Construction and Building Materials 38 (2013) 776–784

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Improvement of the mechanical properties of jute fibre reinforced cement mortar: A statistical approach

Sumit Chakraborty, Sarada Prasad Kundu, Aparna Roy, Ratan Kumar Basak, Basudam Adhikari, S.B. Majumder *

Materials Science Centre, Indian Institute of Technology, Kharagpur 721 302, India

HIGHLIGHTS

- ▶ Effectiveness of short jute fibre as reinforcement in cement matrices.
- ▶ Optimisation of process for uniform dispersion of jute fibre in cement matrices.
- ▶ Use of statistical model for analysing flexural strength data and fibre dispersion.
- ▶ Mechanical superiority of cement mortar due to jute fibre reinforcement.
- ▶ Reinforcement of jute fibre resists the crack propagation and shows gradual failure.

ARTICLE INFO

Article history:
Received 2 March 2012
Received in revised form 3 August 2012
Accepted 20 September 2012
Available online 26 October 2012

Keywords:
Cement mortar
Fibre reinforcement
Physical properties
Mechanical properties
Weibull distribution

ABSTRACT

We have demonstrated that the physical characteristics and mechanical properties of cement mortar are significantly improved by the jute fibre reinforcement. Three different processes methodologies were adopted to mix the jute fibre homogeneously in the mortar matrix. By optimising the processing conditions and fibre loading; the cold crushing strength and flexural strength, flexural toughness and the toughness index of the mortar has significantly been increased. Based on the Fourier transformed infrared spectroscopy and thermo-gravimetric analyses a plausible mechanism of the effect of jute reinforcement controlling the physical and mechanical properties of cement mortar have been proposed.

1. Introduction

For low cost building construction in developing countries, natural fibre reinforced cement composites have been found attractive [1,2]. Natural fibres such as Roselle, sisal, coconut, sugar-cane bagasse, hemp, and jute are reported to yield improved compressive and tensile strength of the cement based composites [3–8]. Thus Ismail [8] has investigated the effect of Roselle fibre in improving the compressive and tensile strengths of cement matrix. The chopped natural fibre reinforcement improves the energy absorption capability of the cement matrix to transform a brittle material into a pseudo-ductile one. It is reported that the natural fibres, as reinforcing agent in cement or cement concrete composites, serve as crack arrestor that eventually retards the crack propagation to lead non-catastrophic failure [9]. A new class of construction materials with superior tensile strength and ductility has been developed by continuous fibre reinforcement [10,11]. The enhancement of the strength and ductility is primarily governed by the fibre reinforcement into matrices. Thus it is reported that the natural fibres, as reinforcing agent, bridge the cracks in the matrix, transfer the loads into it to inhibit the development of micro-cracks in the composites [12]. Accordingly, natural fibre reinforced cement composites are most suitable for shatter and earthquake resistant construction, foundation floor for machinery in factories, fabrication of light weight cement based roofing and ceiling boards, wall plaster, and construction materials for low cost housing [13].

The factors influence the physical and mechanical properties of natural fibre reinforced cement composites can be grouped into three major categories. The first one is the type and characteristics of reinforcing fibres. The second and third important factors are the nature of the cement base matrix (and mix design) and the way of mixing, casting and curing of these composites respectively. Among these parameters, the compatibility between the fibre

* Corresponding author. Tel.: +91 3222 283986; fax: +91 3222 282274.
E-mail address: subhasish@matsc.iitkgp.ernet.in (S.B. Majumder).

0950-0618/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2012.09.067

Table 1
Mix design and nomenclature of the mortar specimens investigated in the present work.

