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Effectiveness of the mild alkali and dilute polymer modification in controlling the durability of jute fibre in alkaline cement medium

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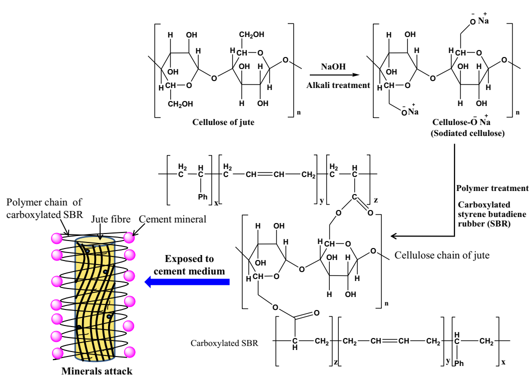
HIGHLIGHTS

- Effective modification of jute fibre using mild alkali and polymer emulsion.
- Evaluation of the durability performances of modified jute fibre in cement medium.
- Prediction of normalized tensile strength of jute fibre exposed to alkaline medium.
- Prediction of jute fibre mineralization using analytical techniques.
- Design of a model to explain durability performances of jute fibre.

GRAPHICAL ABSTRACT



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ABSTRACT

With the aim to improve the durability of natural fibres used as fibre reinforcement in the cement matrix, the combined alkali and polymer modification would be a unique approach. The present investigation deals with the durability performances of the unmodified and combined mild alkali and polymer emulsion modified jute fibres exposed to alkaline medium and cement medium as well. Initially, the jute fibres were modified using mild alkali (0.5% NaOH, 24 h) and dilute polymer emulsion (0.125% carboxylated styrene butadiene rubber (SBR)) sequentially. Afterward, the unmodified and modified jute fibres were then exposed to the saturated lime solution, 0.1 N NaOH solution, and cement paste for 360 days. After periodic exposure in different media, the fibres were removed and tested. Based on the results, it is demonstrated that the combined alkali and polymer modified jute fibre retains 17, 19 and 20% more tensile strength as compared to that of the raw jute fibre after 360 days exposure in saturated lime solution, NaOH solution, and cement paste, respectively. The improved durability of the combined alkali and polymer modified jute appears to be due to the reduction of fibre mineralization by forming a protective coating of polymer on the fibre surface as demonstrated by elemental analysis, FTIR, XRD, NMR, SEM in conjugation with EDS.

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1. Introduction

In recent, the World's increasing need is to develop green and sustainable construction material utilizing natural fibre as fibre reinforcement [1–4]. The major problems associated with the natural fibres like jute as fibre reinforcement in concrete are their susceptibility to water absorption and subsequent degradations [5,6]. The natural fibres are primarily composed of cellulose, hemicellulose, and lignin with very small quantity of pectin [7,8]. Although lignin and pectin enhance the primary dimensional stability of the jute fibres, however, they are brittle and often prevent to transfer the mechanical load [9]. Conversely, crystalline cellulose is predominantly responsible for imparting mechanical strength and ductility to jute fibres. It is reported that the free hydroxyl groups in cellulose molecule of the jute fibres exhibit a tendency to interact with the metal cations (Ca^{2+}/Na^{+}), when these fibres are exposed to the saturated lime solution, NaOH solution, and even in the concrete matrix [10]. As a result, the cellulose molecules are susceptible to chemical degradation and subsequent strength loss of fibres becomes an obvious phenomenon. This phenomenon is called mineralization [11,12]. Hence, improvement in durability of the natural fibres used as fibre reinforcement in construction sector becomes a prime challenge to the researchers. It is stated elsewhere, such problem can be minimized by modifying the natural fibre surface using suitable chemical and polymer [1,13]. Nowadays, researchers have adopted different methods for modifying natural fibres such as mercerization [9], benzoylation [14], esterification [15] and methyl methacrylate grafting [5], etc.

Among the several modification methods, the mercerization of the lignocellulosic fibres is preferred prior to other modification. Mercerization is an effective technique that can increase surface area as well as the surface roughness of the lignocellulosic fibres through the removal of soluble sugars and amorphous materials, which can provide a better fibre–matrix interaction and compaction as well [16,17]. Additionally, it can also improve the mechanical strength of the fibres by arranging the cellulose chains in the preferred direction and relieving internal strain [18–20]. There are several reports available on the mercerization of different lignocellulosic fibres like jute, hemp, kapok, sisal, date palm leaf, banana, coir, napier grass and luffa fibre [16,17,21–23]. Recently, Hossain et al. [24] reported that the alkali modification of single sugarcane fibre bundle leads to improve the tensile strength by 106% as compared to that of the untreated one. However, this modification activates the surface hydroxyl groups of the cellulose by ion exchanging and thus makes the fibre prone to chemical reactions. Hence, for durability enhancement of the natural fibres in alkaline medium, different water repellent organic substances like, linseed oil (LO), paraffin wax (P), colophony (C), and paraffin/rosin (PR), methyl methacrylate, saturated fatty acid, and silane coupling [25–29] are used. Usually, these substances are used to modify the surface active hydroxyl groups of natural fibre by graft copolymerization method. It is also reported that the resistance against mineralization of natural fibres in alkaline cement medium could be increased by applying methacryloxypropyltri-methoxysilane on cellulose pulp fibres [30]. Saravanan and Sivaraja reported that epoxy resin coated coir rope in concrete panel exhibits higher resistance against chemical degradations than uncoated one [31]. Similarly, pectin/polyethylenimin (PP) mixture was applied on flax shives to minimize hydrophilic character of flax shives noticeably and prevent the release of water-soluble molecules into the cement matrix [32]. Monreal et al. [33] reported that coating of linseed oil on the surface of sugar beet pulp shows better dimensional and mechanical stability in the concrete matrix than that of the untreated pulp. The hydrophobicity of natural fibres has been enhanced by applying phenolic resin [34], fluorophenols [35], methyl methacrylate [36] and atmospheric pressure plasma treatment with ethanol pretreatment [37] on fibre surface. Enhancement of the hydrophobicity, durability and tensile strength of natural fibre in all the reported literature was based on the chemical modification such as coating, grafting, esterification and transesterification with synthetic or toxic chemicals.

