Final Technical Report

on

DEVELOPMENT OF JUTE FIBER REINFORCED CEMENT CONCRETE COMPOSITES

FINAL PROJECT REPORT

ON

The Project: DEVELOPMENT OF JUTE FIBER REINFORCED CEMENT CONCRETE COMPOSITES

Project No: JMDC/JTM/MM-IV/7.1/2008, Dated: 31.3.2008

Sponsored by
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Govt. of India
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June 2011

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SECTION A

General introduction

A.1. Introduction

The design of a durable and low cost fiber reinforced cement concrete for building construction is a technological challenge in developing countries. The type of fibers currently been used include steel, glass, polymers, carbon and natural fibers. Economic considerations have restricted the use of carbon fibers in cementitious composites on a commercial level for their non ecological performance. Natural fibers have the potential to be used as reinforcement to overcome the inherent deficiencies in cementitious materials. Considerable researches are being done for use of reinforcing fibers like jute, bamboo, sisal, akwara, coconut husk, sugarcane bagasse in cement composites mostly in case of building materials. Use of natural fibers in a relatively brittle cement matrix has achieved considerable strength, and toughness of the composite. The durability of such fibers in a highly alkaline cement matrix must be taken into consideration by effective modifications. A specific chemical composition has to be chosen that can modify the fiber surface as well as strengthen the cement composite.

A.2. Background

Cement concrete composite is the most important building material and its consumption is increasing in all countries. The only disadvantage of cement concrete is its brittleness, with relatively low tensile strength and poor resistance to crack opening and propagation and negligible elongation at break. To overcome these discrepancies reinforcement with dispersed fibers might play an important role. Steel is the conventional reinforcing material in concrete. Although steel enhances the strength and modulus of concrete but it lacks the ability to absorb mechanical impact. The steel makes the reinforced cement concrete (RCC) structure heavy and in due course of time as a result of water/moisture diffusion through micro crack developed in the RCC structure steel starts corroding leading to failure of the concrete. On the contrary, if the micro crack formation and propagation can be minimized by dispersion of short fibers, the mechanical properties as well as the durability of the concrete can be improved. Such a system would be able to bear high level static as well as dynamic stress. Natural (cellulosic) fibers might offer the opportunity as a convenient reinforcing agent in concrete composite due to its low density and high tensile property. In recent years, considerable research efforts are found to develop high-strength, natural fibers reinforced concrete composites, mostly for using as building and construction materials.

Natural fibers, isolated from plants, are classified into three categories, depending on the part of the plant they are extracted from. The first category is the so called fruit fiber (e.g., coir, cotton, etc.) which are extracted from fruits of the plant. The second category of the fiber is found in the stems of the plant (e.g., jute, flax, ramie, hemp, etc). Such fibers are known as bast fiber. The third category is the fibers extracted from the leaves (e.g., sisal, date palm, oil palm, etc.).

Polymer modified jute fibers have been decided to be used as reinforcing element in cement concrete in which polymer will chemically bridge jute in one side and cement on the other side. Polymer modified jute fiber is expected to act as a flexible reinforcing agent in cement concrete enabling it to transmit both static and dynamic stresses to its surrounding bulk as well as absorb a portion of the stress by virtue of its flexible nature. An optimized weight fraction of polymer modified jute fiber in cement concrete may lead to excellent mechanical properties. It has been anticipated that modification of jute fiber with polymer will reduce degradation possibilities.

Fiber reinforced concrete has been investigated extensively to make light weight corrosion free structural materials. There are global attempts to use natural fibers as reinforcing agent in cement concrete matrices. The advantages of natural fibers over the conventional reinforcing fibers like glass, synthetic (e.g., polypropylene, polyethylene and polyolefin, polyvinyl alcohol), carbon, steel etc., are: abundant availability, low cost, less abrasiveness, ability to absorb mechanical impact, easy to handle and process and environmental friendliness. These composites can be used in various fields of applications such as permanent frameworks, paver blocks, wall panels, pipes, long span roofing elements, strengthening of existing structures and structural building members. The natural fiber reinforced concrete composites present enhanced strength and are likely to encounter a range of static overload and cyclic loading due to possible wind or earthquake loading. When concrete matrix cracks under load, the fibers bridge the cracks and transfer the loads to its surrounding bulk as well as absorb a portion of the load by virtue of its flexible nature. Several investigations have been carried out with different lignocellulosic fibers like, wheat straw, rice straw, coir, hazelnut shell, bagasse, oil palm residues, arhar stalks, etc., to find the potentiality of natural fibers as an effective reinforcement in concrete composites. But no report is found on the use of jute fiber as reinforcement in cement concrete.

Based on the present scenario it has been anticipated that the jute fiber reinforced cement concrete may find potential application as structural items in construction industry. Being a potential agricultural product, the use of jute as reinforcing fiber in cement concrete will promote jute farming industries as well as produce better advanced composites.

A.3. Task and deliverables

Tasks of this project:

- Development of modified jute fiber: Modification of jute fiber with suitable chemical and polymer for its surface activation.
- Development of unmodified and modified chopped jute fiber reinforced cement concrete composite.
- Prototype development of modified jute fiber reinforced cement concrete products.
- Market needs and assessment of modified jute fiber reinforced cement concrete products.

