Tensile properties of compressed moulded Napier/glass fibre reinforced epoxy composites

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Abstract. This paper describes the experimental investigation of the tensile properties of compressed moulded Napier grass fibres reinforced epoxy composites. The effect of treatment 5% sodium hydroxide (NaOH) concentrated solution and hybridization of Napier with CSM E-glass fibres on tensile properties was also studied. The untreated and treated Napier fibres with 25% fibre loading were fabricated with epoxy resin by a cold press process. 7% fibre loading of CSM glass fibre was hybrid as the skin layer for 18% fibre loading of untreated Napier grass fibre. The tensile tests were conducted using Universal Testing Machine in accordance with ASTM D638. The tensile properties of the untreated Napier/epoxy composites were compared with treated Napier/epoxy and untreated Napier/CSM/epoxy composites. The results demonstrated that the tensile performance of untreated Napier fibre composites was significantly improved by both of the modification; alkali treatment and glass fibre hybridization. Napier grass fibres showed promising potentials to be used as reinforcement in the polymer based composites.

Keywords: Natural fibre composites; hybrid composites; tensile properties; compressed moulding.

1. Introduction
The increase in environmental awareness in the general public and community interest, the new environmental regulations and unsustainable consumption of non-renewable petroleum-based materials, have resulted in the promotion of environmentally cautious materials. Natural fibre is regarded as green materials which possess relatively excellent mechanical properties compared to synthetic fibre [1]. Natural fibres in the simple definition are fibres that are not artificial or human-made. They can be harvested from plants or animals [2]. Amongst other attractive properties of natural fibres which make them an attractive alternative to the traditional material are low cost, low density, excellent relative specific tensile strength, non-abrasive, non-irritation, reduced energy consumption thus lower the carbon footprint, less risk to health, renewability, recyclability and biodegradability [3]. Nowadays, natural fibres are used in various applications such as structural materials, particle boards, insulating materials, biomedical and for other biopolymers applications. Besides that, natural fibre composites also have been used in automotive industry for interior components such as door panels, instrument panels, armrests, headrests and seat shells [4]. The natural fibres extracted from banana, bamboo, coir, sisal, ramie, flax, jute, date palm and many more were at present used as reinforcements in polymer matrix composites. The effectiveness of the fibre reinforced composites is highly depended on fibre–matrix interface and its capacity to transfer the stress from the matrix to the reinforcing fibre. To obtain the optimal mechanical properties, several important things must be identified, such as the
fraction of the fibres, fibre orientation, fibre aspect ratio, fibre length, fibre-matrix adhesion, and stress transfer at the interface [5]. Many research works were published to represent the importance of newly identified natural fibres with the optimised fibre length and weight or volume fractions. Usually, high fibre loading is needed to attain excellent properties of natural fibre polymer composites [6]. Moreover, Shinoj et al. [7] noticed that the rise in fibre content causes improvement in the tensile properties of the composites. Furthermore, Facca et al. [8] reported that the tensile strengths of 40-mesh hardwood fibres reinforced HDPE composites increased gradually, and up to a maximum of 25% of the fibre loading by volume before dropped back as the fibre loading further increased above 25%.

However, the major shortcoming of natural fibres as reinforcing materials for polymer based composites is their weak interfacial bonding due to the poor compatibility of the hydrophilic nature of the fibres with hydrophobic polyolefin polymers [9]. Thus it is essential that the fibre–matrix adhesion is to be improved and at the same time to reduce the moisture content of the fibre. This can be achieved by fibre surface modification via physical or chemical treatments. The use of different physical treatment methods (corona discharge, cold plasma, x-ray and UV bombardment) and chemical treatment methods (mercerization (alkali), grafting, acrylation, permanganate, acetylation, silane and peroxide) causes a reduction in moisture gain as well as changes in the fibre surface [10–14]. Alawar et al. [12] have studied the effect of different chemical treatment processes on date palm fibre surrounding the stems of date palm tree. From their work, it has been concluded that 5% NaOH treated date palm fibre shows optimum mechanical properties. Meanwhile, Prasad et al. [15] found that the alkali and acrylic acid treatment and the use of (maleic anhydride grafted LDPE) MA-g-LDPE as a compatibilizer improved the mechanical properties of the LDPE composites. Maheswari et al. [16] found that the mechanical (tensile and flexural) properties improved significantly with the addition of alkali combined with silane-treated fibre composites. Besides that, Maheswari et al. [17] reported that the tensile and thermal properties for the alkali and silane treated fibres were found to be improved by polymer coating.