Process	Component ratio (C:S)[a]	Jute length (mm)	Sample code for different jute loading (%)					
			0	0.5	1.0	2.0	3.0	4.0
PS1	1:3	5	0CM	0.5PS1-5	1.0PS1-5	2.0PS1-5	3.0PS1-5	4.0PS1-5
PS2	1:3	5	–	0.5PS2-5	1.0PS2-5	2.0PS2-5	3.0PS2-5	4.0PS2-5
PS3	1:3	5	–	0.5PS3-5	1.0PS3-5	2.0PS3-5	3.0PS3-5	4.0PS3-5
PS3	1:3	10	–	0.5PS3-10	1.0PS3-10	2.0PS3-10	3.0PS3-10	4.0PS3-10
PS3	1:3	20	–	0.5PS3-20	1.0PS3-20	2.0PS3-20	3.0PS3-20	4.0PS3-20

[a] C: cement, S: sand.

and cement based matrix leading to a homogeneous distribution of the reinforcing fibres remains one of the most dominating factor that influence the mechanical properties of these composites [14].

In the present work we have studied the effect of chopped jute fibre as a reinforcing agent to cement mortar. We have adopted three different mixing sequences for homogeneous distribution of jute fibre in cement matrix. The mixing sequence is found to have major influence in improving the physical characteristics and mechanical properties of cement mortar. The physical and mechanical properties of fibre reinforced cement mortars are investigated by varying fibre contents, fibre length, and mixing sequence of jute fibre into the cement matrix. The flexural strength of the jute fibre reinforced cement mortars are analysed using a two parameter Weibull distribution model. The plausible mechanism of fibre cement interaction controlling the mechanical properties of cement mortar is discussed.

2. Experimental

2.1. Preparation of jute fibre reinforced mortar specimens

The cement mortar was prepared using commercial Portland pozzolana cement (conforming with IS 1489, 1991 [15]) and local river sand which does not contain any organic substances. TD-4 grade jute fibres (Gloster jute mill, Howrah, India) are used as reinforcing agent. In the mix design the weight fraction of cement: sand: fibre: water was kept 1:3: x: 0.6 ($0.0 \leqslant x \leqslant 0.04$). The length of chopped jute fibres were varied in the range of 5–20 mm. Thus in a typical batch with 1.0 wt.% (with respect to cement) jute reinforcement, 3 kg cement is mixed with 9 kg of sand, 0.030 kg of jute fibre and 1.8 kg of water. For reference mortar (with no jute reinforcement) the workability was measured to be 155 ± 5 mm from standard flow table test. The water absorption and tensile strength of the jute fibres were measured in accordance with ASTM D 570 [16] (for water absorption) and ASTM D 3822 [17] (tensile strength) standard respectively. The physical characteristics and mechanical properties of the jute fibres are reported elsewhere.

Homogeneous distribution of jute fibre into cement matrix is thought to be crucial to yield improved mechanical properties of the cement mortar. We have adopted three different mixing sequences for homogeneous dispersion of jute fibres into the cement matrix. In all these mixing processes, unless stated otherwise the length of chopped jute fibre was kept constant ~5 mm. In the first mixing process (termed as PS 1), cement water slurry was made using 50% of the cement and water required to make the mortar batch. In this slurry, the required amount of chopped jute fibre was added with continuous mechanical stirring. The stirring was continued for 10 min. to homogenize the jute–cement–water slurry. The required amount of sand and remaining part of the cement was dry mixed separately for 5 min. The dry mix was added slowly in the jute–cement–water slurry through continuous mechanical stirring for 5 min. Finally, the remaining 50% water was added into the jute–sand–cement slurry through continuous stirring to make fresh jute cement mortar. In the second mixing process (termed as PS 2), the raw jute fibres were initially immersed in 50% of total water required for mortar batch formulation. In this jute suspension, 50% of the required cement was mixed through continuous stirring for 10 min. The required amount of sand and remaining part of the cement was dry mixed separately for 5 min. The dry mix was added slowly in the jute–cement–water slurry through continuous mechanical stirring for 5 min. Finally, the remaining 50% water was added into the jute–sand–cement slurry through continuous stirring to make fresh jute cement mortar. In the third type mixing (termed as PS 3), first the chopped jute fibres are immersed in water (jute: water ~1 g: 30 ml) for 24 h. The fibres were completely saturated with water and the excess water was decanted. A jute–cement slurry was made by mixing the water saturated fibres with 50% of total cement and water required for mortar batch formulation. Similar to that described for PS1 and PS2, required amount of sand and remaining amount of cement and water was then added in the jute–cement slurry to make fresh jute–cement mortar. The fresh mortar prepared using the above processes were immediately cast both in 70.6 mm cubic mould (for compressive strength testing in accordance to IS: 10080, 1982) [18]) and 110 (l) × 20 (b) × 20 (d) mm^3 rectangular mould (for flexural strength testing in accordance to IS: 4332, 1972) [19]). A commercial vibrating table (AIM 365, AMIL Ltd., India) with vibration frequency ~3.6 kHz was used to cast mortar specimens for compressive and flexural strength measurements. The mortar specimens were set in the respective moulds for 24 h under ambient condition. The specimens were then de-moulded and water cured for 28 days. After curing the specimens were dried in ambient conditions and used for testing.