Deliverables of this project

- Selective choice and composition optimization of chemical and polymer for modification of jute fiber.
- Optimized process development for mixing and casting of jute fiber reinforced cement concrete composite.
- Optimized fiber length and loading in cement composite for best possible mechanical properties.
- Prototype products like precast concrete pipes, prestressed concrete pole and precast concrete pavers block.
- Market survey

A.4. Scope and objectives of present investigation

There are two prominent research issues associated with the use of jute fiber in cement concrete. First is the hydrophilicity of natural fiber. The high hydrophilicity of natural fiber makes the wet concrete stiff and non workable due to gradual absorption of water from the wet concrete mixture. The second research issue is the agglomeration of the chopped jute fiber during concrete mixing leading to inhomogeneous fiber dispersion in the concrete matrix. Hence the major challenges in this project is to

- Reduce hydrophilicity of jute fiber by surface modification
- Reduce fiber agglomeration in concrete matrix
- Formulate a novel mixing technique and fabrication of jute fiber reinforced cement concrete/mortar having improved physical and mechanical properties.

The objectives of this project are:

- ➢ To evaluate the suitability of short jute fiber as a reinforcing agent in cement concrete/mortar.
- ➢ Optimization of length of short jute fiber and its loading in cement matrix.
- ➢ Modification of jute fibers with chemicals and polymers and characterization of modified jute fiber.
- ➢ Mixing and casting of untreated and chemically modified jute fiber reinforced cement concrete/mortar.
- ➢ Physical, mechanical and structural characterization of fabricated cement concrete/mortar.
- ➢ Durability study of jute fiber in cement concrete matrix.
- ➢ Prototype development of jute fiber reinforced concrete/mortar products.

A.5. Work plan

The following work plan was formulated keeping in view the above objectives

- ➢ Chemical modification of jute fiber
- ➢ Characterization of unmodified and chemically modified jute fiber
- ➢ Fabrication of jute reinforced cement composite
- ➢ Testing and characterization of jute fiber reinforced cement composite
- ➢ Industrial field trial and prototype product development

SECTION B

Modification and characterization of jute fiber

B.1. Materials

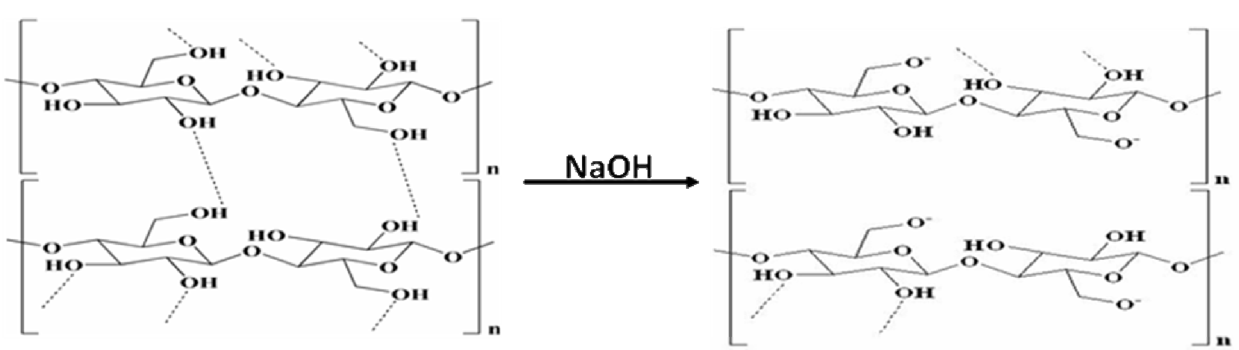
Jute fibers of TD4 grade were collected from Gloster Jute Mill, Howrah, India. Analytical grade sodium hydroxide (NaOH) of Merck, India and commercially available carboxylated styrene-butadiene copolymer based polymer latex (Sika Polymer latex Power) were used for fiber surface modification.

B.2. Chemical modification of jute fiber

From the polar chemical nature and structure of natural fiber it appears that such fibers can interact with polar nature of cement concrete. This concept justifies the reinforcing action of jute in cement concrete. Simultaneously due to polar character of natural fiber, viz., jute, it shows hydrophilic character. Such hydrophilicity might lead to depletion of water from the wet concrete mix as well as it might degrade in due course of time as a result of microbial attack. To overcome such shortcomings jute fibers need suitable physicochemical modification before incorporation in concrete matrix. It was anticipated that after modification with alkali and other chemical constituents, microbial degradation of jute fiber can be either delayed or prevented.

B.2.1. Modification with alkali

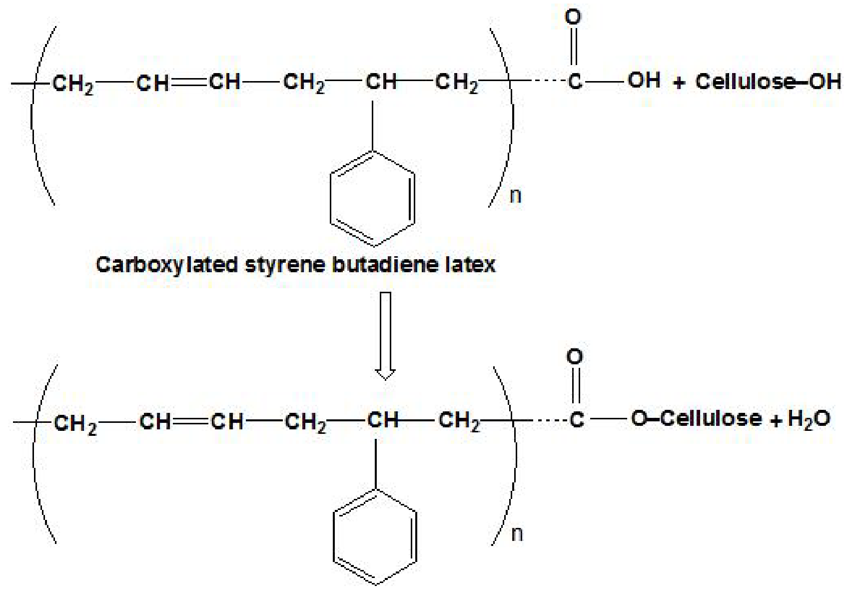
The jute fibers were cut to ~6 cm of length and soaked in 0.25, 0.5 and 1.0% (w/v) NaOH solution at ambient temperature maintaining a fiber to liquor ratio of 1:30. The fibers were kept immersed in the alkali solution for 0.5, 1, 2, 4, 8, 16, 24, 36 and 48 h. The alkali treated fibers were then washed several times with distilled water to remove excess alkali from the fiber surface. The final pH was maintained at 7.0. The fibers were then air dried at room temperature for 24 h followed by oven drying at 55^oC for 24 h. The plausible reaction between jute fiber and alkali is shown in Scheme 1a.