Meanwhile, Pothan et al. [18] suggested one of the modified solutions in most of the limitations is the hybridization of natural fibres with synthetic fibres. Natural and synthetic fibres can be used in the same matrix to produce hybrid composites that take full advantage of the best properties of the constituents, and thereby an optimal, superior but economical composite can be attained. In general, hybridization of synthetic–natural fibres hybrid composites is performed with the aims to reduce the use of synthetic fibres [19]. Mishra et al. [20] proved that addition of glass fibres in small amounts to the sisal and pineapple fibre–polyester composites increased the mechanical properties of the hybrid composites also the use of alkali treated fibres with glass fibres further enhanced the properties with reduced moisture absorption of the composites. Not only that, Noorunnisa et al. [21] found that the mechanical properties of sisal fibre reinforced polyester composites were improved by adding the carbon glass fibres in the sisal composites. Moreover, Idicula et al. [22] indicated that the natural fibre with glass allows a significantly better heat transportability for the composites. Carvalho [23] reported that the addition of 2% and 3% of short jute fibre to the brittle cement matrix changed its stress-strain behaviour significantly under direct tension as well as its load-deflection response under bending load. The energy capacity of the composites was increased expressively under both bending and direct tension load.

The main objective of this paper is to explore the potential of Napier grass fibre as reinforcing materials in polymer composites. Some work had been conducted toward the Napier grass fibre; Fartini et al. [24] studied compressive properties of Napier (Pennisetum Purpureum) filled polyester composites. Reddy et al. [25] analysed chemical composition, and structural characterization of Napier grass fibres while Phitsuwan et al. [26] evaluated structural features and enzymatic digestibility of Napier grass fibre treated with aqueous ammonia. Reddy et al. [27] also investigated the properties of Napier grass pulp as handmade paper sheets. This study involving the treatment of 5% NaOH solution to the Napier grass fibres. This article also involving the fabrication of 25% of fibre-loading of untreated and treated Napier grass fibre reinforced epoxy resin composites and the CSM glass fibre will be utilised as the skin layer of the untreated hybrid Napier fibre composites. The tensile test was
then performed to study the tensile performance for the untreated Napier/epoxy composites, 5% NaOH treated Napier/epoxy composites and untreated Napier/CSM/epoxy composites.

2. Experimental Methods

2.1 Fibre Extraction
Napier grass stems were supplied from a local farm, located at Beseri, Perlis, Malaysia. The water retting process was utilised to extricate the fibre strand from the Napier grass stem. The stems were crushed by a mallet to allow the water to seep into the stems and accelerates the water absorption and thus decomposition. Figure 1 (a) shows the stems were submerged in a tank filled with running tap water for three to four week as by the time the Napier grass fibre strands become easy to separate from the grass internodes. The fibre was extricated physically and dried under the sun for few days to ensure for removal of moisture as shown in Figure 1 (b). Then the Napier grass fibre strands were dried in an air-circulating oven at 60ºC for 2 hours to ensure maximum moisture removal.

![Figure 1. (a) Water retting process, (b) Napier grass fibres](image)

2.2 Alkaline treatment
The Napier grass fibres were treated with 5% of aqueous sodium hydroxide (NaOH) solutions at room temperature for 6 hours as shown in Figure 2 (a), maintaining a liquor ratio of 40:1, which is 40gram of solution for 1gram of fibre to remove the hemicellulose and other greasy materials. After that, the fibres were washed and rinsed using distilled water to remove the remaining traces of NaOH solutions. It also helps to reduce the stress on the fibres during treatment. Next, the fibres were dried under the sun for few days as shown in Figure 2 (b). Moreover, the fibres were oven dried at 60ºC for 1 hour.

