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Hydration study of the polymer modified jute fibre reinforced cement paste using analytical techniques

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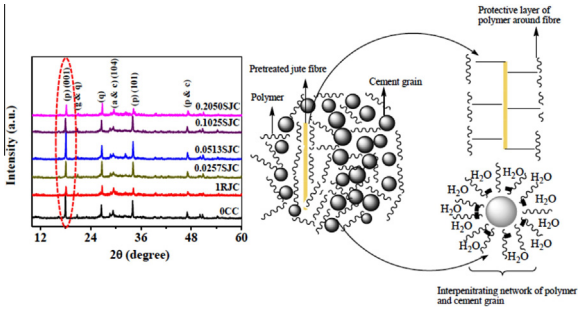
HIGHLIGHTS

- Hydration study of cement in the presence of modified jute fibre.
- Effectiveness of modified jute fibre in controlling the cement hydration reaction.
- Effectiveness of analytical tool in predicting the hydration kinetics of cement.
- Prediction of the optimum dose of polymer in controlling hydration of cement.
- Design of a plausible model to explain the hydration controlling efficiency.

GRAPHICAL ABSTRACT



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ABSTRACT

The paper deals with the hydration behaviour of the polymer modified jute fibre reinforced cement paste. In this investigation, different polymer contents in the emulsion (i.e., 0.0257%, 0.0513%, 0.1025% and 0.2050%) were used to prepare the polymer modified jute fibre reinforced cement paste. The hydration characteristic of the cement samples was assessed by monitoring the extent of hydrated cement product. Based on the X-ray diffraction, Fourier transform infrared spectroscopy, differential scanning calorimetry and thermogravimetry analysis of the hydrated cement samples, it is revealed that the polymer modified (0.0513%) jute fibre reinforced cement sample produces a greater extent of hydrated cement product as compared to that of the unmodified fibre reinforced cement sample. Therefore, it is demonstrated that the unmodified jute fibre delays the cement hydration reaction, whilst, the use of an optimum polymer content in the emulsion (0.0513%) recovers the hydration delaying action of jute fibre. Finally, a model has been proposed to explain the overall performances of the polymer modified jute fibre reinforced cement paste.

1. Introduction

Nowadays, the cement concrete is considered as a crucial component for the development of modern civil infrastructures. Usually, the concrete composites possess high strength and high modulus of elasticity. The strength of the concrete composites is primarily governed by the hydration of cement in the presence of water [1,2]. The cement hydration is a complex sequence of chemical reactions occurring among the clinker phases (C_3S, C_2S, C_3A and C_4AF) and water [1–3]. Just soon after the addition of water, the clinker sulphates dissolve readily in the water, followed by reacting with C_3A phase [1]. Afterwards, C_3S and C_2S phases react with the water sequentially to form calcium hydroxide $Ca(OH)_2$ and calcium silicate hydrate (C–S–H) as predominant products [1,3]. Eventually, these reactions lead to set and harden the cement composites [1]. Although, the cement composites possess high compressive strength; however, these are brittle in nature due to

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the lack of ability to achieve high tensile and flexural properties. The low tensile and flexural strength of the cement composites could be due the presence of microcracks especially at the interface between aggregates and mortar [4]. Microcaraks are usually developed in the cement composites due the shrinkage. Additionally, these are developed during loading because of the difference in stiffness between aggregates and mortar. During loading, the coalescence of the microcracks leads to attribute a brittle fracture of the cement composite at a low-stress level [5,6]. Once the crack is initiated in the system, it propagates rapidly to yield a brittle fracture [6]. In order to inhibit the propagation crack, fibre reinforcement is a unique scheme.

These days, several fibres, such as steel, synthetic, and natural fibres are used for the development of the fibre reinforced cement composites. Nevertheless, the natural fibres including jute have recently attracted the attention of scientists and technologists for the development of the green and sustainable cement composite [7]. An extensive research has been executed to improve the ductility, flexural strength and fracture toughness of cement composite by reinforcing with natural fibre [8,9]. The most important reason for the use of natural fibres as fibre reinforcement is their abundant availability, low-cost, low-density and environmental friendliness [10]. Additionally, the specific properties of the natural fibres are comparable with those of other fibres which are used as a conventional reinforcement. In the fibre reinforced cement composites, the random distribution and uniform orientation of fibres throughout the cement matrix is considered to inhibit the propagation of crack more effectively. The important function of the natural fibres in the cement composite is to bridge the crack, which can create a stage of slow crack propagation and a gradual failure [8,9]. The short and discrete natural fibre reinforcement can able to reduce the inherent brittleness of the cement composites; however, some other issues are associated with it. The natural fibres are less durable in the highly alkaline cement medium and delayed the cement setting and hydration reaction. Usually, the natural fibre releases some organic compounds during mixing with cement, which are absorbed on the surface of the hydrated cement product [11,12]. This in turn leads to form a temporary barrier around the cement particle and inhibits to diffuse water for further hydration [13,14]. This phenomenon inhibits the nucleation and growth of hydrated cement products, consequently, delays the cement hydration [11–14].

