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Effect of alkali treatment on microstructure and mechanical properties of coir fibres, coir fibre reinforced-polymer composites and reinforced-cementitious composites

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HIGHLIGHTS

- Untreated and alkali-treated coir were used as reinforcement for epoxy and cement composites.
- Alkali treatment improved tensile and flexural modulus and strength of coir/epoxy composite.
- Alkali treatment improved compressive and flexural strength of coir/cement composite.
- SEM studies confirmed improved fibre/matrix interfaces by alkali treatment.

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ABSTRACT

In this study, coir fibres were studied for use as reinforcement materials for polymer and cementitious composites. The effect of fibre treatment (i.e. 5 wt.% NaOH solution at 20 °C for 30 min) on microstructure and mechanical properties of coir fibre, coir fibre reinforced epoxy (CFRE) and coir fibre reinforced cementitious (CFRC) composites were investigated. Scanning electronic microscope (SEM) studies were carried out to examine the microstructures of untreated and treated coir fibres, fibre/epoxy and fibre/cement interfaces. Mechanical properties of CFRE were determined by vibration, tensile and flexure tests and mechanical properties of CFRC were determined by compression and four-point bending tests, respectively. The test results show that coir fibre had a much cleaner and rougher fibre surface after the alkali treatment. Compared with the untreated CFRE, treatment improved the tensile and flexural properties of composites, i.e. 17.8% and 16.7% growth in tensile and flexural strength, respectively. However, the treatment also reduced the damping ratio of the CFRE. The increase in tensile and flexural properties and reduction in damping ratio are attributed to the improvement of fibre and epoxy matrix interfacial adhesion due to the treatment, as displayed by SEM micrographs. Compared with the plain concrete, coir fibre improved the compressive strength, flexural strength and toughness effectively. The treatment can further improve these properties of CFRC. SEM studies clearly confirmed that the failure modes of coir fibres in cement matrix are fibre breakage, fibre pull-out and fibre debonding from the cement matrix. The microstructure of coir fibre, CFRE and CFRC were correlated with their mechanical properties.

1. Introduction

The ever-increasing environmental concern and awareness of industrial pollution have forced various engineering industries to develop innovative, reliable and sustainable materials which can replace conventional materials (e.g. synthetic fibres and steel rebar) as reinforcement of structural materials [1–3]. In automotive industry, the use of natural fibres to replace glass and carbon fibres as reinforcements in polymer composites has gained popularity [4–9]. The advent and application of nanotechnology have generated renewed interest in natural fibre reinforced polymers composites which show promising potential as next generation of structural materials [10–12]. In construction and building indus-

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tries, the use of natural fibres as reinforcement of concrete to replace conventional steel rebar is considered as a great step for the development of a sustainable concrete industry [13–19]. Natural fibres, such as flax, sisal, jute, hemp, coir and cotton, are cost effective, have low density with high specific strength and stiffness, and are readily available worldwide [20–22]. Natural fibres are also biodegradable and non-abrasive which are the representatives of "environmentally-friendly" materials [23,24]. The use of natural fibres as reinforcement of polymer and cement matrices will improve the mechanical properties of the matrices such as tensile, flexural and impact properties, etc. It also offers environmental advantages such as independence on non-renewable energy/material sources, lower pollutant emission, lower greenhouse gas emission, enhanced energy recovery and biodegradability [1,25,26]. Therefore, using these "sustainable" natural fibres will reduce structural cost and weight, improve structural performance and increase energy efficiency which provides a solution to immediate automotive and infrastructure needs while promoting the concept of sustainability.

Among natural fibres, coir fibres are widely used because of their inexpensive cost, durability and other advantages, which have been utilized for producing floor furnishing materials, yarn, rope, etc. [27]. Coir is found in tropical regions such as India, Bangladesh, Sri Lanka, Thailand etc., which plays an important role in their regional economy. Coir occupies a prominent position owing to its qualities such as resilience, extensibility, fungi and rot resistance, moth-proof, excellent insulation against temperature and sound, which enhance its commercial and industrial application [28]. Coir is mainly a multicellular fibre which contains 30–300 or more cells in its cross section. Cells in coir is the crystalline cellulose arranged helically in a matrix consisting of a noncrystalline cellulose-lignin complex [27]. Coir fibre has been reported possessing the highest elongation at break among typical natural fibres, which is also capable of taking strain 4–6 times more than other fibres [29–31].

