Effects of fibre loading and moisture absorption on the tensile properties of hybrid Napier/glass/epoxy composites

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Abstract. The primary objective of this study was to investigate the effect of moisture absorption on the mechanical degradation of hybrid Napier/glass-epoxy composites. The hybrid Napier/glass-epoxy composites plates were produced by the vacuum infusion method using epoxy resin as a matrix. The hybrid composite specimens were tested after following 50 h of water immersion. The moisture content decreased as the glass fibre content increased. The wet and dry hybrid composite samples were subjected to tensile tests. The incorporation of the glass fibre into the Napier grass fibre-epoxy composites enhanced their tensile strength and tensile modulus. The tensile strength and tensile modulus of the hybrid Napier/glass-epoxy composites (24/6–70 vol%) were 43 MPa and 3.2 GPa, respectively. However, the tensile strength and tensile modulus properties highly degraded under wet conditions.

Keywords: Hybrid composites; natural fibres; tensile properties; moisture absorption; fibre loading.

1. Introduction
Greater than before pressure from ecological campaigners, conservation of natural resources, and emergence of stringency of laws passed have results in promotion of natural materials with an attention on renewable materials. Composite manufacturers have been searching for plant based fibre such as flax, hemp, jute, sisal, kenaf, banana as alternative substitute for reinforcing materials. Natural fibre-reinforced polymer composites are preferred today as they are harvested from renewable resources, environmentally friendly, biodegradable, low density, lightweight, and recyclable compared to conventional synthetic fibres [1–3]. However, the nature of natural fibre itself which is hydrophilic, permits the composite to absorb a large quantity of moisture from the environment than that of the synthetic composites [4]. The high moisture in composites is known to cause dimensional variation and greatly affects the mechanical properties of the composites. Moisture allowed the formation of voids and inversely affected the fibre–matrix bonding which eventually result in a reduction of their mechanical properties.

Hybrid composites are fabricated by the joining of at least two sorts of fibre into a single matrix. The performance of these hybrid composites highly influenced by types the matrix used, length and shape of individual fibres, fibre–matrix interface bonding, and volume fraction of the natural/synthetic fibres[5]. There were few investigations on the previous studies on the impact of changing the quantity of fibre loading on the mechanical properties of hybrid composites comprising of natural fibres and
glass fibre reported which amongst them are sisal/glass [6], kenaf/glass [7], okra/glass[8] and jute/glass [9] hybrid composites. Mishra et al. investigated the water take-up of hybrid composites is low compared to un-hybridized composites [6].

Mechanical degradation of the polymeric composites due to moisture absorption have been studied by several researchers [6,8,9]. The length of the fibres and the hybridization ratio utilized for the reinforcement are highly significant towards the mechanical properties and moisture absorption of and polymeric composites. Phan Braga and Magalhaes have studied that jute/glass composites, which consisted of a larger quantity of jute fibre have high moisture content than those that have a larger quantity of glass [9]. Recently, research conducted on Napier grass fibres suggested possible alternatives as reinforcement material in polymer composites [1,2,10].

The current work discusses the experimental investigation conducted to evaluate the mechanical degradation of hybrid Napier/glass-epoxy composites as results of exposure to moisture.

2. Materials and experimental procedure

2.1 Materials
The Napier grass fibre was acquired from a local plantation near Bukit Kayu Hitam, Kedah, Malaysia. In producing, hybrid composite, woven E-glass fibres were provided by a local provider, with the dimensions of 300 × 300 × 15 mm for each layer. EpoxAmite 100 series resin mixed with a hardener to a proportion of 3:1 is used for the matrix material.