![Figure 2. (a) Soaking process, (b) treated Napier grass fibre](image)
2.3 Composite Fabrication

The composite was produced by the cold press process as shown in Figure 3 (a). Firstly, the male and female section of the mould was cleaned and coated with the releasing agent for easy removal of the specimens. EpoxeAmite was mixed with a slow hardener in a weight ratio of 100g epoxy: 28.4g hardener and they were gently stirred, avoiding the formation of air bubbles, until the mix was entirely homogeneous. After that, some of the resin was poured first into the mould base, followed by placing the untreated Napier fibres randomly oriented into the mould and the remaining resin was poured slowly over the fibres. Initially, the fibres were oven dried for 30 minutes at 65°C. It is often necessary to preheat the natural fibres to reduce the moisture before processing the composites. A roller was used to expel entrapped air and to spread the resin all over the fibres uniformly. Then a load (5-8 kg) was placed on the top of the mould and compressed (0.6-2 MPa) to remove all excess resin and attain designated dimensions. The composite plates (300 x 300 x 3.5 mm) as shown in Figure 3 (b) were then left to cure at room temperature and removed from the mould after 24 h. Eventually, 240 g of epoxy resin and 26 g of Napier fibres were used to produce both untreated and treated composites plates of 25% fibre loading. However, 19 g of Napier fibres and 50 g of CSM glass fibres were used to produce the hybrid composites of 25% fibre loading. The volume fraction fibre for hybrid composite becomes 18% of Napier fibre and 7% of CSM glass fibre. This is because the CSM glass fibre was applied to the skin layer for untreated Napier fibres and was placed at the top and bottom of the Napier fibres during their hybrid composite plates fabrication.

![Composite Fabrication](image)

Figure 3. (a) Cold press process, (b) Napier grass fibre reinforced epoxy composite plates

2.4 Tensile Testing

The composite plates were cut with a Dremel 4000 tool according to the ASTMD638 requirement as shown in Figure 4 (a). The tensile test was performed toward untreated Napier, treated Napier and hybrid untreated Napier/CSM composites with a crosshead speed 1mm/min using 100kN Universal Testing Machine. The ultimate strength, the elongation and the modulus of elasticity of the composites were calculated from the average of 5 samples for each composite. The extensometer was used to measure the strain as shown in Figure 4 (b).

3. Results and Discussion

The results of the tensile test conducted are presented in Figure 5 and 6 respectively. All the stress-strain curves for the three types of the Napier composites is similar to the brittle materials [28,29] The ultimate strength for the 25% of fibre loading of untreated Napier/epoxy composites was recorded about 22.78 MPa and modulus elasticity at 3.42 GPa. In contrast, Hameem et al. [30] reported the ultimate strength and modulus elasticity for 25% of fibre loading for untreated Napier fibre reinforced polyester composites are at 18.17 MPa and 2.00 GPa respectively. This indicates that the strength of the untreated Napier/epoxy is 25% stronger than the untreated Napier/polyester composites. The modulus elasticity of Napier/epoxy composites is almost 71% higher than Napier/polyester composites. This is due to the mechanical properties strength of epoxy resin is noticeably stronger
compared to polyester resin. Gopinath et al. [31] reported that the jute reinforced epoxy composite exhibited better mechanical properties than jute-polyester composites. Also, Satishkumar et al. [32] also found the maximum tensile strength and modulus of randomly oriented chopped snake grass fibre reinforced isophthalic polyester composites at 25% volume fraction fibre loading and reported that the volume fraction significantly influenced the mechanical properties of composites. Nirmal and Premkumar [33] concluded that the tensile strength of the composite increased up to 25% of the volume fraction of the fibres and further for the increase in the volume fraction of fibre the mechanical properties were decreased.