Scheme 1a. Plausible reaction between jute fiber and alkali

B.2.2. Modification with polymer latex

Commercially available aqueous emulsion of carboxylated styrene-butadiene copolymer based polymer latex was used to modify the jute fibers. The solid content of undiluted polymer latex was found to be 41%. Alkali treated jute fibers were dipped into 0.25, 0.5, and 1.0% (v/v) polymer latex for 24 h, maintaining a liquor ratio 1:30 at ambient condition. The fibers were then air dried at room temperature for 24 h followed by oven drying at 55^{o}C for 24 h. The plausible reaction chemistry of alkali treated jute fiber and polymer latex is shown in Scheme 1b.



Scheme 1b. Plausible reaction chemistry of alkali treated jute fiber and polymer latex

B.3. Characterization of unmodified and modified jute fiber

B.3.1. Chemical characterization by FTIR spectroscopy

FTIR spectroscopic study of unmodified and modified jute fiber was performed by Thermo Nicolet, Nexus 870 spectrophotometer with a scanning range from 4000 to 500 cm^{-1}. In the FTIR study of untreated and alkali treated jute fiber a characteristic broad absorbance band at 3200–3600 cm^{-1} range is observed for hydrogen bonded –OH stretching (Fig. 1a). The absorbance peak at 2910 cm^{-1} represents –CH stretching vibration of methyl and methylene groups in cellulose and hemicellulose. The absorbance bands at 1452 cm^{-1}, 1374 cm^{-1} and 1035 cm^{-1} are ascribed to –CH_3 asymmetric, –CH symmetric stretching and aromatic –CH in plane deformation in lignin respectively. The band at 1738 cm^{-1} for C–O stretching of the carboxyl and acetyl groups in hemicellulose part of the fiber was prominent in raw jute fiber. But this peak gradually decreases as the time of alkali treatment on jute fiber increases and finally disappears in 24 h 0.5% alkali treated fiber. When alkali treated jute fiber was modified with polymer latex the band at 1738 cm^{-1} reappears (Fig. 1b). This may be due to the formation of an ester type linkage between –OH group of jute fiber and –COOH group of carboxylated styrene butadiene polymer present in the polymer latex.

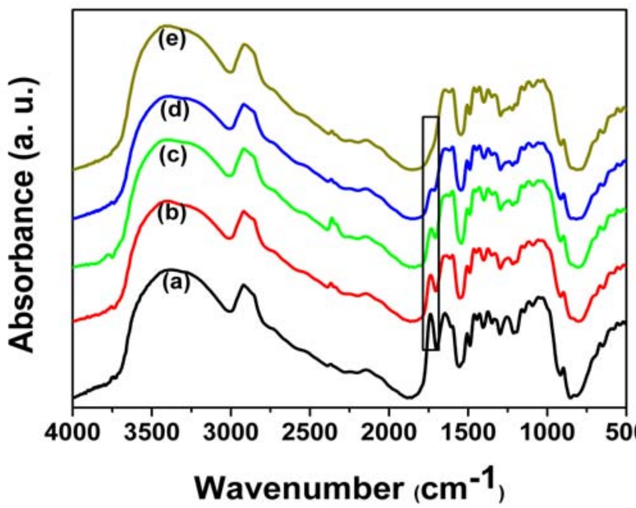


Fig. 1a. FTIR spectra of jute fiber: (a) untreated, (b) 0.5 h, 0.5% alkali treated, (c) 2 h, 0.5% alkali treated, (d) 8 h, 0.5% alkali treated, (e) 24 h, 0.5% alkali treated.

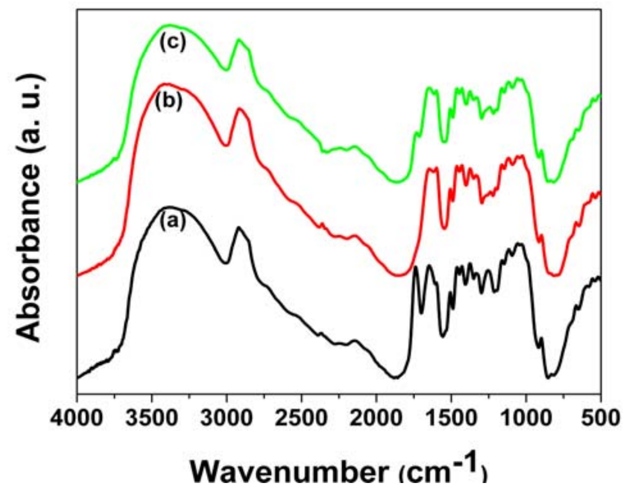


Fig. 1b. FTIR spectra of jute fiber: (a) raw (b) 0.5%, 24 h alkali treated, (c) 0.5%, 24 h alkali treated and 0.5% latex treated jute fiber.

B.3.2. X-ray diffraction

X-ray diffraction data of the powdered jute fiber samples were collected using a RIGAKU X-ray diffractometer (ULTIMA III). The XRD study was done maintaining the operating range between 10^0 and 50^0 and a scanning speed of 2^0 /min. The crystallinity index and crystallite size were calculated. The crystallite size and crystallinity index were also calculated from the X-ray diffractogram. From Table 1a it can be observed that the crystallite size and crystallinity index increase with the increase in time of alkali treatment. But the FWHM of diffraction peak decreases after alkali treatment. The increment of crystallinity index and crystallite size is due to the removal of amorphous components of jute fiber.