2.2 Composite fabrication
The hybrid Napier/glass-epoxy composites were fabricated through in house-built vacuum infusion machine. The reinforcement plies were laminated over a glass mould, having dimensions of 300 × 300 × (3.2 ± 0.4) mm³. The resin was infused into the lamination plies through near vacuum in-mould pressure (~10 mbar) during infusion process. Afterwards, the specimens were left for 12h at room temperature (25 °C) for curing process. Next, post-curing was proceeded in an oven for 2h at temperature of 80 °C, under air circulation [11]. Five different types of composite plates were produced at different volume fraction of the Napier and glass fibres. Their volume fraction contents are showed in Table 1. Specimens were then prepared to specific size and shape according to the standard for testing using a Dremel 4000 tool.

Table 1: Percentage (by volume) of the constituents of the hybrid composite samples

| Composite sample | Epoxy resin (% volume) | Napier grass fibre content (% volume) | Glass fibre content (% volume) |
|------------------|------------------------|--------------------------------------|-------------------------------|
| S1               | 70                     | 30                                   | 0                             |
| S2               | 70                     | 24                                   | 6                             |
| S3               | 70                     | 18                                   | 12                            |
| S4               | 70                     | 12                                   | 18                            |
| S5               | 70                     | 6                                    | 24                            |
2.3 Moisture absorption test
Specimens of 76.2 × 25.4 × (3.2 ± 0.4) mm dimension were immersed in distilled water at room temperature, as per the standards provided by ASTM D570 [12]. The change of mass of the samples was recorded using an analytical balance at intervals of 10 h. The water take-up by the samples was measured in period, up to 50h immersion period. The moisture uptake, expressed as the percentage of weight gain, \( \Delta M(t) \), is given as:

\[
\Delta M(t) = \frac{M_t - M_0}{M_0} \times 100
\]

Where \( M_0 \) and \( M_t \) represent the mass of the dry sample and the mass after time (wet), \( t \), respectively. The relation between the moisture uptakes by the specimen as a function of immersion period then established. Next, the procedure was repeated for the dog-bone shaped specimens before proceeding with tensile testing. Afterwards, tensile test was conducted in order to determine the residual strength and elastic modulus following moisture exposure. The tests were conducted for five replicate for each type of the composite. The average results were recorded and reported.

2.4 Tensile testing
Dog-bone composite samples with dimensions of 165 × 19 × (3.2 ± 0.4) mm\(^3\) prepared from the composite plates were tested in accordance with ASTM D638-10 [13]. The specimens were tested to failure under tension using a universal testing machine (Instron) with a load cell of 100 kN at a crosshead speed of 1 mm/min. An extensometer was attached to a 50 mm gauge length for strain measurement. The unidirectional Napier grass fibres of the samples were parallel to the loading direction throughout testing period. The tests were conducted repeated for five replicates for each type of composites and the average result was recorded. The tensile strength and tensile modulus of the specimens were then computed.

3. Results and discussion

3.1 Moisture absorption
Figure 1 shows the % of moisture absorption of five composite samples as a function of the immersion time. The % of moisture absorption of the composites was determined by computing the differences between the weight of the wet sample following immersion in water and that of the dry sample, using Eq. 2. Based on Figure 1, it can be observed that the moisture absorption increases along with the extended immersion time. Previous reports stated the similar results with different types of natural composites [14,15].Besides that, it can be clearly seen moisture absorption rate reduced as the glass fibre volume content increased. The results show that sample S1 absorbs the greatest moisture content of 7% after being soaked in water for a 50 h period. Increasing the glass fibre content in composite sample S2 showed that the moisture content of the sample S2 was half that of the Napier-epoxy composite sample(S1) when pursuing 50 h immersion period.

The moisture content obviously decreased as the glass fibre content of the samples increased: the S3 and S4 samples show the moisture contents of 3.78 and 3.06%, individually. Finally, the moisture content of samples S5 was 1.51% indicates a reduction of over 78% after following a 50h period of immersion time. The results also were proved from the similar observation reported by Salleh [15]. This is because the natures of the Napier grass itself which is hydrophilic, enabling the formation of microvoids within the resin matrix [16]. The observation differed from the hybrid composite which is the fibres are arranged in a closed packed manner, where the water-impermeable glass fibres act as barriers to avert contact between the water and Napier fibre [15]. Therefore, Napier-epoxy composite allowed high moisture absorption than of Napier/glass-epoxy composites. Other than that, a fibre/matrix interface of a composite that contains only natural fibres would be fully damaged because of moisture absorption effects [17]. This differs from the natural/synthetic hybrid composites, which are only less adversely affected due to their resistance towards water uptake [18]. In addition,
the quantity of moisture absorbed by the epoxy is practically negligible because of its hydrophobic nature [16].

