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Dynamic mechanical analysis and effects of moisture on mechanical properties of interwoven hemp/polyethylene terephthalate (PET) hybrid composites

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HIGHLIGHTS

- Hemp/PET hybridisation yielded highest char residue thus better thermal stability.
- Maximum storage and loss modulus values were recorded for the hemp/PET composites.
- The hemp/PET hybrid (HP) composites had superior tensile and flexural properties.
- The presence of the PET fibres reduces the water uptake of the hybrid composites.

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ABSTRACT

A dynamic mechanical analysis was undertaken to determine the influence of moisture on the mechanical properties of interwoven hemp/polyethylene terephthalate (PET) hybrid composites. Composite laminates were fabricated using vacuum infusion process; form epoxy resin reinforced with interwoven hemp and PET fibres. Woven hemp, woven PET, and interwoven hemp/PET hybrid composites were produced. The hybrid hemp/PET composites yielded the highest final residue % due to the PET fibres which improved the thermal stability. The glass transition temperatures of the woven hemp, woven PET, and interwoven hemp/PET hybrid composites were 68, 67, and 69 °C, respectively. Water absorption tests were conducted, and tensile and flexural tests were conducted on the wet and dry specimens. The water uptake of the hemp/PET hybrid composite was half that of the woven hemp composites. The tensile and flexural strengths of the interwoven hemp/PET hybrid composites were 4% and 22% greater than those of the woven hemp composites, respectively.

1. Introduction

In recent years, growing environmental awareness has driven researchers to investigate the appropriate use of reinforcing materials in the production of polymer composites. Natural fibres, used as reinforcing agents, are in demand because they are relatively inexpensive, renewable, biodegradable, easily handled, non-abrasive, and have excellent mechanical properties and a low density [1–4]. Despite their advantages, natural fibres also have limitations, such as their high level of moisture absorption, low strength, and relatively poor durability; they are also incompatible with polymers [5]. However, through ongoing research, scientists have determined that such reinforcement materials can be hybridised with synthetic fibres, while the performance of natural fibres can be improved by treatment.

Polymer composites have more advantages and can be used in construction and building materials [6,7]. Some researchers have investigated the properties of externally bonded polymer composite systems that can be used to strengthen the structures of polymer-reinforced concrete. These can influence the polymer composite due to the effect of the temperature change and mechanical load [8]. Zhang demonstrated that the addition of macro polypropylene (PP) fibre can significantly improve the mechanical performance of a concrete element [9]. Kenaf-reinforced polymer composites, moulded into lightweight panels,

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have been used to replace solid and plastic–wood composites due to economic pricing [10].

The mechanical and thermal properties of natural fibres can be improved by hybridising them with either natural or synthetic fibres to form hybrid composites such as okra/glass [11], jute/glass [12], and kenaf/glass [13,14]. Yahaya suggested that kenaf/Kevlar hybrid composites could be used in impact applications because of their satisfactory performance [15]. In addition, Alavudeen stated that the strengths of composites with woven fabrics are typically superior to those of unidirectional and randomly oriented composites [16]. The woven fabric provides an excellent interlocking arrangement between the reinforced fibres, enabling uniform stress distribution, which increases the strength of the composite [17]. A study by Khan demonstrated that the strength of a woven jute-reinforced poly(L-lactic acid) composite was greater when tested along the direction of the warp yarn than along the direction of the weft yarn [18]. In addition, to improve the degree of fibre alignment, weaving, knitting, and braiding can be applied to the production of such polymer composites [19]. These hybrid composites are influenced by several factors, such as the fibre orientation, fibre volume fraction, and fibre/matrix interfacial bonding.

In a previous study, the thermal stability of a matrix polymer was improved with the incorporation of bamboo and glass. A previous researcher determined that the thermal properties of ramie fibre composites improved when they were hybridised with glass fibres [20]. Ridzuan studied the thermal and mechanical properties of *Pennisetum purpureum*/glass-reinforced hybrid composites. When the alkali concentration used for the treatment of the *Pennisetum purpureum* was increased, there was a reduction in the quantity of residue produced [21]. Moreover, the thermal stability of the composites improved when the natural fibres were hybridised with glass fibres; in addition, the improvement was also observed when the natural fibres were chemically modified via treatments with NaOH and silane [22].