![Figure 4](image1.png)  
(a) Tensile dog bone specimens, (b) tensile test

Meanwhile, the maximum ultimate strength and modulus elasticity for the treated Napier reinforced epoxy composites were computed at 40.06 MPa and 3.86 GPa respectively. The increase of strength and modulus between 5% NaOH Napier grass fibre and untreated Napier grass fibre composites were about 75% and 12% respectively. Besides that, the elongation for treated Napier epoxy composites which at 0.0217 mm was two times higher than the elongation for untreated Napier epoxy composites which at 0.00995 mm. The effect of alkali treatment toward Napier fibre was very significant in term of strength and elongation compared to modulus elasticity. This is because the alkali treatment helps to extract the non-cellulosic components (hemicellulose, lignin, pectin, waxes and impurities) and some part of amorphous cellulose which is responsible for poor surface wetting and inefficient fibre-matrix interaction [34]. Removal of these components increases the surface roughness and reduces its hydrophilic nature, thus generates a larger contact surface area and leads to better mechanical interlocking between Napier fibres and epoxy matrix which provides better mechanical properties. Amroune et al. [35] reported that the tensile tests show that use of post-processing NaOH-based chemical treatments towards date palm fruit branches (Phoenix dactylifera L.) allow a significant increase in stress at failure and Young’s modulus with a profound influence on strain at failure. Also, Hossain et al. [36] concluded that fibres treated with 5% alkali solution yielded the best mechanical properties.

Not only that, the ultimate strength and modulus elasticity for untreated Napier fibres hybrid CSM glass fibres composites showed the highest result among these composites which at 44.71 MPa and 4.09 GPa respectively. The strength of hybrid Napier/CSM glass composite was 96% stronger than untreated Napier composites and only 11% stronger than 5% NaOH treated Napier fibre composites. While for the modulus elasticity of untreated Napier/CSM glass fibre composites showed about 19% higher than untreated Napier composites and only 6% higher than treated Napier composites. However, the elongation of untreated Napier/CSM glass fibre composites was 0.0311 mm
which three times higher than untreated Napier composites and 43% higher than treated Napier composites. The elongation of Napier hybrid fibre showed biggest effect compare than the strength and modulus elasticity toward the untreated and treated Napier/epoxy composites probably due to a little ductility behaviour of the CSM glass fibres. This indicates that Napier grass fibre hybrid with CSM glass fibres composites gives significant effect toward the untreated Napier composites, but small impact toward the 5% NaOH treated Napier composites. Heckadka et al. [37] concluded that combination of three plain weave mats demonstrated better tensile, flexural, and interlaminar shear properties. However, the arrangement of three chopped strand mats resulted in inferior properties except for impact strength. However, Tshai et al. [38] reported that the inclusion of chopped strand E-glass fibres in Hybrid polylactide acid (PLA) composites reinforced with palm empty fruit bunch (EFB) improved the tensile and flexural performance of the hybrid composites. Besides that, hybrid composite with Kevlar as outer layers display better mechanical properties as compared to hybrid composites with kenaf as the outer layer was demonstrated by Yahaya et al. [39]. Vijaya et al. [40] also agreed that glass fibre is used to laminate the composite on the top and bottom layer, which improves the surface finish and adds strength to the composites. They also suggested that, generally, the % elongation of single fibre composite is less than that of the hybrid composite which indicates that the hybrid composite tolerates more strain than the single fibre composites before failure. Thus it can be concluded that the hybrid composite is more ductile than the neat composite.

Figure 5. Comparison of the tensile strength of untreated Napier, treated Napier and hybrid untreated Napier/CSM glass fibre composites.
4. Conclusion
The mechanical properties of untreated Napier fibre, 5% NaOH treated Napier fibre and untreated Napier hybrid with CSM glass fibre reinforced epoxy composites were investigated through the tensile test. The result showed that Napier fibre with 25% of fibre loading exhibit efficient load transfer between the fibre and the matrix. The modified Napier grass fibres reinforced epoxy composites by both alkali treatment, and E-glass fibre hybridization gives a significant increase in ultimate strength, elastic modulus and fibre elongation behaviour of Napier fibre reinforced epoxy composites. The results of tensile strength and the modulus elasticity between Napier hybrid CSM glass fibres and 5% NaOH treated Napier fibre composites did not exhibit much differences gap. However, the modification of Napier grass fibres between hybridization with CSM glass fibres as the skin layer for Napier fibre and treatment of 5% NaOH concentration demonstrated a significant distinction regarding fibre elongation. Napier grass fibres appear to have bright future as an alternative reinforcement for fibre reinforced polymer composites.

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