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Comparison of harakeke with hemp fibre as a potential reinforcement in composites

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ABSTRACT

The objective of this study was to characterize the performance of untreated and chemically treated harakeke fibre (a leaf fibre from a plant native to New Zealand) and compare with hemp fibre to assess its use as potential reinforcement in composites. Alkali treatment is amongst the most popular treatments used to remove unwanted fibre constituents such as pectin, hemicellulose and waxes; it can enhance fibre properties, fibre separation, interfacial bonding and fibre dispersion within a composite. Physical and mechanical properties of untreated and alkali treated fibres were assessed using single fibre tensile testing, X-ray diffraction (XRD), scanning electron microscopy (SEM) and thermal analysis using thermogravimetric analysis (TGA). Untreated harakeke fibre was found to be lower in tensile strength compared to untreated hemp fibre. It was also found that the tensile strength of harakeke and hemp fibres treated with 5 wt% NaOH/2 wt% Na_2SO_3 and 5 wt% NaOH was not significantly affected and these fibres had good fibre separation. However, alkali treatment was found to lead to higher crystallinity index (I_c) and better thermal stability for harakeke as well as hemp fibres.

1. Introduction

Increased environmental awareness has led to growing interest in the use of more sustainable materials. Typical construction materials have large ecological footprints; production of synthetic composites is generally energy intensive and construction and demolition debris constitute a large percentage of landfill volume [1]. Natural-fibre-reinforced bio-derived polymer matrix composites, commonly referred to as bio-composites have gained renewed interest over the past few decades because of their low material costs, low densities, high specific moduli and environmentally friendly appeal, as well as their low production energy requirements [2]. The natural fibres used are renewable, nonabrasive, can be incinerated for energy recovery and they give less concern regarding health and safety during handling than synthetic fibres. Their excellent price-performance ratios at low weight in combination with their low environmental impact has resulted in increasing uptake by engineering markets such as the automotive and construction industries [3].

Many studies have been carried out internationally to assess the possibility of using natural fibre-composites for non-structural and structural applications [4–8]. However, development of such low cost materials with elevated durability and high mechanical performance is still a real challenge faced by engineers of the 21st century to enable natural fibre to be put on a par with synthetic fibre. Important factors regarding composite performance are:

- the fibre, including fibre type, alignment and length,
- the matrix used and
- the interfacial bonding which enables transfer of the applied load to the fibres.

Weak interfacial bonding between the reinforcing agent and the matrix in natural reinforced composites is a major drawback which limits their application. Interfacial strength plays a vital role in determining the mechanical properties of composite materials. A strong interface provides composites that display good strength and stiffness but tend to be brittle. A weaker interface on the other hand, may reduce the stress transfer from matrix to the fibre, hence the composite may display lower strength and stiffness but may in contrast have increased toughness. Depending on the application, interfacial strength can be engineered by modifying the fibre surface using physical and chemical treatment and

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modifying the matrix by addition of coupling agent. The literature shows that these methods increase compatibility and potential reactivity between fibre and matrix and hence increase the interfacial strength between matrix and reinforcing agent [9].

The present work is a preliminary study of the mechanical and physical properties of harakeke fibre compared to hemp fibre including the effect of alkali treatment. Harakeke is a monocotyledonous plant endemic to New Zealand and is renowned for its fibre which was used by early European settlers in New Zealand as a replacement for European flax and here is commonly called 'native flax'. It fibre can be extracted from upper and lower side of its leaves. However, unlike European flax, from which fibre is extracted from stalk, the fibre from harakeke is extracted from the leaves of this plant. The leaves are stiff and tough and can grow up to 3 m long and 125 mm wide. The favourable strength and stiffness of the fibre and mechanisation of the extraction around the 1920s resulted in an expansion of the harakeke fibre industry with the fibres becoming an important export commodity used in a variety of applications such as clothing, mats, baskets, ropes, fishing lines and nets [10,11]. The chemical composition of harakeke fibre is tabulated in Table 1 [12]. Two different types of alkali with various concentrations were used in isolation or in combination with the aim of maximising the fibre properties for enhancement of mechanical and physical properties of composites. There are several papers published reporting the improvement of fibre properties when treated with various alkali treatments [10,13,14], but only limited papers discussing the mechanical behaviour of single fibres, with none for harakeke that have been found by the authors. This work was aimed at acquiring a better understanding of the potential of these fibres for reinforcement in composites. Together with mechanical and physical assessments, this paper also includes analysis of fibre strength using Weibull statistics.

