Palm Fibre Reinforcement

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Abstract: Plant-based fibres are commonly used as reinforcements in polymer composites for applications such as packaging, construction, automotive, and decorative household items. This process will reduce the cost of production along with eliminating solid wastes. Here, composite materials were prepared using epoxy resin as the matrix and date palm fibres, polyester, and carbon fibre mats as the reinforcement. The date palm fibres were pre-treated in a 10% alkali solution before use. Composites laminates were prepared using vacuum moulding technique. As these composites are intended to use for structural applications, it is necessary to study the tensile and flexural strength of the prepared composites. The effects of the date palm fiber with polyester and carbon fiber materials on the mechanical properties were determined. Along with The mechanical properties, the morphology of the fibre-matrix interface after fracture was evaluated. It was realized that the composites materials fails due to fiberpullout and debonding. It was also found that natural fibers are hydrophilic in nature, which causes delamination. These results were supported by scanning electron micrographs taken of the fracture surfaces. The hybrid composite containing date palm fibres and the polyester mat showed the highest ultimate tensile strength of 43.41 MPa, which was attributed to enhanced fibre-matrix adhesion due to the alkali pre-treatment. The results indicated that when the date palm fiber were added along with polyester mat, the tensile and bending strength were incresed. whereas both the strength uneffected when datepalmfiber added along with hybrid combination of carbon and polyester mat.

Keywords: Fibres, Mechanical Properties, Fracture, Mechanical Testing

1. Introduction

Natural fiber reinforced natural or polymer composites, have been studied for decades. Natural fibers have different origins such as wood, pulp, cotton, bark, nut shells, bagasse, bamboo, cereal straw, flax, jute, hemp, sisal, and ramie. These fibers are mainly made of cellulose, hemicelluloses, lignin and pectins, with a small quantity of extractives. The fiber constituents vary depending on their origination. Compared with conventional inorganic fillers such as glass fiber and carbon fibers, natural fibers provide many advantages: abundance and therefore low cost, biodegradability, flexibility during processing and less resulting machine wear, minimal health hazards, low density, desirable fiber aspect ratio, and relatively high tensile and flexural modulus. Incorporating the tough and light-weight natural fibers into polymer (thermoplastic and thermoset) matrices produces composites with a high specific stiffness and strength.

Currently, materials research has been focusing on composites using natural fibre reinforcement as these fibres are eco-friendly and easily available from plant and animal sources [1]. Another important advantage is that natural fibres possess good mechanical and thermal properties, which are almost equivalent to those of conventional materials like glass and armid [2]. Al-Kaabi et al. studied the mechanical properties of date palm fibre (DPF)-reinforced unsaturated polyester resin composites, where DPF fibres with diameters of 100–1000 μm and a density of 0.917 g/cm^3 were used [3].

The mechanical properties of a single DPF were poorer than those reported values for other natural fibres but comparable to those of coir fibres [4]. The tensile strength of raw DPF ranged from 170–275 MPa and the modulus of elasticity ranged from 5–12 GPa with an elongation to break of 5–10%.

The chemical composition of DPF is comparable to that of other common natural fibres and consists of approximately 46 wt.% cellulose, 20 wt.% lignin, and 18 wt.% hemicelluloses [5] and thermal degradation of DPF starts at 250°C [6]. Composite samples containing fibres of a critical length and optimum fibre fraction had a flexural strength of 52.86 MPa and flexural modulus of 6.93 GPa. The impact strength of DPF reinforced unsaturated polyester resin composites was determined to be 6.71 KJm^{-2}. These low values were attributed to poor fibre-matrix adhesion.

Neher et al. investigated the mechanical properties of palm fibre (PF)-reinforced acrylonitrile butadiene styrene (ABS) composites prepared by injection moulding [7]. PF was collected from ten different trees of different ages from the Comilla region in Bangladesh. Samples were prepared with three different weight fractions (5%, 10% and 20%) of fibre. The mechanical properties (tensile strength, flexural stress, and micro hardness) and physical properties (bulk density and water absorption) were characterized. The results revealed that the tensile strength (TS) and flexural stress (FS) decreased with increasing fibre content in the PF-ABS composites, except for the sample with 10% fibre content. The mechanical properties did not change in the same ratio. This was attributed to the fact that the random fibre orientation resulted in poorer properties due to improper load transfer between the fibre and matrix. Pre-treatment of the PF using an alkali solution before incorporation in the ABS matrix did not result in significant changes in the mechanical properties of the composites.