The polar groups (hydroxyls) of the cellulose and lignin within the natural fibre allow the absorption of water molecules [5]. Hameem reported that when a composite is exposed to an environment with high levels of humidity and moisture, water molecules are more likely to penetrate the gaps and cracks resulting from fibre swelling [23]. These factors result in poor fibre/matrix interfacial adhesion within the resultant polymer composite, and impair the mechanical properties of the composite. In addition, Akil found that the water molecules penetrated the composite through three routes, as follows; through the micro gaps between the polymer chain, through the cracks in the polymer matrix caused by fibre swelling, and through the flaws at the composite interphase because of the poor wettability between the fibre and the matrix [24].

In the present study, experimental investigations were conducted to evaluate the thermal, mechanical, and morphological properties of woven and interwoven hybrid composites. Hemp fibre was selected for the investigation because it is locally available and offers excellent water resistance [5]. The mechanical characteristics of the cost-effective natural/synthetic hybrid composites were evaluated. It is expected that the results of this study will provide evidence to support the development of hemp-reinforced composites with improved water resistance for outdoor structural applications.

2. Materials and methods

2.1. Materials

The hemp fibre, PET fibre, and epoxy resin were supplied by a local supplier in Malaysia. The hemp and PET yarn were used as reinforcing materials in the form of woven and interwoven fabrics, with dimensions of 300 × 300 mm. EpoxAmite 100 series resin was used as the matrix, by being mixed with a hardener, namely, EpoxAmite 103 slow hardener. An epoxy: hardener ratio of 100:28.4 (g) was used. The properties of the fibres and epoxy resin are listed in Table 1. The single-fibre test was conducted for the hemp and PET fibres, while the properties of the epoxy were taken from the literature [25].

2.2. Woven fabric

A woven fabric sample was produced using a customised wooden frame measuring 400 × 400 mm; nails were placed on both sides of the frame to function as warp-yarn guides. The nails were carefully positioned on the wooden frame to ensure that the fabric remained taut during the weaving process. Fig. 1 shows the weaving process and the finished woven fabric. In the present study, woven hemp, woven PET, and interwoven hemp/PET hybrid fabrics were produced. In the case of the woven fabrics, identical fibre types were as used as the warp and weft yarns. Meanwhile, for the interwoven fabric, during the weaving process, hemp and PET fibres were used as the warp and weft yarns, respectively, as shown in Fig. 2.

2.3. Composite fabrication

The composites were manufactured using a vacuum-infusion process. Composites were prepared using the different types of fabrics produced as described above, as listed in Table 2. The vacuum-infusion machine features a high-vacuum pump (AST 22, AIRSPEC), pressure gauge, suction hose, and a container, which is used to collect any residual resin, as shown in Fig. 3. Initially, the woven and interwoven hybrid plies were laminated above a glass mould. Next, the resin was mixed, using the weight ratio specified by the manufacturer; the mixture was then allowed to flow through the hose (by evacuating the mould area) and into the residual resin container. Then, the in-mould pressure was controlled such that it was <300 Pa when the vacuum pump was switched on. Finally, the infused composite was allowed to cure within the mould for 12 h at room temperature (25 °C). The composite plate was cut using a Dremel 4000 tool to produce specimens with the required dimensions for testing, in accordance with the relevant standards.

2.4. Thermogravimetric analysis (TGA)

The TGA results define the weight loss of the specimen with increases in the temperature or the duration of the analysis. Tests were performed on the woven and interwoven composites using a Gas Controller GC 200 STAR System Analyser (METTLER TOLEDO). To prevent oxidation, the test was performed under nitrogen at a flow rate of 20 ml/min. A specimen, with a weight of 5–10 mg, was heated on a platinum pan to maintain its temperature during the measurements, which were performed using a thermocouple. Then, the specimen was heated from 30 to 1000 °C at a heating rate of 10 °C/min [21].

Table 1
Mechanical properties of fibres and epoxy resin.

Mechanical properties	PET	Hemp	Epoxy
Tensile strength (MPa)	100	250	55
Elastic Modulus (GPa)	0.9	6.9	1.75
Tensile Strain (%)	1.5–1.8	2–4	6
Absorption Rate (%)	–	6.5	–