Table 1a. Calculated and observed crystalline parameters from XRD diffractograms of raw and alkali treated jute fibers

Treatment duration (h)	Peak position (2θ)	FWHM (2θ)	Area (%)	Amplitude (counts/s)	Crystallite size (nm)	CrI (%)
0	15.62	4.23	42.05	232.74	1.88	50.4
	23.36	2.89	57.94	469.23	2.78	
0.5	15.64	3.63	39.70	492.00	2.19	53.7
	22.73	2.55	60.30	1063.46	3.16	
4	15.69	3.62	39.53	387.98	2.17	53.6
	22.11	2.59	60.46	827.59	3.11	
24	15.67	3.42	35.34	438.33	2.33	62.6
	22.35	2.34	64.65	1172.17	3.43	

But when alkali treated jute fibers were further treated with polymer latex, the amorphous polymer was dispersed in the inter-fibrillar region of fiber, which might decrease the CrI (Table 1b).

Table 1b. Calculated and observed crystalline parameters from XRD diffractograms of latex treated jute

Latex (v/v %)	Peak position (2θ)	FWHM (2θ)	Area (%)	Amplitude (counts/s)	Crystallite size (nm)	CrI (%)
0.25	15.76	5.93	47.11	371.20	1.69	53.47
	22.40	3.10	52.88	797.87	2.27	
0.50	15.51	4.76	43.47	433.65	2.14	54.36
	22.31	2.82	56.52	950.04	2.51	
1.00	15.43	5.90	46.66	422.23	1.73	52.36
	22.33	3.21	53.33	886.32	2.20	

B.3.3. Surface topography studies of jute fiber by scanning electron microscope (SEM)

The surface topography of jute fibers was investigated to examine the effect of chemical treatment upon the fiber surface using a scanning electron microscope (SEM). The powdered samples were coated with a thin layer of gold and scanning electron micrographs of fiber samples were taken in TESCAN $Vega_{LSV}$ SEM. SEM micrographs (Fig. 2) indicate a significant change in surface topography after chemical treatment. The surface of raw jute fiber was smooth with multicellular nature, whereas rough surface morphology with fragments and better fibril separation were observed due to alkali treatment. This phenomenon may be attributed to the leaching of surface impurities, non-cellulosic materials, inorganic substances and wax. The rough surface obtained after alkali treatment may improve the adhesion between fiber and matrix when used in reinforcing composite materials. After modification with polymer latex a thin coating of polymer was observed on jute fiber surface.

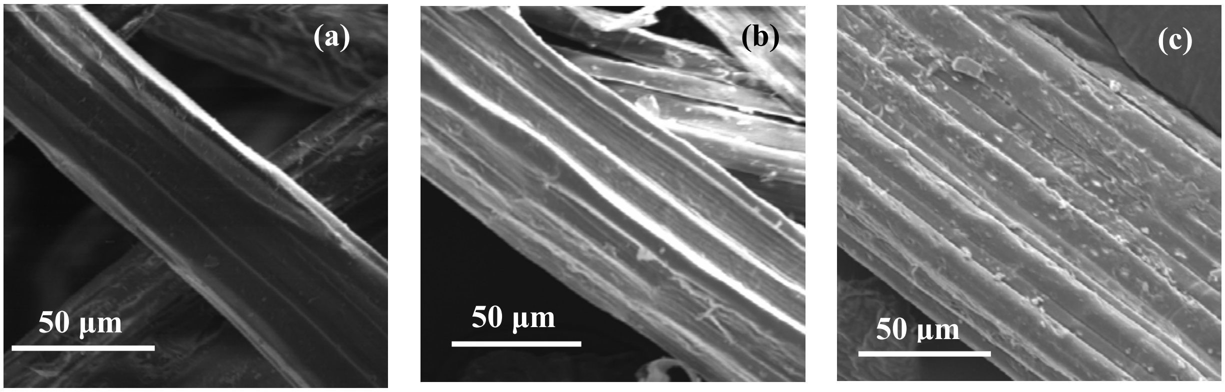


Fig. 2. Surface morphologies of different jute fibers: (a) Raw jute fiber, (b) Alkali (0.5%, 24 h) treated jute fiber, (c) Alkali and polymer (0.5%, 24 h) treated jute fiber.

B.3.4. Water absorption and hydrophilicity study of jute fiber

The water absorption study of jute fibers was done in accordance with ASTM D570-98. The water absorption was calculated as

$$\text{Water absorption (\%)} = [(w_2 - w_1)/w_1] \times 100 \qquad (1)$$

Where, w_1 is the initial weight of oven dried jute fiber before water absorption and w_2 is the weight of jute fiber after water absorption. Water absorption of jute fiber decreases after chemical modification. Water absorption of untreated jute fiber is 210% but reduces to 112% after 0.5% alkali and 0.25% polymer treatment (Table 2).

