MECHANICAL BEHAVIOUR OF NATURAL FIBRE REINFORCED THERMOPLASTIC BRAIDED COMPOSITE RODS

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Abstract
In the present work, braided composite rods (BCRs) have been developed through braiding of polypropylene (PP) fibres around an axially oriented core, made of a mixture of PP and sisal fibres and subsequent consolidation of the produced structures under heat and pressure. Tensile properties of these BCRs were characterized. The effect of alkali treatment of sisal fibres on their surface morphology as well as mechanical properties of sisal fibres and produced BCRs was thoroughly investigated. It was observed that the tensile properties of developed BCRs improved strongly with the increase in sisal fibre vol.% and moreover, the alkali treatment improved the tensile properties of sisal fibre and their interfacial interactions with PP matrix, leading to enhanced tensile behaviour of BCRs.

1 Introduction
Natural plant fibres such as sisal, flax, banana, jute, coir, bamboo, etc. offer several benefits with respect to metallic and synthetic fibres (glass, carbon, aramid, etc.) such as: abundance and low cost, renewable and sustainable, eco-friendly, low density and high specific properties, minimum health hazard and biodegradability. Due to these attractive properties, use of natural fibres in various industrial sectors such as leisure, medical and building industries has increased approximately 13% over last 10 years and the annual consumption is currently ~275 million kg [1]. In structural and other applications, natural fibres are being used either in the form of fibre reinforced polymers (FRPs) to construct different parts of structure, targeting to reduce concrete usage and associate environmental problems (CO_2 emissions) or in the form of fibre reinforced concrete (FRC), to substitute steel rebars that presents corrosion problems. However, high absorption of moisture and subsequent swelling and degradation forming cracks in the brittle matrices, less resistance to chemicals, high temperature and fire and, poor interface with different matrices are the principal demerits of natural fibres when considered for these applications [2]. Therefore, for their successful implementation, natural fibres have been modified using different chemical [2] and physical methods [3]. Treatment with water repelling agents was targeted to reduce moisture absorption. Silane treatment of natural fibre was found effective to improve the durability of natural fibre reinforced concrete. Pretreatment of natural fibres with alkali has been reported to remove hemicellulose and lignin and therefore, to reduce water absorption. Mechanical

properties of natural fibres can also be improved after alkali treatment due to removal of such weak components.

The use of thermoplastic materials as composite matrices are advantageous due to their short process cycles, ability to be reshape upon heating, good fracture toughness and fatigue strength [4]. In addition to that, thermoplastic composites can be readily recycled, which is an increasingly important issue in many markets. In order to produce fibre reinforced composite rods two different possibilities can mainly be employed. Besides the typically used pultrusion technique, composite rods can also be manufactured using braiding technology [5]. Both technologies can also be combined in pull-braiding process [6], in which a conventional horizontal braiding machine is added to the pultrusion line. Braiding is a relatively easy and low-cost process, which can be automated and is capable of high volume production [7]. The excellent damage and impact tolerance is another important characteristic of braided structures [8].

The present paper reports the development of sisal fibre reinforced thermoplastic (PP) composite rods using braiding technology for applications in sustainable construction and other civil engineering sectors. The effect of alkali treatment of sisal fibre on the fiber's tensile properties and surface morphology as well as on the tensile properties of developed composite rods was thoroughly investigated.

2 Materials and methods

2.1 Alkali treatment

Sisal fibres used in this study was supplied from Brazil. A bundle of sisal fibres was soaked with a solution containing 0.15 wt. % of NaOH and 0.2 wt. % of a wetting agent (Erkantol), for 20 minutes at 98°C. This was followed by washing of the fibres with water and neutralizing alkali with 0.025 wt. % of sulfuric acid, till the drained water achieves a pH value between 6 and 8. Finally the fibres were dried in an oven at 70°C.