In this context, modification of fibre and cement matrix would be a unique approach to restraining the problems. Previously, a few research was executed to develop chemical and/or polymer modified cement composites, especially, for the improvement of the mechanical properties and durability [15,16]. It is reported elsewhere, the use of styrene acrylate, polyvinylidene chloride, styrene acrylate with silane delays the cement hydration reaction and reduces the long term calcium hydroxide content [17]. Whereas, poly vinyl acetate, polystyrene, poly vinyl chloride, polyacrylates influences the crystallization of the hydrated product during cement hydration and improves the mechanical properties as well [18]. Oxalic acid, calcium chloride, sugar, hydroxy carboxylic acid, etc. are also used to accelerate the cement hydration reaction [19]. Additionally, optimum dose of styrene butadiene rubber is used to accelerate the cement hydration reaction [20]. However, there is a lack of information about the hydration behaviour of cement composites in the presence of the chemical and polymer modified fibre. Although, the polymer modified fibre reinforcement (modification fibre and cement matrices) is reported to be a unique scheme to improve the fibre matrix bond and the durability of fibre in the cement medium [16]. Okino et al. [21], reported the effect of $CaCl_2$ on the eucalypts and rubberwood based cement system, in which eucalypts delays the cement hydration which is counterbalanced by the addition of $CaCl_2$. Recently, we investigated the effect of unmodified and mild alkali modified jute fibre on the hydration characteristics of cement [12,14]. Additionally, a hypothetical model was proposed to explain the effect of a combined alkali and polymer modified jute fibre on the hydration behaviour of cement [13]. However, we failed to analyse the possible interaction between polymer modified jute fibres and cement components.

Reviewing the literature, an adequate information has been assembled about the cement hydration in the presence of fibre and different chemicals separately, nevertheless, no consensus clarification has yet available about the hydration of cement in the presence of polymer modified fibre. Therefore, in this investigation, we have studied the effect of polymer modified jute fibre in controlling the hydration behaviour of cement paste using several analytical techniques. Additionally, we have tried to establish a plausible model in favour of the polymer modified fibre–matrix interaction.

2. Experimental

2.1. Materials

The cement paste samples were fabricated using a commercial Portland-pozzolana cement (conforming to IS 1489, 1991) [22] purchased from Ambuja cement Ltd., India. It contains 27.28% SiO_2, 50% CaO, 1.96% MgO, 6.18% Fe_2O_3 and 9.20% Al_2O_3.

In order to prepare the jute cement paste, the Tossa Indian jute (corhorus olitorius) of TD4 grade, purchased from the Gloster jute mill, Howrah, India, was used as a reinforcing agent. The water absorption of this jute fibre is reported to be 210%. As the received jute fibres were long enough, therefore, these were cut into 5 ± 0.5 mm length. The average diameter of the used jute fibre is measured to be 0.062 ± 0.014 mm.

Commercially available carboxylated styrene butadiene copolymer emulsion containing 41% solid polymer (product code KL001308, supplied by Sika India Pvt. Ltd., India) was used to modify the surface of the alkali treated jute fibres and the cement matrix as well. Usually, the styrene butadiene copolymer emulsion is used for damp proofing of the concrete. Therefore, the higher dose of this polymer may affect the strength and hydration characteristic of the cement composites. Additionally, due to the amorphous nature of the polymer, modification of jute fibre with a high polymer content in the emulsion may lead to reducing the tensile property of the jute fibre. Therefore, in this investigation, the polymer latex was diluted with water for the modification of fibre and cement matrix simultaneously. The volume (water):volume (polymer latex) ratio for dilution are 1:6.25E−4, 1:1.25E−3, 1:2.5E−3, and 1:5.0E−3.

2.2. Hydrated sample preparation

In this investigation, the cement samples were prepared using Portland pozzolanic cement, jute fibre and diluted polymer emulsion. Table 1 represents the formulation details of the cement paste samples. Initially, the used jute fibres (5 mm long) were ground in a mixer grinder to obtain a homogeneous fibre cement mixture. Prior to the fabrication of polymer modified jute cement paste, the requisite amount of jute as mentioned in Table 1, was soaked with the alkali solution for 24 h following which the spent alkali solution was decanted out. Afterwards, the respective amounts of the Sika latex (41% solid content) were diluted with 100 ml water and added to the alkali soaked wet jute fibre. Thereafter, the total amount of cement required for the fabrication of a cement paste was added gradually in the mixture of the alkali treated jute fibre and polymer emulsion. A mechanical mixer was used to obtain a uniform mixing of the jute fibre in the cement slurry. The mixture was then cast immediately in the glass petri dish and allowed to set for 24 h at the ambient temperature (30 ± 2 °C). Subsequently, the samples were removed from the petri dish and allowed to water cure for 28 days. After completion of the desired curing period, the samples were removed from the curing chamber and ground by a mortar pestle to obtain a powder. The powder samples were then washed with water and treated with acetone, followed by drying in an oven at 105 °C for 24 h. This step was performed to terminate the cement hydration reaction at the specific curing time. The dried powder samples were then stored in a desiccator to avoid the moisture absorption. During the fabrication of the cement paste samples, the ratio of cement:fibre:water was kept fixed, however, the solid polymer:water (weight to volume) ratio was varied. The solid polymer content in the emulsion (defined as the weight of the solid polymer in 100 ml water) was varied in between 0.0257% and 0.205% (w/v). Table 1 represents the composition of the prepared sample as well as sample codes.