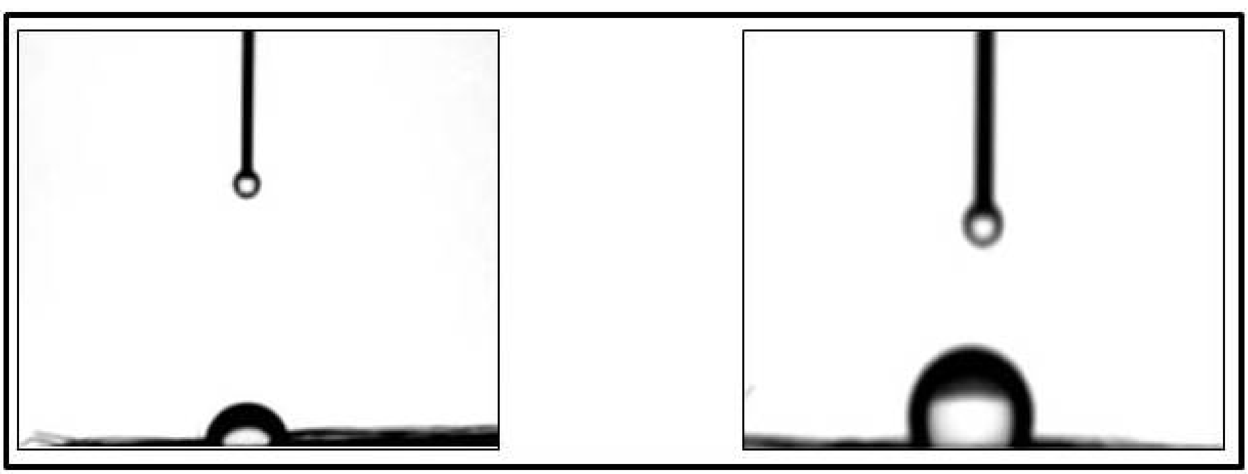


Fig. 3a. Contact angle of raw jute fiber.

Fig. 3b. Contact angle of chemically treated jute fiber.

This result was further supported by hydrophilicity study, which was studied by contact angle measurement. This shows that the contact angle of jute fiber increases after alkali and polymer latex treatment (Table 2 and Fig. 3a and 3b).

Table 2. Water absorption of untreated and chemically treated jute fiber

NaOH (wt %)	Latex (v/v %)	Treatment duration (h)	Water absorption (%)	Contact angle (degree)
0.0	0.0	0.0	210 ± 2.0	63.9 ± 2.8
0.25	0.00	0.5	200 ± 1.7	69.3 ± 2.3
0.25	0.00	4.0	192 ± 1.9	74.7 ± 3.2
0.25	0.00	24.0	187 ± 2.2	76.4 ± 6.4
0.25	0.00	48.0	180 ± 1.5	77.7 ± 5.6
0.5	0.00	0.5	173 ± 2.1	80.4 ± 4.4
0.5	0.00	4.0	170 ± 2.3	83.7 ± 3.8
0.5	0.00	24.0	161 ± 1.4	86.5 ± 5.5
0.5	0.00	48.0	160 ± 1.6	89.2 ± 1.6
1.0	0.00	0.5	168 ± 2.3	92.3 ± 4.3
1.0	0.00	4.0	155 ± 1.8	93.7 ± 4.6
1.0	0.00	24.0	152 ± 1.7	95.3 ± 5.4
1.0	0.00	48.0	148 ± 2.1	96.2 ± 3.4
0.5	0.25	24.0	112 ± 1.9	103.6 ± 4.1
0.5	0.50	24.0	108 ± 2.2	108.1 ± 3.7
0.5	1.00	24.0	104 ± 1.7	110.8 ± 5.1

B.3.5. Tensile properties

The tensile properties of the jute fibers were measured using Hounsfield 10K tensile testing machine in accordance with ASTM D3822-01. The obtained results were analyzed statistically by Weibull distribution method.

This two-parameter semi-empirical distribution is given by

$$f(x) = m(x)^{m-1} \exp\left(-x^m\right) \tag{2}$$

where, f(x) is the frequency distribution of the random variable x and m is a shape factor usually referred to as Weibull modulus. When Eq. (2) is plotted a bell shaped curve results, the width of which depends on m, as m gets larger the distribution narrows. Since here it was dealt with tensile strength, the random variable x is defined as σ/σ_0, where σ is the failure stress and σ_0 is a normalizing parameter.

Survival probability (S), i.e., the fraction of samples that would survive at a given stress level, can be calculated by replacing x by σ/σ_0 in Eq. (2)

$$S = \int_{\sigma/\sigma_0}^{\infty} f\left(\frac{\sigma}{\sigma_0}\right) d\left(\frac{\sigma}{\sigma_0}\right) \tag{3}$$

$$\text{or } S = \exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right] \tag{4}$$

Rewriting Eq. (4) as $1/S = \exp(\sigma/\sigma_0)^m$ and taking logarithm of both sides twice yields

$$-\ln \ln \left(\frac{1}{S}\right) = -m \ln \sigma + m \ln \sigma_0 \tag{5}$$

Plotting – ln ln (1/S) versus ln σ a straight line with slope – m can be obtained and from the intercept and slope σ_0 value can be calculated. σ_0 is the stress level at which S = 1/e = 0.37. A low value of the Weibull modulus indicates a high variability.

The tensile strength (σ_0) of jute fiber was found to be increased after alkali treatment. After 24 h, 0.5% alkali solution treatment, at ambient temperature, the tensile strength of jute fiber was improved by 82% compared to that of untreated jute fiber (337 MPa) and the elongation at break was also improved by 35% with respect to elongation at break of untreated jute fiber (1.26%), i.e., the alkali treatment makes the fibers more flexible (Table 3a and 3b, Fig. 4a). Variation of tensile strength of jute fiber (σ_0) with alkali treatment time is shown in Fig. 4b.

Table 3a. Tensile strength of jute fibers after alkali treatment at ambient temperature

NaOH (wt %)	Tensile strength (MPa) for different treatment duration								
	0.5 h	1 h	2 h	4 h	8 h	16 h	24 h	36 h	48 h
0.25	297	320	294	302	340	354	353	400	368
0.5	374	388	429	452	481	502	610	517	403
1.0	453	525	489	413	319	340	360	303	307

The tensile strength at 80% probability (σ), i.e., the failure stress and Weibull modulus (m) achieve a maximum value of 296 MPa and 2.1 respectively after treatment with 0.5% alkali solution for 24 h (at ambient temperature).