Recently, some researchers reported the effect of alkali and combined alkali and polymer modified jute fibre as fibre reinforcement on the physical, mechanical, and hydration behavior of cement composite [13,38,39]. However, the durability of jute fibre in highly alkaline cement medium has not studied yet. Hence, the present study aims to develop an alternative non-hazardous process for modifying the jute fibres using combined mild alkali and a water-based carboxylated styrene-butadiene copolymer to improve the durability of fibres in the alkaline cementitious medium and to provide an advanced understanding of the mechanism in controlling the durability of natural jute fibres in the alkaline cementitious medium. Such an effective combination technique and materials will not only offer a durability controlling solution of the natural fibres used as fibre reinforcement in cementitious matrix, but also deliver a sustainable infrastructural maintenance alternative.

2. Materials and method

2.1. Materials

Jute fibres (*Corchorus olitorius*) of TD4 grade as per IS 271 [40] were collected from Gloster Jute Mill, Howrah, India. The received jute fibres were 2–3 m long. Therefore, the jute fibres were cut in a requisite length (i.e., 50 mm) during experiment.

In this study, sodium hydroxide pellet purified purchased from Merck, India, and a functional polymer, e.g., carboxylated styrene-butadiene copolymer based latex (Sika Latex) supplied by Sika India Pvt. Ltd. India (product code KL001308), were used to modify the jute fibre surface. In fact, the alkali treatment using sodium hydroxide is recommended prior to modifying the jute fibre using carboxylated styrene butadiene rubber (SBR) for improving the fibre surface area, surface roughness, and reactivity as well. The prime reason for selecting carboxylated SBR as a jute fibre surface modifier is that it is an aqueous based nonhazardous polymer containing carboxylated functional group which can interact with fibre surface to develop a protective coating on the fibre surface. Additionally, it contains both rigid styrene and flexible butadiene unit that may contribute to improving strength and ductility of jute fibre, respectively [13].

The durability of jute fibres was studied by exposing the fibres in three different media such as sodium hydroxide solution, saturated lime solution, and cement paste. The saturated lime solution was prepared using calcium hydroxide powder collected from Merck, India. Additionally, the cement paste was prepared using Portland Pozzolana Cement (PPC) conforming to IS 1489-2005 [41] supplied by Ambuja Cements Ltd., India. Nowadays, PPC is used adequately in the construction sector not only in India but also throughout the world due to its several advantages, such as comparable properties with the Ordinary Portland Cement (OPC), prepared using solid industrial waste minerals replacing clinker, improved durability performances, and low carbon dioxide emission process. In this study, the used PPC contains 27.28% SiO_2, 50.0% CaO, 1.96% MgO, 9.20% Al_2O_3, and 6.18% Fe_2O_3 [13]. Additionally, the standard consistency, initial and final setting time of the used cement are measured to be 35%, 130 min, and 170 min, respectively [6].

2.2. Fibre surface modification

In this study, surface modification of jute fibres was carried out by treating the jute fibres using sodium hydroxide solution, followed by carboxylated SBR. Initially, the jute fibres were chopped into 50 mm length and immersed in 0.5% alkali (NaOH) solution for 24 h with a weight ratio of 1:30 (jute: alkali solution). After 24 h of immersion, the excess alkali solution was removed to yield alkali treated wet jute fibres. In our previous research [7], it was reported that the modification of jute fibre using 0.5% NaOH solution for 24 h can improve the physical and mechanical performances of jute fibre, which, in turn, motivates to use this particular NaOH concentration. On the other hand, commercially available carboxylated styrene-butadiene copolymer emulsion (Sika latex), containing 41% solid content was diluted with water in a ratio 1: 1.25E−3 (v/v water: polymer emulsion) for surface coating of the alkali treated jute fibres. In fact, for a particular batch, 2.5 ml of carboxylated SBR (Sika latex) was mixed with 2000 ml of water to produce the dilute polymer emulsion. Subsequently, the alkali treated jute fibres were