2.2. Physical and mechanical properties of jute reinforced mortar

Flow behaviour of the freshly prepared cement mortar (which indicates its workability) is estimated by a flow table test in accordance with IS 1727 standard [20]. The bulk density of the water cured mortar samples were estimated according to ASTM C 948 [21] standard.

Fourier transformed infra-red spectroscopy (FTIR) measurements were performed on jute fibre as well as mortar samples using a spectrometer (Nexus 870, Thermo Nicolet Corp. USA). Oven dried (at 105 °C for 1 h) powdered mortar samples were mixed with KBR to make pellets for FTIR measurements. The FTIR spectra were recorded in the wave number range between 4000 and 400 cm^{-1} after averaging 32 scans. The thermo-gravimetric analyses (TGA) of fibre–cement slurry were performed using a TGA instrument (TG209F1, NETZSCH Inc. UK). The cement slurry was water cured for 28 days. Then it was crushed into powder and 10 mg powder of each sample used for TGA measurements. The temperature range of measurement was 30–1000 °C. A heating rate was maintained ~10 °C/min and oxygen ambient was used for TG measurements.

The photographs of the mortar specimen were taken using a digital camera (IXUS 230 HS, Canon, UK)

The micrographs of the fractured surface of the mortar specimens were recorded using a scanning electron microscope (Vega-LSV, TESCAN, Czech Republic). Thin gold was sputter coated on the surface of the mortar samples to avoid charging.

The compressive strength measurements were carried out using a 1000 kN hydraulic universal testing machine (AIM: 31402, S. No. 091020, AMIL Ltd., India). Mortar cubes (volume ~351895.816 mm^3) samples were tested (without any preload) using a loading rate 13 kN min^{-1} in compliance with the IS 516 standard [22]. The cold crushing strength (CCS in MPa) was calculated measuring the fracture load (F in Newton) and area of the face of the cube (A in m^2) using the following relation.

Table 2
Physical properties of the control and jute fibre reinforced mortar specimens.

Sample code	Flow table value (mm)	Bulk density (kg/m^3)
0CM	154 ± 9	2280 ± 10
0.5PS1-5	142 ± 6	2215 ± 20
1.0PS1-5	135 ± 8	2200 ± 30
2.0PS1-5	126 ± 6	2090 ± 20
3.0PS1-5	110 ± 8	2080 ± 10
4.0PS1-5	110 ± 9	2000 ± 40
0.5PS2-5	136 ± 7	2120 ± 20
1.0PS2-5	127 ± 9	2100 ± 30
2.0PS2-5	115 ± 7	2100 ± 80
3.0PS2-5	110 ± 6	1900 ± 40
4.0PS2-5	110 ± 8	1800 ± 50
0.5PS3-5	154 ± 7	2275 ± 20
1.0PS3-5	156 ± 6	2270 ± 10
2.0PS3-5	157 ± 8	2220 ± 50
3.0PS3-5	159 ± 9	2190 ± 10
4.0PS3-5	161 ± 8	2100 ± 10