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High performance aligned short natural fibre – Epoxy composites

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ABSTRACT

Aligned short harakeke fibre (New Zealand flax) mats were produced using dynamic sheet forming, impregnated with epoxy resin, then pressed and cured on a compression moulder to manufacture composite materials. These composites were found to have significantly higher tensile properties than planar random oriented short fibre composites; the tensile strength (136 MPa) obtained for the composites is higher than any seen in the literature to date for short natural fibre composites. Fibre orientation was not affected by fibre content despite the higher processing pressure required and fibre orientation factors obtained from Modified Rule of Mixtures equations for Young's modulus and tensile strength were found to be similar.

1. Introduction

Fibre orientation is an important parameter that affects the mechanical properties of composites including natural short fibre reinforced composites. Even basic models for composite strength support that alignment is a major factor determining mechanical properties, through the use of an orientation factor, including the following Modified Rule of Mixtures for composite strength [1]:

$$\sigma_c = k_1 k_2 \sigma_f V_f + \sigma_m \left(1 - V_f\right) \tag{1}$$

where k_1 is an orientation factor; σ and V are average tensile strength and volume fraction, respectively; subscripts c, f and m denotes composite, fibre and matrix, respectively; k_2 is the length efficiency factor (incorporating to interfacial strength).

Reinforcing fibres aligned parallel to the direction of the applied load provide the greatest composite strength. Long natural fibre can be easily aligned by hand combing [2,3] or hand carding machines [4,5]. Alternatively, intermediate processing can also be conducted such as that carried out for textile fibre including spinning to produce continuous material that can then be directionally controlled during composite manufacture, although this requires substantial infrastructure. It is more difficult to control alignment of short fibres, however, some degree of alignment can occur in processes involving material flow such as extrusion and injection moulding, although fibre can also be damaged during such processes. Production of aligned short natural fibre mats that could be used in compression moulding with both thermoplastic and thermosetting matrices to make composites sets a challenge.

In this work, dynamic sheet forming, a technique normally used to make paper sheets, was used to prepare aligned short harakeke mats. Tensile properties of epoxy matrix composites made from these mats using compression moulding were evaluated and compared with randomly oriented short harakeke fibre-epoxy composites. Orientation of fibres in composites was also quantitatively estimated.

2. Experimental

2.1. Materials

Long fibre bundles extracted mechanically from leaves of harakeke plants were obtained from the Templeton Flax Mill, Riverton, New Zealand and then were alkali treated at elevated temperatures for pulp which would be used as reinforcement in this work. The matrix was a low viscosity epoxy system comprised of Nuplex resin R180 and Nuplex standard hardener H180 (mixing ratio 5:1 by weight).

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2.2. Methods

2.2.1. Fibre pulping

Harakeke fibre bundles were initially granulated using a mesh with holes diameter of 4 mm and then pulped using a laboratory scale pulp digester to remove unwanted fibre components and to break down fibre bundles into finer bundles and even single fibres (individual cells). Pulping conditions were similar to those published previously for harakeke fibre [6,7]; fibre (70 g) and 2% NaOH solution with ratio of 1:8 by weight were placed in a stainless steel canister. Canisters were then heated in a digester with a set programme so that the temperature was elevated from ambient to 170 °C over 90 min and then held for 40 min. The pulp was cooled and thoroughly washed with water, then dried in an oven at 80 °C for 24 h. A pulp yield of 51% was determined from the weight of oven-dried pulp and raw fibre. Dried pulp was stored in air tight bags for later use.

2.2.2. Fibre characterisation

Fibre length and diameter were measured using Kajaani Fibrelab electronic sequential fibre analyser. Two samples of approximately 6000 fibres were analysed and a mean fibre length, diameter and fibre length distribution were reported. A few long and (or) coarse fibres which could block the analyser were removed from the sample using tweezers so actual fibre length and diameter could be slightly higher than from those analysed, however, due to the huge number of fibres measured, the difference was assumed negligible.

Density of pulped harakeke fibre was measured based on ASTM D3800-99 which was described in the previous report [8]. Five rolls of pulped harakeke fibre mats weighing about 1 g were oven dried at 60° C for 72 h and then placed in a vacuum oven at room temperature for 5 min to remove trapped air between fibre cells before testing. An average density was obtained.

