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Effect of water absorption on the mechanical properties of hybrid interwoven cellulosic-cellulosic fibre reinforced epoxy composites

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ABSTRACT

The absorption behaviour of water and its effect on the tensile and flexural properties of interwoven cellulosic fibres were investigated. Hybrid composites consisting of interwoven kenaf/jute and kenaf/hemp yarns were prepared by an infusion process that used epoxy as the polymer matrix. The water absorption characteristics of the fibres were obtained by immersing the composite samples in tap water at room temperature, until reaching their water content saturation point. The dry and water-immersed woven and interwoven hybrid composite samples were subjected to tensile and flexural tests. To study the effect of water penetration in the fibre/matrix interface, fractured samples were examined using field emission scanning electron microscopy (FESEM). The study shows that the mechanical and water-resistant properties of the kenaf, jute, and hemp fibres were improved through hybridization. However, as a result of water penetrating the fibre/matrix interface, longer water-immersion times reduced the tensile and flexural strength of the composites.

1. Introduction

Due to environmental concerns, the potential use of natural fibres as replacements of synthetic fibres has been investigated. In comparison with glass fibres, one of the advantages of using natural fibres is their low density, which endows them with excellent specific mechanical properties, easier handling and processing, recyclability, and good thermal and acoustic insulation [1]. Despite these advantages, natural fibre reinforced composites have several drawbacks that limit their application, such as a low strength, variability in quality, high moisture absorption, limited processing temperature, and a lesser durability and incompatibility between fibres and polymer matrices [1,2]. However, through continuous studies, researchers have come out with a number of methods and treatments to improve the performance of natural fibre composites. Nowadays, natural fibre composites have been widely implemented in load bearing and outdoor applications, such as in the exterior underfloor panelling of cars, sports equipment, and marine structures [3]. Faruk et al. [4] summarised the development of biocomposites from the years 2000 to 2010, and reported that flax, jute, hemp, sisal, ramie, and kenaf fibres are among the most widely used and studied fibre materials.

Hybrid composites are commonly termed as the mixture of two or more reinforcing fibres in a single matrix system. Through proper fibre selection and design, the balance between cost and performance of hybrid composites could be achieved through hybridization [5]. For example, the incorporation of glass with different cellulosic fibres such as abaca, jute, banana, hemp, and napier have been previously reported in the literature [6–9], with results that showed the mechanical properties of the hybrid composites being superior to those of the single-fibre reinforced composites. There are also published works about synthetic/synthetic [10], and cellulosic/cellulosic [11–13] fibres based on reinforced hybrid composites. Furthermore, the performance of a hybrid kenaf/kevlar composite was investigated by Yahaya et al. [14,15], who found that the composite had the potential to be used in impact applications. In the industry, FlexForm Technologies mixed hemp with kenaf fibre and used it in Chrysler's Sebring door panels, and the company is currently in the process of using the natural composite in other automotive parts [5]. A review by Swolfs et al. [16] indicates that hybridization is a method that can be used to increase the toughness of fibre reinforced composites, and that

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there are three main hybrid configurations that can be used to combine two fibres: the (1) interlayer or layer-by-layer, (2) intra-layer or yarn-by-yarn, and (3) intra-yarn or fibre-by-fibre configurations.

One important factor that contributes to the excellent properties of hybrid composites is the fibre orientation. For example, a continuous and long fibre aligned parallel to the load direction exhibits a higher strength, in comparison with a randomly oriented fibre [3]. To attain a greater degree of fibre alignment, different textile processing methods such as weaving, knitting, and braiding can be applied [17]. Specifically, weaving is the interlacing of two sets of yarns to construct a woven fabric. In a plain weave, for example, the *warp* is defined as the yarn that runs along the length of the fabric, and the *weft* is defined as the yarn that has been weaved over and underneath the warp yarn [18]. As reported in the literature [19,20], the tensile, flexural and impact properties of woven fabric composites are higher than those of unidirectional and randomly oriented composites. In woven structures, the stress is uniformly transferred, and the interlocking between the reinforced fibres further increases the strength of the composite [21]. Khan et al. [19] investigated the influence of the fibre direction and found that the mechanical properties of a woven jute reinforced poly(l-lactic acid) composite are greater when tested along the warp direction, than along the weft direction. A woven banana reinforced epoxy composite was used by Sapuan et al. [22] in the fabrication of household telephone stands, and they proved that the natural based composite was able to replace the conventional material in the furniture industry.