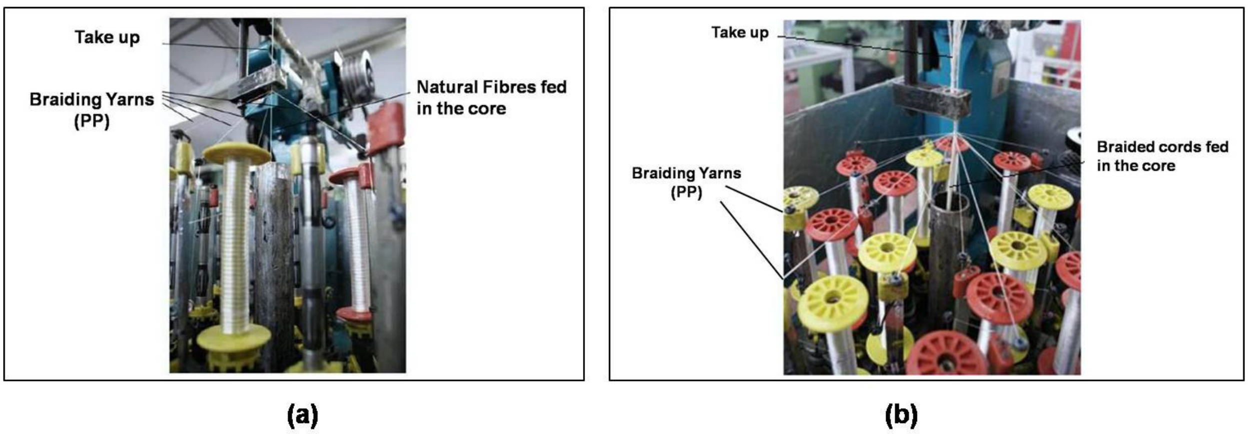

Figure 1. Production of braided structures: (a) braided cords and (b) final braided preform

2.2 Production of BCR

Braided structures were produced in a circular braiding machine (Trenz-Export S.A., Santpedor, Spain, model 16/100). In the first step, cords were produced through braiding of 4 multi-filament PP yarns around different number of sisal yarns (4, 5 and 6). In the second step, a number of these cords were fed in the core and braided with 15 PP yarns to produce circular braided structures with an average diameter of 3 mm. Subsequently, the braided preforms produced in the second step were put under tension in a metal frame [Figure 2(a)], in order keep the core natural fibres straight and aligned and consolidated under heat (160°C for 20 sec) and pressure (5 ton) in a compression molding setup shown in Figure 2(b) and 2(c). During consolidation, the PP yarns melt and form the matrix of BCRs.

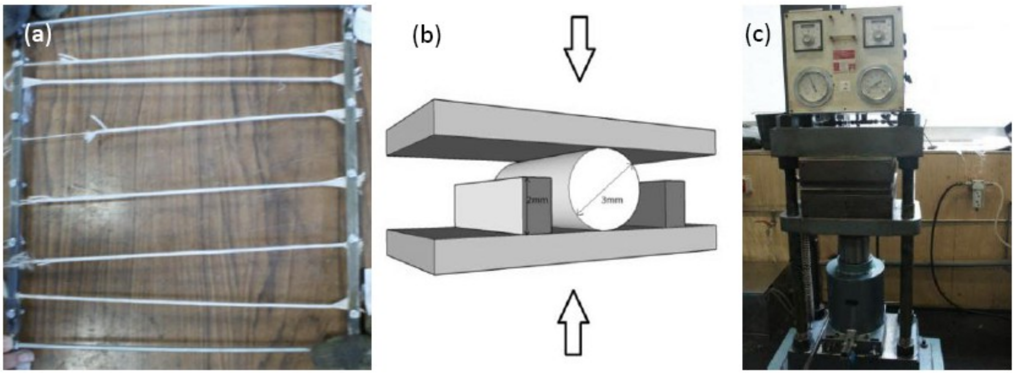

Figure 2. Frame for tensioning (a), schematic of compression setup (b), and used compression molding machine (c)

2.3 Characterization

Tensile properties of untreated and alkali treated sisal fibres were measured in Hounsfield tensile tester according to ISO 5079 standard using a gauge length of 100 mm and crosshead speed of 100 mm/min. Tensile properties of BCRs were characterized in the same machine using a gauge length of 120 mm and cross-head speed of 25 mm/min. The surface morphology of alkali treated sisal fibres was investigated using Scanning Electron Microscopy (SEM, Model FEI Nova 200; EDAX - Pegasus X4M).