Thirty single pulped harakeke fibres were tensile tested based on ASTM C 1557-03. The method was described in detail in a previous research [8] with a system compliance value of 0.3136 was applied to obtain Young's modulus of fibres. Average fibre tensile strength and Young's modulus were calculated.

2.2.3. Preparation of fibre mats

Aligned harakeke pulped fibre mats were produced using an automatic dynamic sheet former (DSF) manufactured by Canpa, Canada. The main parts of the machine include a rotating centrifugal drum with screening fabric (called wire) on the inside surface of the drum and a travelling nozzle (Fig. 1). Water is introduced through the nozzle to build up a water wall on the wire which functions as a fibre cushion. The thickness of the water wall can be set depending on the amount of fibre desired. During operation, the traversing nozzle sprays a flow of water and fibres (called stock) onto the wire to build up a fibre layer until the required thickness is obtained. Then the water is removed and a wet fibre web is formed on the wire. In this work, 40 g of pulped harakeke fibre diluted in 20 L of water was prepared to make a fibre web. The web was oven-dried at 80 °C for 24 h and then cut into fibre mats (Fig. 2) with a size of 22 × 15 cm to fit in a compression mould. Planar random oriented harakeke pulped fibre mats were formed by hand. For this, a suspension of fibre in water was poured onto a screen with very fine holes such that fibres were deposited on the screen surface to form a wet fibre mat whilst the water ran through the screen. The mat was press-dried with paper towels and then removed and oven-dried at 80 °C for 24 h. Dried fibre mats were cut to a size of 15 × 15 cm. A fibre mat weight of 105 g/m^2 was determined. Mats were stored in sealed bags for use later.

2.2.4. Fibre mat tensile testing

The tensile testing of fibre mats was based on the Tappi standard T 404 cm-92. Ten strips of 15 × 2 cm for each direction, longitudinal and transverse, were cut from fibre mats and conditioned at 23° ± 3 °C and 50% ± 5% relative humidity for at least 40 h. Strips were then tensile tested using Instron-4204 universal testing machine fitted with a 10 N load cell at a crosshead speed of 1 mm/min. Breaking load was recorded and tensile strength was calculated by dividing the breaking load by the width of the tested specimen. Average longitudinal tensile strength (LTS) and transverse tensile strength (TTS) of ten specimens were reported. The fraction of TTS/LTS varies from 0 to 1, indicating the degree of fibre orientation in the paper, such that when fibres in the paper are randomly oriented, TTS/LTS equals 1; conversely, when fibres are unidirectionally oriented, the ratio is close to 0.

2.2.5. Composite fabrication

Aligned or randomly oriented short fibre mats reinforced epoxy composites were manufactured using compression moulding. Processes of resin impregnation, curing and post-curing were described previously [8]. Compression pressures of 0.5, 2.0,

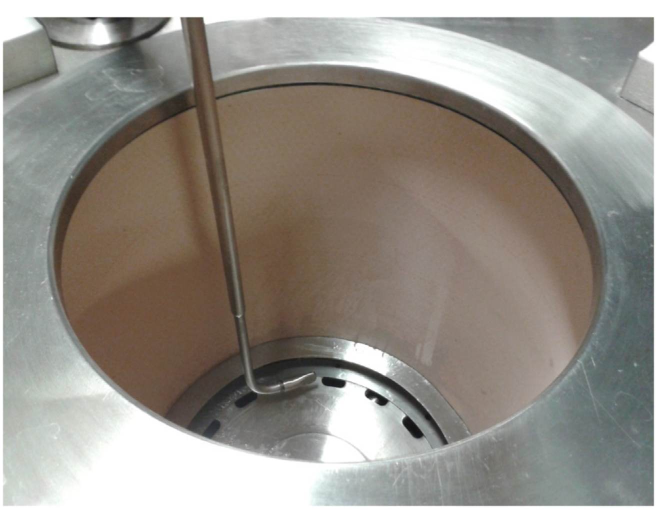

Fig. 1. Centrifugal drum and nozzle of a DSF.

Fig. 2. SEM image of a fibre mat made from pulped harakeke using DSF.