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Effects of water absorption on Napier grass fibre/polyester composites

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A B S T R A C T

The effect of moisture absorption on untreated and alkaline-treated Napier grass fibre-reinforced polyester composites was evaluated. Under room-temperature immersion, the water absorption behaviour of the Napier grass fibre composites conformed to the Fickian diffusion mechanism. Compared with the untreated fibres, the treated fibres absorbed less water due to the removal of lignin and hemicelluloses. The tensile and flexural strength of the Napier grass composites decreased with increased water absorption. SEM analysis showed that the treated Napier grass fibre composites contained fewer fibre pull-outs and splits compared with the untreated composites, which supports the improved performance.
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1. Introduction

Synthetic fibres such as glass and carbon fibres have been used in various applications ranging from household appliances to aerospace components. However, they are not easily recycled following producing solid waste that generates environmental pollution for landfills. Consequently, there is an increased interest in the use of natural fibres as reinforcement materials within composites because of their availability, low weight, renewability, and satisfactory mechanical properties. Natural fibre-reinforced composites are primarily used in applications such as automotive interior parts, construction, and packaging.

Compared with synthetic fibres, natural fibre-reinforced composites have many advantages, such as their acceptable mechanical properties, low density, low tool wear, good thermal and acoustic insulating properties, and because they can be produced at a very low cost from renewable resources [1]. However, natural fibre-reinforced composites also have some drawbacks, such as poor wettability between the natural fibres and matrices. Over short and even long-term usage, the properties of natural fibre-reinforced composites can be impaired as a result of water absorption [2].

This is because natural fibres consist of lignocelluloses (hemicellulose, cellulose and lignin), which render the fibre highly hydrophilic characteristic [3]. Carteret al. recently investigated the moisture absorption of low-density polyethylene reinforced with pineapple leaf at loadings of 0, 20, and 30 wt%. The moisture absorption increased as the volume fraction of the natural fibre increased [4]. Rakesh explored the use of banana fibres in reinforced composites, as well as soy protein resin for use as a binding material. He indicated that the mechanical properties of the composites were highly dependent on the volume fraction of the fibres [5].

A few studies on the utilisation of natural fibres as composite materials have demonstrated that the moisture intake can be further reduced by the correct usage of coupling agents, as well as the surface modification of the fibre [6,7]. Munirah and Ishak conducted research on coconut fibres using different kinds of treatments. They determined that silane treatment reduced the water intake of the composites and improved the fibre bonding [8]. Rokbi et al. reported that a 10% alkaline treatment improved the flexural strength and modulus of Alfa fibre by approximately 60% compared with virgin unsaturated polyester [9]. Haameem et al. have studied the effects of alkaline treatments of various percentages on the tensile strength of Napier grass fibres. They concluded that a 10% alkaline-treated fibre achieved superior results compared with untreated, 5%, 15%, and 20% alkaline-treated fibres [10]. Manalo investigated bamboo fibres and determined that an alkaline treatment at a concentration of 6% was optimal; compared with untreated fibres, this treatment resulted in fibres with good mechanical properties [11].

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Karmaker and Akil suggested that moisture diffusion can be categorised into three mechanisms. The first mechanism concerns the diffusion of water molecules within the micro gaps between polymer chains. Secondly, the water molecules are capillary transported into gaps and flaws between the fibres, as well as the adhesive bonding of the matrix. Finally, micro cracks occur in composites due to the swelling of the natural fibres [12,13]. In general, the diffusion of moisture in a composite depends on certain factors, such as the volume of the fibre, void content, viscosity of the matrix, humidity, and temperature.

Daly et al. suggested that moisture absorption mechanisms can be categorised into several different types. The first type is known as linear Fickian behaviour, where the weight of the moisture gradually reaches equilibrium following an initial rapid ascent. The second type is known as pseudo-Fickian behaviour, where the moisture weight gain never reaches equilibrium. The third involves a diffusion process, where there is an initial abrupt increase in the moisture weight gain. The fourth involves moisture weight gain within the fibre, as well as debonding of the matrix. Finally, there is an initial decrease in the moisture weight gain rate as a result of material, chemical, or physical breakdown [14].

Composites that contain different types of reinforcement are used for many applications, where the degradation of mechanical properties on exposure to certain conditions, such as moisture or heat, is a major concern. Therefore, this research aims to focus on the development of Napier grass, known as *Pennisetum purpureum* fibres, as a reinforcement material for composites. This work will also study the effect of water absorption prior to, and following alkaline treatments, on the mechanical properties of Napier grass fibre-reinforced unsaturated polyester composites.