**Figure 1.** Moisture absorption responses of hybrid Napier/glass fibre-reinforced composites

3.2 Effect of fibre loading and moisture absorption on the tensile behaviour of hybrid Napier/glass-epoxy composites

Figure 2 illustrates the tensile strength performance of the dry and wet (immersed in water) hybrid Napier/glass-epoxy composites. From the figure, it can be clearly observed that the tensile strength of the Napier fibre/epoxy composite is greatly enhanced with the higher presence of the glass fibre. The tensile strengths of composite samples S1, S2, S3, S4 and S5 were 21, 43, 73, 109 and 131 MPa, respectively. The results indicates that 6 vol % content of glass fibre hybridization has improved the tensile strength of the composites by 105%.

**Figure 2.** Tensile strength of dry and wet hybrid Napier/glass fibre-reinforced composites
Following 50 h of immersion period, the extensive matrix/interface cracking correlated with the moisture absorption of the composites has clearly influenced the tensile strength of the hybrid Napier/glass epoxy composites under axial loading. The tensile strength of the Napier-epoxy composites (S1) decreased by more than 50% from 21 MPa under dry conditions to 11 MPa under wet conditions. Moreover, the tensile strength of the hybrid Napier/glass-epoxy composite under wet condition decreased by 24, 30, 31, and 8% for the S2, S3, S4, and S5 samples, respectively. It was suspected that, under wet conditions the absorbed water molecules within the composites had weakened the intermolecular hydrogen bonding between the cellulose molecules in the fibre and the water molecules [16]. Hence, the interfacial adhesion between the fibre and the matrix was weakened. As a result, the tensile strength of the composite was decreased.

Figure 3 shows the effect of the glass fibre loading on the tensile modulus of the hybrid Napier/glass-epoxy composites. From the data obtained indicate that the reinforcing glass fibres resulted in higher stiffness of the hybrid composites either under dry or wet condition. Under dry conditions, it can be clearly observed that the tensile modulus of the Napier fibre-reinforced composite (S1) increased from 1.7 to 3.2 GPa with a glass fibre content of 6 vol% (S2) indicates an increase of 88%. Besides, the tensile modulus of the hybrid Napier/glass-epoxy composite samples of S3, S4, and S5 also increased by 5.3, 7.6, and 9.1 GPa, respectively.

Under the wet condition, the tensile modulus of the Napier fibre-epoxy composites (S1) decreased from 1.7 to 1.0 GPa, representing drop by over 45% after immersed in water for 50 h of the period. Moreover, the tensile modulus of the hybrid Napier/glass-epoxy composites sample of S2, S3, S4, and S5 decreased by 19, 23, 8, and 8 %, respectively under wet condition. Thus, the increases in the synthetic fibre content have found its capability to reduce the degradation due to moisture absorption. This shows that hybridization acts a significance impact in reducing the mechanical degradation of the hybrid fibre composites.

![Figure 3. Tensile Modulus of dry and wet samples](image)

4. Conclusions
The effects of fibre loading and moisture absorption on the mechanical degradation of hybrid Napier/glass/epoxy composites were investigated. The moisture absorption of the hybrid Napier/glass-epoxy composites found increased with the water-immersion period of samples and diminished as the glass fibre content in the samples increased. The tensile strength of the wet samples was recorded lower than the dry sample. Finally, the tensile strength increased as the glass fibre content of the composite increased and has a similar response towards their tensile modulus.
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