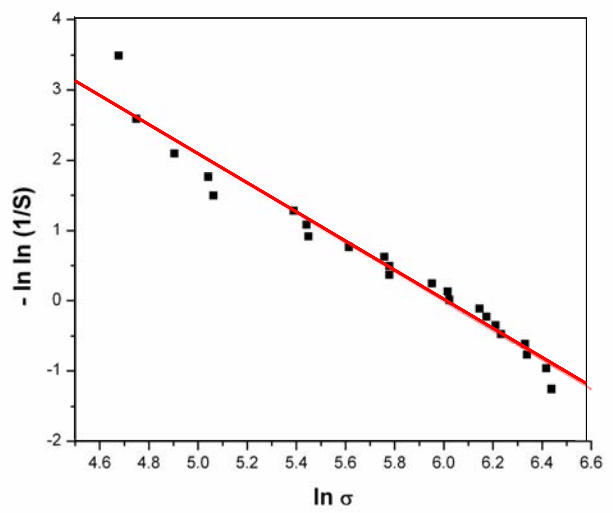


Fig. 4a. Plot of – ln ln (1/S) vs. ln σ for the tensile strength of 0.5% alkali treated jute fiber.

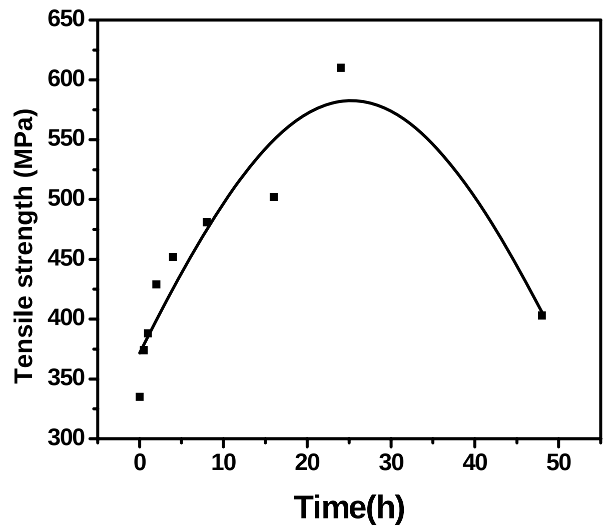


Fig. 4b. Tensile strength (σ_0) of 0.5% alkali treated jute fiber at different time intervals.

Table 3b. Elongation at break of jute fiber after alkali treatment at ambient temperature

NaOH (wt %)	Elongation at break (%) for different treatment duration								
	0.5 h	1 h	2 h	4 h	8 h	16 h	24 h	36 h	48 h
0.25	1.46	1.34	1.48	1.49	1.44	1.45	1.46	1.47	1.42
0.5	1.36	1.41	1.45	1.48	1.54	1.66	1.70	1.55	1.39
1.0	1.54	1.58	1.54	1.50	1.41	1.40	1.42	1.44	1.46

When 24 h 0.5% alkali treated jute fiber was modified with 0.5% polymer latex tensile strength increases by 40% w.r.t. that of untreated jute fiber (Table 3c). For polymer latex treated jute fiber, the Weibull modulus increases as tensile strength increases.

Table 3c. Tensile properties and diameter for 0.5% alkali (24 h) and polymer latex treated jute fiber

Polymer latex (v/v %)	Diameter (mm)	Elongation at break (%)	Tensile strength (MPa)	Weibull modulus (m) of tensile strength
0.25	0.056 ± 0.004	1.41	396	2.39
0.5	0.060 ± 0.016	1.69	471	3.32
1.0	0.071 ± 0.020	1.68	435	3.36

B.3.6. Durability of unmodified and modified jute fiber in cement matrix

Untreated and 0.5% alkali and 0.5% polymer latex treated jute fibers were kept in cement matrix for 7, 28, 42, 90 days. The jute fibers were pulled out from the cement matrix after specified days and tensile strength was measured. Ageing test of untreated and treated jute fiber in cement matrix shows that least degradation had occurred for 24 h, 0.5% alkali and 0.5% polymer latex treated jute fiber (Table 4).

Table 4. Change in tensile strength of jute fiber in cement paste with time

Type of jute fiber	Tensile strength (MPa) of jute fiber in cement paste at different ageing duration					Degradation (%) after 90 days
	0 day	7 days	28 days	42 days	90 days	
Untreated	335	330	311	308	275	18
Alkali and latex treated	470	469	466	464	459	2.3

Fig. 5 shows the relative degradation of jute fiber in terms of loss of tensile strength with respect to aging time in days, after performing degradation study. The extent of degradation of polymer treated jute fibers incorporated in cement paste is much lower as compared to that of untreated raw jute. The degradation is also much slower for polymer treated jute in contrast to raw jute.

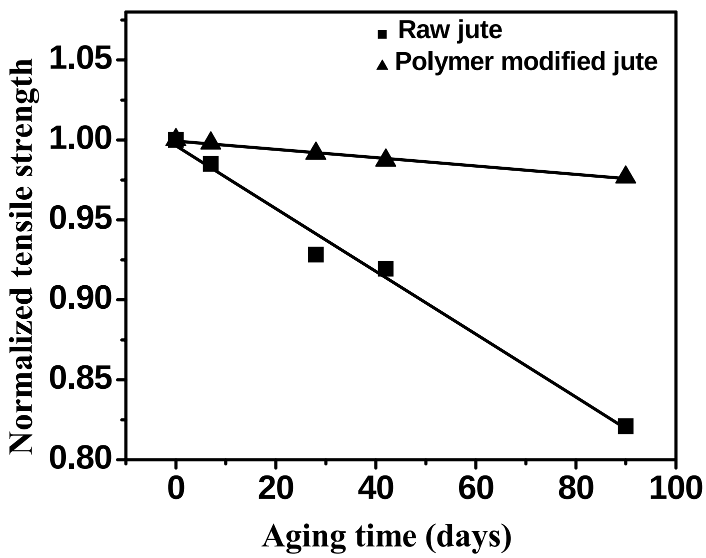


Fig. 5. Degradation study of untreated and chemically treated jute fiber in cement paste