Natural fiber composites are also claimed to suggest environmental advantages such as reduced emission rate, an alternative to non-renewable sources and most importantly biodegradability of components. All these factors encouraged the material scientists all over the globe to develop newer materials using natural fibres. Most of the natural fibres from agricultural waste were utilised to develop theses natural fibre composites.

The chemical modification will make the fiber cell walls more dimensionally stable, reduce water sorption, or increase the resistance against fungal decay, It improves the interfacial adhesion between fiber and matrix, The important modification done by alkaline treatment is the disruption of hydrogen bonding in the network structure, thereby increasing surface roughness. This treatment removes a certain amount of lignin, wax and oils covering the external surface of the fiber cell wall, depolymerises cellulose and exposes the short length crystallites. Hence natural is treated with NaOH solution.

The aim of this study was to make an initial investigation how epoxy will act as matrix material for natural fibre composites. As epoxy has been using with synthetic fibres to prepare composites, it should be possible to prepare date palm fibers, polyester and carbon fibre mat reinforced composites by vacuum mold technique. The mechanical properties of the composites were studied according to the tensile testing. Further, the morphology was studied with scanning electron microscopy (SEM) [8-19].

2. Materials and Methods

Palm date tree fronds were collected from the Nizwa region of the United Arab Emirates. The polyester and carbon fibre mat both had bi-directional weaves of 70 gsm and were procured from Sun Tech Fibre, Bangalore, India. The densities of polyester and carbon fibre mats were 1.38 and 1.82 g/cm^3 respectively. Epoxy resin 3062 and K6 grade hardener were used (Density 1.14g/cm^3-, Tensile strength - 73.3 MPa, Elastic modulus-3470 MPa and Hardner % 1:2) to prepare the composites which were supplied by Yukey Enterprises, Bangalore, India.

DPFs with lengths of 5 mm were extracted from fronds by mechanical crushing. The crushed fibres were treated with 10% concentrated alkali solution (NaOH) for 8 h in order to remove impurities from the fibre. Treated fibers were washed with distil water to remove acidic contents over the fiber surfaces and dried.

Vacuum bagging technique was used to prepare laminates this is achieved by sealing a plastic film over the wet laid up laminate and onto the tool. The air under the bag is extracted by a vacuum pump and thus up to one atmosphere of pressure can be applied to the laminate to consolidate it. The vacuum infusion technique provides a number of improvements over traditional methods such as better fibre-to-resin ratio, less wasted resin, very consistent resin usage, and unlimited set-up time, and it is cleaner. In Vacuum bagging technique, pressure is built over the laminates from air trapping along with fiber orientation. Importantly from this method humidity reduces inside the vaccume bag.

Three different laminates were prepared using the DPFs with either the polyester mat or carbon fibre mat separately or both mats together, as shown in Table 1. Laminates of all three samples were prepared in the ratio of 70:30 fibres to matrix. In addition, laminates were designated as NP (DPF + polyester mat), NPC (DPF + polyester mat + carbon fibre mat), and NC (DPF + carbon fibre mat).

The advantages of hybrid composites which are made from natural and synthetic fibers are it can be mix with the same matrix to produce hybrid composites, from these mechanical strength can be enhanced. [20].

All the laminates were prepared with a thickness of 4 mm.

The tensile and impact tests were conducted as per the ASTM D1037-12 and ASTM D 7137 standards, respectively. Flexural tests were carried out using an Instron Houhns field 25 kN instrument according to ASTM standard D4476-03.

Scanning electron microscopy (SEM; LEO 440i) was used to identify the tensile fracture morphology of the composite samples after mechanical testing.

Table 1. *Mechanical properties of the three different composite samples.*

Sample	Tensile strength (MPa)	Elongation (%)	Young´s modulus (MPa)	Bending strength (MPa)
NP	43.41	2.81	15.60	84.83
NPC	32.92	1.30	26.37	22.54
NC	33.56	4.46	11.90	28.55

(NP =DPF + polyester mat, NPC =DPF + polyester mat + carbon fibre mat and NC =DPF + carbon fibre mat**)**

3. Results and Discussion

3.1. Tensile Strength

The tensile strength of the alkali-treated DPF along with carbon fibre and polyester mat hybrid composites are shown in Table 1. The NP sample composite showed the highest tensile strength of 43.41 MPa, which was due to good adhesion between the DPF and polyester mat in the epoxy matrix. In addition, the low Young´s modulus of the NP composites (15.60 MPa) was due to the presence of the polyester mat, which exhibits ductile behaviour, as seen in the microscopy image shown in Figure 1a. The NPC composite showed the highest Young's modulus of 26.37 MPa, which was mainly due to the carbon fibre mat and polyester mat. The NPC sample showed an ultimate tensile strength (UTS) of 32.92 MPa, which was 65.82% higher than that of the pure epoxy matrix (11.25 MPa). The NC composite showed a tensile strength of 33.56 MPa, which was 66.47% higher than that of the pure matrix. It was observed from SEM images (Figure 1c) of the NC sample that the adhesion between the carbon fibre and epoxy was good and the DPFs were completely wetted and effectively bonded with the matrix.