2. Experimental

2.1. Materials

Harakeke fibre was obtained from the Templeton Flax mill, Riverton. It was mechanically prepared and supplied in bundle form. Hemp fibre was locally grown from October 2012 and harvested in February 2013 after 120 days and donated by the Hemp Farm NZ Ltd. Green hemp stalks were dried exposed to air for two weeks and then the bast fibre was hand separated from the stalks.

2.2. Methods

2.2.1. Alkali fibre treatment

Alkali treatment was carried out using a laboratory scale pulp digester (normally used for paper making) at different temperatures and for different durations. Three alkali formulations were used in this investigation: 5 wt% sodium hydroxide (NaOH), 10 wt% NaOH and 5 wt% NaOH with 2 wt% sodium sulphite (Na_2SO_3). The chemicals used (purchased from Scharlau Chemie S.A.) were analytical grade Na_2SO_3 pellets and NaOH powder, both with 98% purity level. The abbreviations used for the fibres and treatments are shown in Table 2.

Table 1
Chemical composition of harakeke fibre.

Composition	Content (%)
Cellulose	60.9 ± 4.4
Hemicellulose	27.3 ± 4.1
Lignin	7.8 ± 1.3
Extractives	4.0 ± 0.3

Table 2
Abbreviations used for fibre and treatment.

Fibre and treatments	Abbreviation
Harakeke – untreated	HR-U
Harakeke – treated with 5 wt%NaOH	HR-5
Harakeke – treated with 10 wt%NaOH	HR-10
Harakeke – treated with 5 wt%NaOH/2 wt%Na_2SO_3	HR-5/2
Hemp – untreated	HM-U
Hemp – treated with 5 wt%NaOH	HM-5
Hemp – treated with 10 wt%NaOH	HM-10
Hemp – treated with 5 wt%NaOH/2 wt%Na_2SO_3	HM-5/2

The three alkali solutions were used with a fibre (harakeke or hemp) to solution ratio of 1:8 by weight. Predetermined amounts of harakeke and hemp fibres were placed in stainless steel canisters with pre-mixed NaOH and Na_2SO_3 solutions. The canisters were then placed into a small lab-scale pulp digester with the treatment cycles, controlled by a 4-step controlled programme, chosen based on preliminary screening trials. Trials had previously been conducted raising the temperature from ambient to a maximum temperature over 90 min. It had been demonstrated that treatment conducted for longer than 30 min at a temperature for more than 160 °C reduced the tensile strength of hemp fibre considerably. However, with treatment conducted at less than 160 °C the fibre tensile strength was maintained, but the separation of the fibre was very poor. Therefore, treatment at 160 °C for 30 min was chosen for hemp fibre. For harakeke, it was found that in order to get fibre separation, treatment was required to be conducted at 170 °C for at least 40 min, however, harakeke fibre treated at higher than 170 °C was slightly degraded even though the fibre separation was improved. This is supported by research conducted elsewhere, such that treatment at 170 °C was found to give the optimum fibre separation for harakeke [15]. Therefore, treatment at 170 °C for 40 min was chosen for harakeke fibre.

2.2.2. Scanning electron microscopy

SEM micrographs of untreated and treated fibres were taken using a Hitachi S-4100 field emission scanning electron microscope (SEM). Prior to SEM observation, the samples were mounted on aluminium stubs using carbon tape and then coated with plasma sputtering to avoid the sample becoming charged under the electron beam. SEM observation was carried out at 5 kV.

2.2.3. Single fibre tensile testing

The tensile strength and Young's modulus of untreated, NaOH and NaOH/Na_2SO_3 treated harakeke and hemp fibres were tested according to the ASTM D3379-75: Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single Filament Materials. Single fibres were mounted on 2 mm thick cardboard mounting-cards with a 2 mm gauge length as schematically shown in Fig. 1. PVA glue was applied to hold the fibres to the cardboard and define the gauge length.

Harakeke and hemp fibres, similar to other cellulosic fibres generally have variable cross-sectional areas and diameters along their length. To account for this, the diameter of the fibres was measured at five different points along the fibres length by means of an Olympus BX60F5 optical microscope. Typical single harakeke and hemp fibres observed under optical microscope are shown in Figs. 2 and 3 respectively. It can be seen that harakeke fibre is finer than hemp fibre, but otherwise looked similar.

The apparent cross-sectional area of each fibre was then calculated using the mean fibre diameter and assuming a circular cross-section. The measured and mounted fibres were then placed in the grips of an Instron-4204 universal testing machine and the supporting sides of the mounting cards were cut using a hot-wire