Achievement

- ✓ Alkali and polymer modifications of jute fiber improve tensile strength and elongation at break about 41 and 34 % respectively.
- ✓ Water absorption of jute fiber is reduced to 108 % from 210 % after alkali and polymer treatment.
- ✓ Degradation study of jute fiber in cement matrices shows that the rate of degradation of treated jute fibers incorporated in cement paste is constant with time whereas in case of untreated jute fibers incorporated in cement paste degraded rapidly with time.

SECTION C

Fabrication and characterization of jute reinforced cement composite

C.1. Materials

Portland Pozzolona cement was supplied by Ambuja Cement Pvt. Ltd. Locally available coarse aggregate (stone chips of size 0 - 20 mm) and sand (of 300 µm) were used for composite fabrication as per IS: 383-2002. Tannin, a natural polyphenolic admixture, was procured from local market. Jute fibers of TD4 grade were collected from Gloster Jute Mill, Howrah, India.

C.2. Setting characteristics of Portland Pozzolonic cement

Standard consistency of cement means the minimum amount of water required to prepare a plastic mix. The setting and hardening of cement is a continuous process, but two points are distinguished for test purposes. The initial setting time is the interval between the mixing of the cement with water and the time when the mix has lost plasticity, stiffening to a certain degree. It marks roughly the end of the period when the wet mix can be molded into shape. The final setting time is the point at which the set cement has acquired a sufficient firmness to resist a certain defined pressure.Consistency, initial and final setting time of cement pastes with and without jute fiber was measured by Vicat Apparatus according to IS: 4031.

From Tables 5a and 5b it is observed that the initial and final setting times of raw jute fiber incorporated cement paste are higher than that of the control cement paste. It has been reported and observed by us also that the presence of hydrophilic jute in wet cement matrix delays the hydration reaction. This in turn delays the initial and final setting time of cement paste. But when polymer latex modified jute fibers were incorporated into cement matrix, the initial and final setting time was decreased than that of the raw jute fiber reinforced cement. Treating jute with polymer latex decreases the hydrophilicity of jute which in turn do not affect the normal setting time appreciably. Addition of organic admixture tannin to cement is also found to delay the setting time of cement.

As the content of jute fiber in cement matrix increases, the initial and final setting time of cement paste increases (Fig. 6a). But the setting time decreases as the polymer content increases in cement matrix (Fig. 6b).

Table 5a. Influence of jute fiber on setting time of cement paste (measured by consistency method)

Sample code	Jute loading (%)	Polymer emulsion (%)	Standard consistency (W/C)	W/C for setting time measurement (% of standard consistency)	Initial setting time (min)	Final setting time (min)	Difference between initial and final setting time (min)
Control	0	0	0.390	85	130	170	40
RJC	1	0	0.400	85	160	205	45
RJC	2	0	0.410	85	169	223	54
RJC	3	0	0.420	85	175	236	61
RJC	4	0	0.430	85	180	246	64
AJC	1	0	0.400	85	154	194	40
LJC	1	0.0625	0.400	85	152	191	39
LJC	1	0.1250	0.395	85	149	186	37
LJC	1	0.2500	0.390	85	146	182	36
LJC	1	0.5000	0.385	85	144	178	34
LTJC	1	0.1250	0.350	85	176	210	34

N.B. RJC: raw jute cement, AJC: alkali treated jute cement, LJC: alkali and polymer latex treated jute cement, LTJC: Alkali and polymer latex treated jute cement modified with tannin, W: water, C: cement.

Table 5b. Influence of jute fiber on setting time of cement paste (measured by constant water method)

Sample code	Jute loading (%)	Polymer emulsion (%)	Standard consistency (W/C)	W/C for setting time measurement	Initial setting time (min)	Final setting time (min)	Difference between initial and final setting time (min)
Control	0	0	0.390	0.3315	130	170	40
RJC	1	0	0.400	0.3315	151	193	42
RJC	2	0	0.410	0.3315	155	199	46
RJC	3	0	0.420	0.3315	162	213	51
RJC	4	0	0.430	0.3315	167	220	53
AJC	1	0	0.400	0.3315	151	190	39
LJC	1	0.0625	0.400	0.3315	150	188	38
LJC	1	0.1250	0.395	0.3315	147	184	37
LJC	1	0.2500	0.390	0.3315	146	182	36
LJC	1	0.5000	0.385	0.3315	143	178	35
LTJC	1	0.1250	0.350	0.3315	176	210	34

N.B. RJC: raw jute cement, AJC: alkali treated jute cement, LJC: alkali and latex treated jute cement, LTJC: Alkali and latex treated jute cement modified with tannin, W: water, C: cement.