3.2. Flexural Strength

Table 1 shows the effect of adding alkali-treated DPF to polyester and carbon mat composites on their mechanical properties. The flexural strength of pure epoxy was used as a reference (15.1 MPa). The highest flexural strength of 84.83 MPa was found for sample NP, which was 67.14% higher than that of pure epoxy. This was attributed to better fibre-matrix adhesion of the polyester mat and DPF in epoxy, as seen in the SEM image shown in Figure 1 where close packing of the mat and fibres was observed (i.e. smaller spacing between the fibres and matrix). The NPC sample showed the lowest flexural strength of 22.54 MPa, which exhibited only a marginal improvement compared to that of the pure matrix. The SEM image of the NPC composite (Figure 1b) revealed voids between the carbon mat and matrix, indicating poor adhesion. The DPF/carbon mat composite showed a flexural strength of 28.55 MPa, which was 47.42% higher than that of the pure matrix.

It can be seen that alignment of fibre is a major factor which influencing composite properties, as in this study random fibers was used along with bi directional mats. The highest tensile and flexural strength is achieved for DPF + polyester mat composites.

3.3. Scanning Electron Microscopy

Scanning electron microscopy was used to study the surface morphology of fractured specimens. Since tested samples was non metallic, fractured surface were gold coated before analysing through Scanning electron microscopy. Figure 1 shows the fracture surface of the NP, NPC and NC composites. It is possible to see that there are many fibre pull-outs and voids between fibre and matrix which indicates poor adhesion. Further, Figure 1(b) Shows that the polyester mat is oriented due to fracture. It is also seen in Figure 1(c) The fibres are also very well dispersed in the epoxy matrix. Good dispersion of fibres and fibre orientation should result in very high mechanical properties.

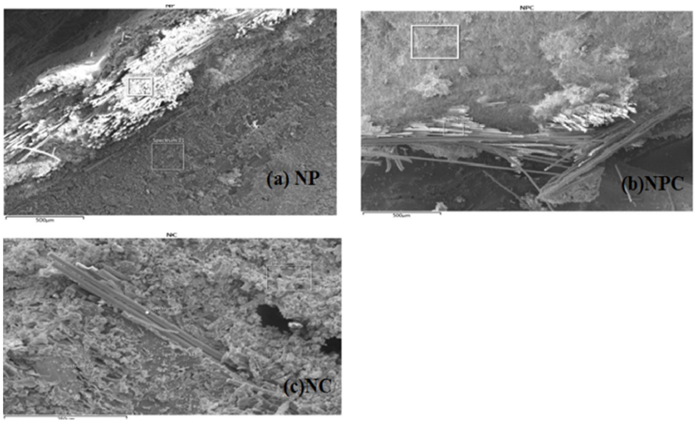

Figure 1. *Scanning electron microscopy image of the fracture surface of the (a) NP (b) NPC and (c) NC composites.*

4. Conclusion

Natural fibre composites are the latest generation of materials developed over the past two decades and are an alternative to conventional materials like glass fibre polymers composites. In this study, DPFs, which are widely available in Arab countries, were used along with carbon and polyester mats as reinforcements in an epoxy matrix to prepare hybrid composites.

Natural fibers are considered as prospective replacement for conventional fibers in composite materials. Although natural fibers have advantages of being low cost and low density, they are not totally free of problems. Hydrophilic characteristics of natural fibre can damage structure of composites. Chemical treatments can increase the interface adhesion between the fiber and matrix, and decrease the water absorption of fibers. Therefore, chemical treatments can be considered in modifying the properties of natural fibers.

The tensile and flexural strengths of the DPF and polyester fibre mat hybrid composites were the highest of all samples and it is proposed that they are suitable for use as structural materials like household interior decorative components and automobile interiors, doors, and window panels. In addition, the DPF and carbon polyester fibre hybrid composite exhibited higher strengths compared to the pure matrix material.

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