Like other natural fibres, coir fibres also possess some negative characteristics: they are hydrophilic; their mechanical and physical properties are strongly dependent on the climate, location and weather, and thus it is difficult to predict their respective composite properties [32]. Because of the presence of pendant hydroxyl and polar groups in various constituents of fibres, moisture absorption of fibres is very high and leads to poor interfacial bonding with the hydrophobic matrix polymers [33]. Thus, it is necessary to decrease the moisture absorption and hydrophilic character of fibres by suitable surface chemical modification [21,32,33]. To date, only few work has been conducted on chemical treatment of coir fibre to improve the mechanical properties of coir fibre reinforced polymer composites [27,33] and coir fibre reinforced cementitious composites [34–36]. Therefore, in current study, coir fibres were chemically treated with 5 wt.% NaOH solution (20 °C) for 30 min to increase the compatibility of coir fibre with epoxy and cement matrices. The microstructures and mechanical properties of untreated and alkali-treated coir fibres, coir fibre reinforced epoxy (CFRE) composites and coir fibre reinforced cementitious (CFRC) composites were investigated.

2. Experimental work

2.1. Materials

Coir fibres prepared for special purposes like brushes and mats was used for the study because of its availability. These fibres were pre-cut in a length of 200 mm as received. These fibres were then cut into an average length of 50 mm for study. The epoxy used is the SP High Modulus Prime 20 LV epoxy system, which is specifically designed for use in a variety of resin infusion processes. The mix ratio of the resin and its slow hardener is 100:26. The resin and hardener has a viscosity at 20 °C of 1010–1070 cP and 22–24 cP, respectively. The density of the resin and its hardener is 1.123 g/cm^3 and 0.936 g/cm^3, respectively.

For concrete, the cement used was CEM I 42.5 normal Portland cement with a general use type. The coarse aggregate was gravel having a density of 1850 kg/m^3. The gravel has a maximum size of 15 mm (passing through 15 mm sieve and retained at 10 mm sieve). The natural sand was used as a fine aggregate with a fineness modulus of 2.75.

2.2. Surface treatment of fibres

For alkali-treated coir fibres, these fibres were washed three times with tap water to remove debris, dusts and contaminants and dried at room temperature for 48 h. The dried coir fibres were then immersed in 5 wt.% NaOH solution at a lab temperature of 20 °C for 30 min, followed by washed ten times with fresh water to allow absorbed alkali to leach from the fibres. Next, these washed fibres were naturally dried for 24 h and then dried at 50 °C in an oven for 8 h. Finally, the dried fibres were sealed in a plastic bag before the composite manufacturing to avoid atmospheric moisture contamination.

2.3. Fabrication of composites

2.3.1. Fabrication of CFRE

For preparing CFRE, the composite panels with and without alkali treatment were manufactured by the vacuum bagging technique [37]. This technique consists of an initial hand lay-up of a fibre preform and then impregnation of the preform with resin in a flexible bag in which negative pressure is generated by a vacuum pump (see Fig. 1). For the composite processing, the coir fibres were randomly oriented and placed in a rectangular paper frame, with a dimension of 300 mm × 600 mm. Once all the fibres were placed, the paper frame was removed and an aluminium plate with the same dimension was applied on the surfaces of the fibres to ensure the fibres were evenly distributed and to maintain the thickness of the panel. Details for manufacturing of CFRE are displayed in Fig. 2. The composite panel was cured under vacuum at room temperature for 24 h when the fibres were fully impregnated with the epoxy. The CFRE panel was then cured at 65 °C for 7 h. After cured, the aluminium plate was removed from the composite panel

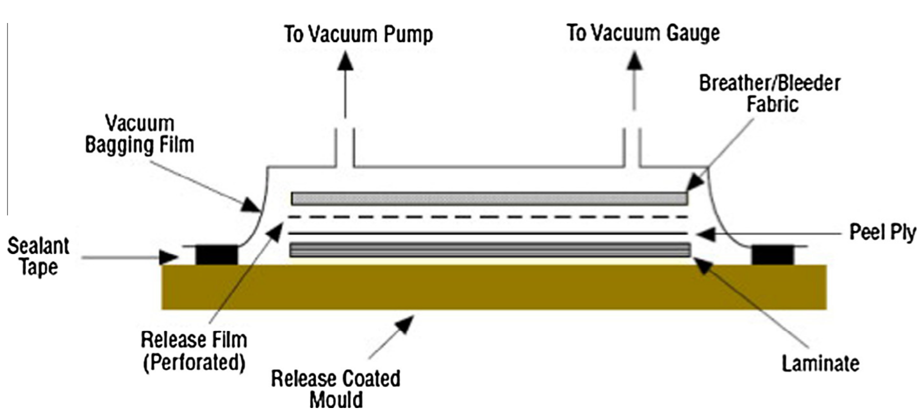

Fig. 1. Setup of vacuum bagging technique [37].