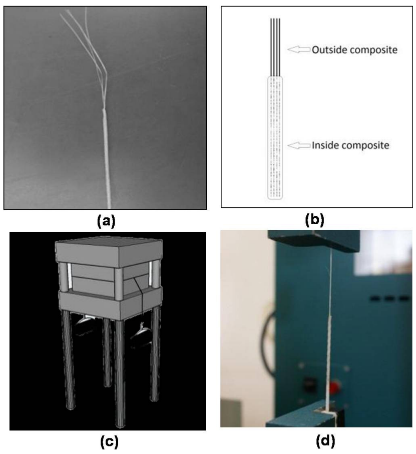

Figure 3. Sample for pull-out test (a) and (b), setup for consolidation (c) and pull-out test setup (d)

Pull-out tests were performed on BCR samples that were prepared through braiding of 15 PP yarns around a core of sisal fibres. However, the sisal fibres were braided only half of their lengths and the braided part was consolidated in the compression molding machine, keeping the unbraided sisal fibre core outside. Tension was applied by connecting weights of 300g on both sides to assure straight and aligned orientation of sisal fibres inside the braided rods. Figure 3 presents the configuration of pull-out samples, production process and testing setup.

3 Results and Discussion

3.1 Effect of Alkali Treatment on Sisal Fibre Properties

The physical properties of sisal fibres, before and after alkali treatment are listed in Table 1 and their tensile properties are provided in Table 2. It can be observed that the diameter of sisal fibres increased after alkali treatment due to swelling and also, there was slight increase in the moisture content probably due to creation of micro porosity in the fibres after alkali treatment.

Type of fibre	Linear density [Tex]	Diameter [mm]	Moisture content [%]
Untreated	28	0.169	9.0
Alkali treated	28	0.177	10.1

Table 1. Physical properties of untreated and alkali treated sisal fibres.

It is clear from Table 2 that the tensile strength of sisal fibres improved significantly after alkali treatment, owing to removal of weak components from the fibre structure. However, an unexpected decrease in the elastic modulus was also observed, whereas extension at break was nearly the same.

Type of fibre	Strength [MPa]	Modulus [GPa]	Elongation [%]
Untreated	412.5	7.8	2.5
Alkali treated	436.3	4.3	2.4

Table 2. Tensile properties of untreated and alkali treated sisal fibres.

Surface morphology of untreated sisal fibres is presented in Figure 4(a), (b) and (c), which show three different surface morphologies. In Figure 4(a), the typical cellulose fibre morphology is shown: long strands arranged in parallel lines. Impurities are visible on these longitudinal strands, giving it some relief. The second image, Figure 4 (b) shows a chaotic and random surface. There is no clear pattern, but random protruding and crumpled strands. Also on the surfaces of these strands impurities are clearly visible. Figure 4 (c) shows kind of a grid pattern with impurities.