In regards to natural based composites, the presence of polar groups (e.g. hydroxyl, among others) in natural fibres allows them to absorb high amounts of moisture, and also makes them incompatible with the polymer matrix. Together, these two factors lead to a reduced fibre/matrix bonding strength, which results in a weaker mechanical performance of fibre/matrix hybrid composites [23,24]. Akil et al. [25] found that when pultruded jute/glass fibre reinforced polyester hybrid composites were exposed to humidity or aqueous environments, water molecules penetrated the composites through three routes, as follows: through the flaws at the composites interphase attributed to the poor wettability between the fibre and matrix, through micro-gaps between the polymer chains, and through the cracks in the polymer matrix induced by the fibre swelling.

In this work, water absorption and its effect on the mechanical properties of interwoven kenaf/jute and kenaf/hemp hybrid composites were experimentally investigated as an extension of the research regarding hybrid- and woven-structured composites. Up to date, only few works have been conducted involving interwoven cellulosic fibres, and this study will provide useful information to the research community.

2. Experimental procedure

2.1. Materials

The kenaf, jute, and hemp yarns that were to produce the woven fabrics were obtained from a local supplier. The EpoxAmite 100 series resin was selected as the polymer matrix, and it was mixed with a hardener in a ratio of 3:1 to form the binder for the composite preparation. The chemical compositions of the reinforcement fibres are listed in Table 1, while Table 2 details their mechanical properties, alongside those of the matrix. The kenaf, jute and hemp fibres were chosen as reinforcements because they are easily available in Malaysia, and they are also among the most widely used materials in the natural fibre reinforced polymer composite industry [3].

2.2. Woven fabric production

Woven fabrics were produced by weaving the fibre yarns using a wooden frame. The wooden frame (400 mm × 400 mm) was manually constructed, and it contained nails that acted as the warp yarn guider on both of its sides. The weaving process was done by passing the weft yarn over and underneath the warp yarn, which had been previously arranged on the frame with the help of the warp yarn guider. The wooden frame, weaving process, and completed woven fabric are shown in Fig. 1. Fig. 2 illustrates the construction of the interwoven kenaf/jute and kenaf/hemp hybrid composites, where the interlacing of the kenaf yarns followed the warp fibre direction, while the jute and hemp yarns were arranged in the weft fibre direction.

2.3. Composite fabrication

A vacuum infusion manufacturing technique was used to prepare the composite specimens, which had a fibre weight content of 30% ± 2%. Five types of composites were prepared, and the symbols that represent each type of composite are listed in Table 3. The fabrication process began by polishing the glass surface with acetone to remove any dirt and balanced resin from the previous infusion process. A thin layer of wax, or catalyst, was used for the easy removal of the composites after infusion. The woven fabrics were positioned on the glass surface followed by a peel ply, netting, and an enka channel, as shown in Fig. 3. The resin inlet and outlet, which were made from a PVC hose, were placed over the mould area before it was wrapped with a plastic sheet. The vacuum pump was switched on, and the in-mould pressure was controlled at below 2000 Pa, to make sure that the air was fully evacuated. The resin mixture, which was prepared according to the manufacturer's specification, was infused into the mould, where it flowed evenly until it reached the end. Excess resin flowed into a resin trap. The infused composite was removed from the mould and cured for 24 h at room temperature (25 °C).

2.4. Moisture absorption test

The water absorption tests were carried out as elucidated in the ASTM D570 standard [31]. First, the specimens were submerged in a container filled with tap water at room temperature for up to 1400 h. Thereafter, to monitor the mass during the ageing process, the specimens were withdrawn from the water, wiped dry to remove any surface moisture, and then weighted using a high accuracy 4-digit analytical balance. For each type of composite, five specimens were tested, and the average result was recorded. The moisture content percentage, $\Delta M(t)$, was calculated using the following equation:

$$\Delta M(t) = \frac{M_t - M_0}{M_0} \times 100 \quad (1)$$

Table 1
Chemical composition of the reinforcement [4].

Constituent/Fibre	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)	Waxes (wt%)
Kenaf	72	20.3	9	–
Jute	61–71	14–20	12–13	0.5
Hemp	68	15	10	0.8