2. Materials and methods

2.1. Extraction of fibres

Fresh Napier grass stems were obtained from a nearby plantation located at Kedah, Malaysia. The leaves were removed from the Napier grass stems. The internodes were then removed. The internodes were beaten using a mallet and then soaked in water, as shown in Fig. 1(a). The water inside the tank was continuously changed for a period of three weeks. The soaked internodes were extracted using a water retting process. The fibres were then manually extracted and sun-dried to remove any trapped moisture.

2.2. Alkaline treatment of the fibres

The extracted dried Napier grass fibres were treated using NaOH solution with a concentration of 10 wt%. The fibre to solution ratio was maintained at 1:40, and the fibres were soaked for a period of 24 h. The fibres were subsequently washed four times to remove any traces of NaOH, as shown in Fig. 1(b). The washed fibres were then sun-dried and sealed within a container.

2.3. Composite fabrication

Plates measuring 300 × 300 × 2.7 mm with a volume fraction of 25% (by density),were fabricated using a hydraulic compression machine, located at AMREC Sirim, Kulim Kedah, Malaysia. The Napier grass fibres were fabricated into several thin sheets, known as ply, to achieve an even distribution of the fibres throughout the plates, as shown in Fig. 1(c). A releasing agent was applied to the hydraulic compression machine moulds to ease the removal of the plates following compression. Based on a weight ratio of 100:1, unsaturated polyester and hardener (methyl ethyl ketone peroxide) were thoroughly mixed, using gentle stirring to minimise any air entrapment. The Napier grass plies were placed inside the machine and the resin mixture was carefully poured on top. The resin was allowed to remain on top of the plies for approximately 5 min to allow it to soak into the Napier grass fibres. Using a pressure of 5 bar, the soaked plies were pressed and cured at a temperature of 60 °C for approximately 45 min. A schematic of the hydraulic compression moulding machine that was used to fabricate the composite plates is shown in Fig. 2. Following curing, the composite was removed from the mould and was then cut into specimens with specific dimensions.

2.4. Water absorption behaviour

To measure the water absorption of the composites, testing was conducted in accordance with ASTM D570. The composites were prepared with dimensions of 150 × 20 × 2.7 mm. Each specimen was dried at 50 °C in an oven, and then placed into a desiccator to cool. Immediately, they were then weighed to the nearest 0.001 g using an electronic balance. A total of five specimens were completely immersed in distiled water at a temperature of 25 °C, as shown in Fig. 1(d). Following a period of 24 h, the specimens were individually removed from the distiled water and wiped with a dry cloth to remove any existing surface water. Immediately, they were weighed to nearest 0.001 g. The specimens were weighed following water-immersion periods of 24, 48, 98, 196 and up to 552 h. The water absorption was determined by calculating by the difference in weight at the various time intervals. For each specimen, the percentage weight gain was measured at different time intervals, and the moisture absorption was plotted against the square root of time.

2.5. Tensile and flexural testing

The tensile strength and modulus of the dry and water-immersed Napier grass fibre-reinforced composites were tested

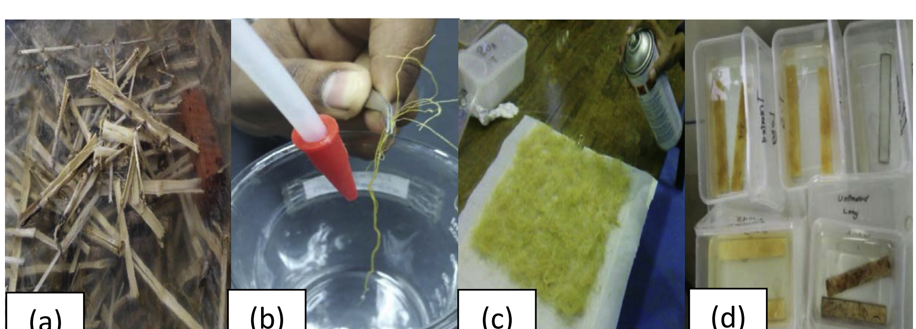

Fig. 1. (a) Soaked Napier grass stems in tank, (b) washing of Napier grass fibres with distiled water following soaking in NaOH solution, (c) ply of Napier grass fibres produced with adhesive spray as temporary bonding, and (d) immersed samples in distiled water to evaluate absorption behaviour.

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