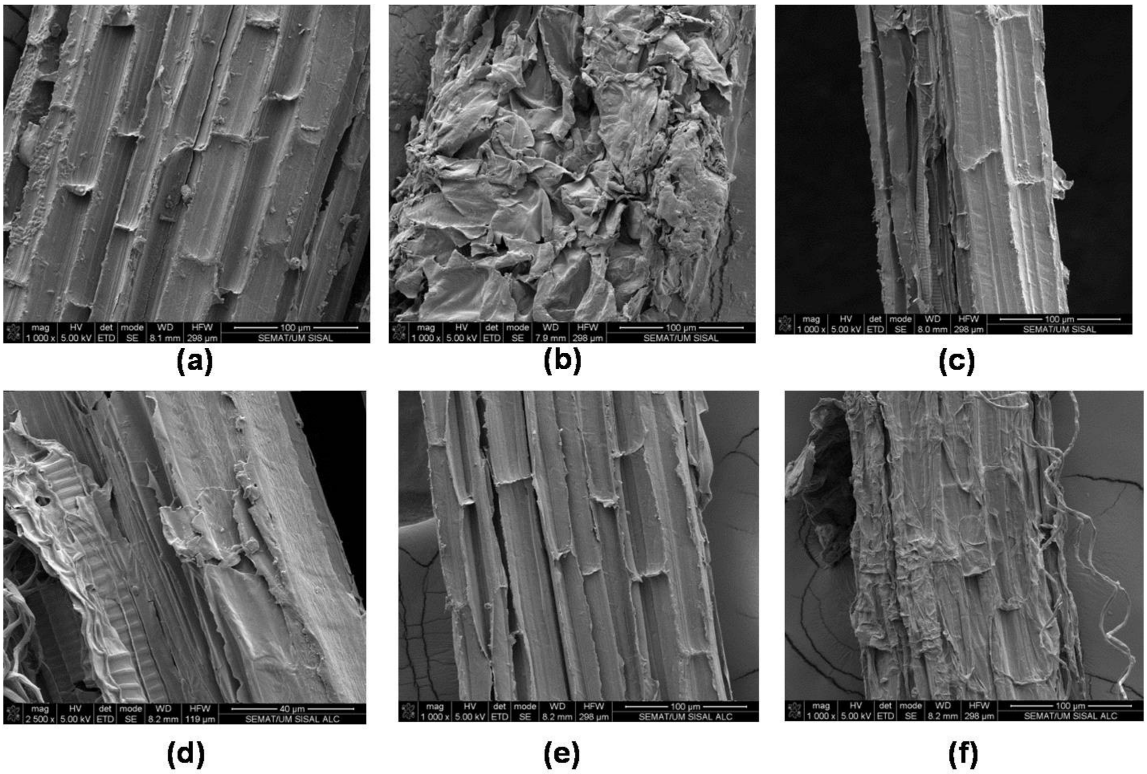

Figure 3. Sample for pull-out test (a) and (b), setup for consolidation (c) and pull-out test setup (d)

After the chemical treatment significant changes to the surface morphology of sisal fibre were observed compared to the untreated sisal fibre morphology. In Figure 4 (d), the surface appears much cleaner than the surface of the untreated sisal fibres. It shows almost no impurities and looks much smoother. A few small holes are visible, probably due to the porosity of the fibre. Figure 4 (e) shows a surface less chaotic and random. Again a few small holes can be observed. In Figure 4 (f) the grid pattern is still visible but also much cleaner. In higher magnifications, the pattern looks very clean with few impurities. Also here holes are visible, just like the first and second image, due to the chemical treatment and porosity of the fibres.

3.2 Tensile properties of BCR

The results of tensile tests of BCRs with untreated and alkali treated sisal fibres are listed in Table 3.

Type of BCR	Fibre Vol. [%]	Strength [MPa]	Modulus [GPa]	Elongation [%]
56 sisal fibre in core	17	37	1.8	3.3
72 sisal fibre in core	23	48	3.2	3.8
72 treated sisal fibre in core	23	64	3.3	3.5

Table 3. Tensile properties of BCRs

It can be seen from Table 3 that an increase in sisal fibre vol.% in the core (from 17% to 23%) improved tensile strength by nearly 30%, elastic modulus by 77% and extension at break by 15%. Moreover, the BCR with alkali treated sisal fibres shows considerably higher strength

(33%) as compared to untreated fibres. This is due to the higher strength of alkali treated sisal fibres as well as due to stronger interface with PP matrix in case of alkali treated fibres. In the pull-out tests, the alkali treated sisal fibres mainly break outside the consolidated area (Figure 3) and this indicates very strong interface with the PP matrix. On the contrary, in case of untreated sisal fibres, breakage was mainly observed within the consolidated area, also accompanied by sliding of sisal fibres to some extent before breakage.

4 Conclusions

In the present work, sisal fibre reinforced thermoplastic braided composite rods were developed and characterized for mechanical properties. The experimental results showed that the incorporation of sisal fibres in the core resulted in significant improvement in the tensile properties of BCR. An increase in sisal fibre content from 17% to 23% by volume resulted in 78%, 30% and 15% improvement in elastic modulus, tensile strength and ultimate strain of BCR respectively. The alkali treatment resulted in different rougher surface morphology of sisal fibres as compared to the untreated fibres. Fibre pullout tests showed improved adhesion between sisal fibres and PP matrix after alkali treatment and as a result, led to 3% and 33% improvement in elastic modulus and tensile strength respectively. The produced BCRs presented a ribbed and rough surface texture, which may result in strong adhesion between BCR and cementitious matrix. Moreover, the natural fibres can be protected from degradation conditions by the PP matrix. Therefore, the developed sisal fibre reinforced thermoplastic rods may be used as a potential material for sustainable, low cost and durable construction.

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