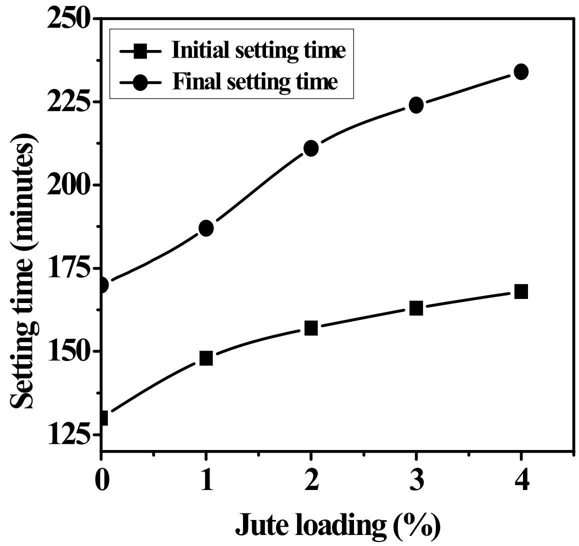


Fig. 6a. Setting time measurement of cement paste containing varying percents of jute fiber

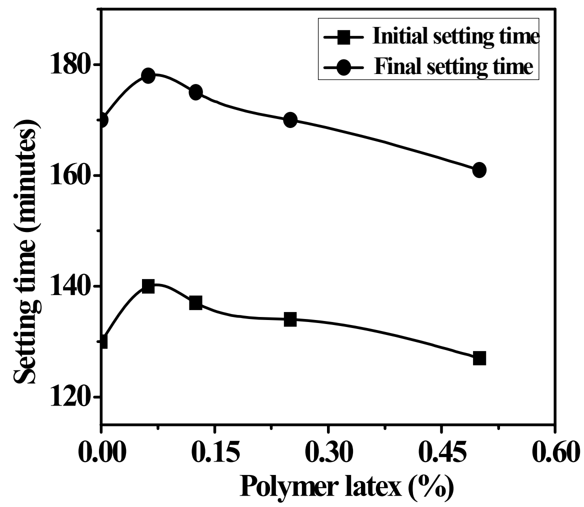


Fig. 6b. Setting time measurement of polymer latex modified jute fiber reinforced cement paste by measuring standard consistency

C.3. Processing of unmodified and chemically modified jute fiber reinforced cement mortar /concrete composites

The mortar mix design of cement and sand was 1:3 by weight. Untreated and chemically treated chopped jute fibers were used as reinforcing agent in different weight percentages in cement composite. The major problems encountered with jute fiber as a reinforcing agent in cement matrix are its non uniform dispersion due to agglomeration of the fiber and its hydrophilic nature. Hence to achieve a uniform dispersion of fibers in cement matrix two different mixing procedures were followed for preparing jute fiber reinforced cement mortar composite (JRM), viz., Process-A and Process-B.

In Process-A, for untreated jute fiber reinforced mortar (UJRM), initially the chopped fibers were immersed for 24 h in half of the total volume of water required for mortar preparation in a container. Next the half of the total amount of cement required was added to wet jute in that container with constant stirring to obtain jute-cement slurry. The jute cement slurry was then slowly poured into the pan-mixer with stirring provision and the pan-mixer was run for 2 min. Sand and rest of cement was mixed with this jute-cement slurry. The remaining amount of water was then added and the pan-mixer was run for further 5 min. The fresh cement mortar thus obtained was cast immediately in molds and allowed to setting.

In Process-B, equilibrium water soaked jute was used for mortar preparation. Half of the amount of total cement required and half of the total volume of water required were then added to the wet jute fibers with constant stirring in a pan mixer to obtain jute-cement slurry. Sand and rest of cement were mixed with the jute-cement slurry. The remaining amount of water was then added and the pan-mixer was run for extra 5 min. The fresh cement mortar thus obtained was cast immediately in molds and kept for 24 h.

Polymer latex treated jute fiber reinforced mortar (LJRM) specimens were prepared by Process-B. For LJRM fabrication, jute fibers were initially immersed in 0.5% alkali solution maintaining a liquor ratio 1:30 (jute: alkali solution) and after 24 h excess amount of liquor, which was not absorbed by jute, was drained out. 0.0625-0.5% polymer latex (v/v) was prepared by adding water (which is the total water required for mortar). Half of the total volume of diluted polymer latex and half of the amount of cement required was used to prepare jute-cement slurry. Sand, rest of cement and remaining amount of polymer latex were mixed with the jute-cement slurry and LJRM specimens were prepared. In Process-B the water cement ratio was calculated to be 0.6 for both UJRM and LJRM.

Optimization of length of jute fiber in cement matrix was done by incorporating jute fiber of 5, 10 and 20 mm lengths following Process-B.

The jute fiber reinforced concrete (JRC) samples of mix design 1:2:4 (cement: sand: coarse aggregate, by weight) were fabricated by following Processe-B. During the fabrication of JRC by Process-B, a natural water reducing polyphenolic admixture (tannin) was used. A tannin polymer mixture was prepared by adding 0.25% tannin powder (w.r.t. cement weight) in total amount of polymer emulsion. Half of the total volume of this mixture and half of the amount of cement required were used to prepare jute-cement slurry. This jute cement slurry was then poured into the concrete-mixer containing sand and stone chips. The concrete-mixer was run for 5 min for achieving proper mixing of the components. The fresh chemically treated jute fiber reinforced concrete thus obtained was cast immediately in molds and kept for 24 h. The addition of tannin during the preparation of jute cement concrete reduces water cement ratio to 0.50-0.52 in contrast to 0.6 and the slump value of the prepared concrete mix was 75 ± 10 mm. In JRC specimens the incorporated jute fibers were of 5 mm length. Fig. 7 shows the schematic flow diagram of chemically treated jute fiber reinforced concrete fabrication by Process-B.

All the specimens were demolded after 24 h of casting and water cured for 28, 42 and 90 days respectively. At the specified date they were removed from water, surface dried and tested.

Each test result represented the mean of at least five specimens. Each mix series is coded. For example, the code A1UJRM/B1UJRM refers to Process-A (B stands for Process-B), 1% (w. r. t. the weight of cement) untreated jute fiber content by weight (UJ for untreated jute, LJ for alkali and polymer latex treated jute); R stands for reinforced, M stands for mortar. The code B1UJRC refers to Process-B, (C refers to concrete). Other letters in the code designate the same as described above.

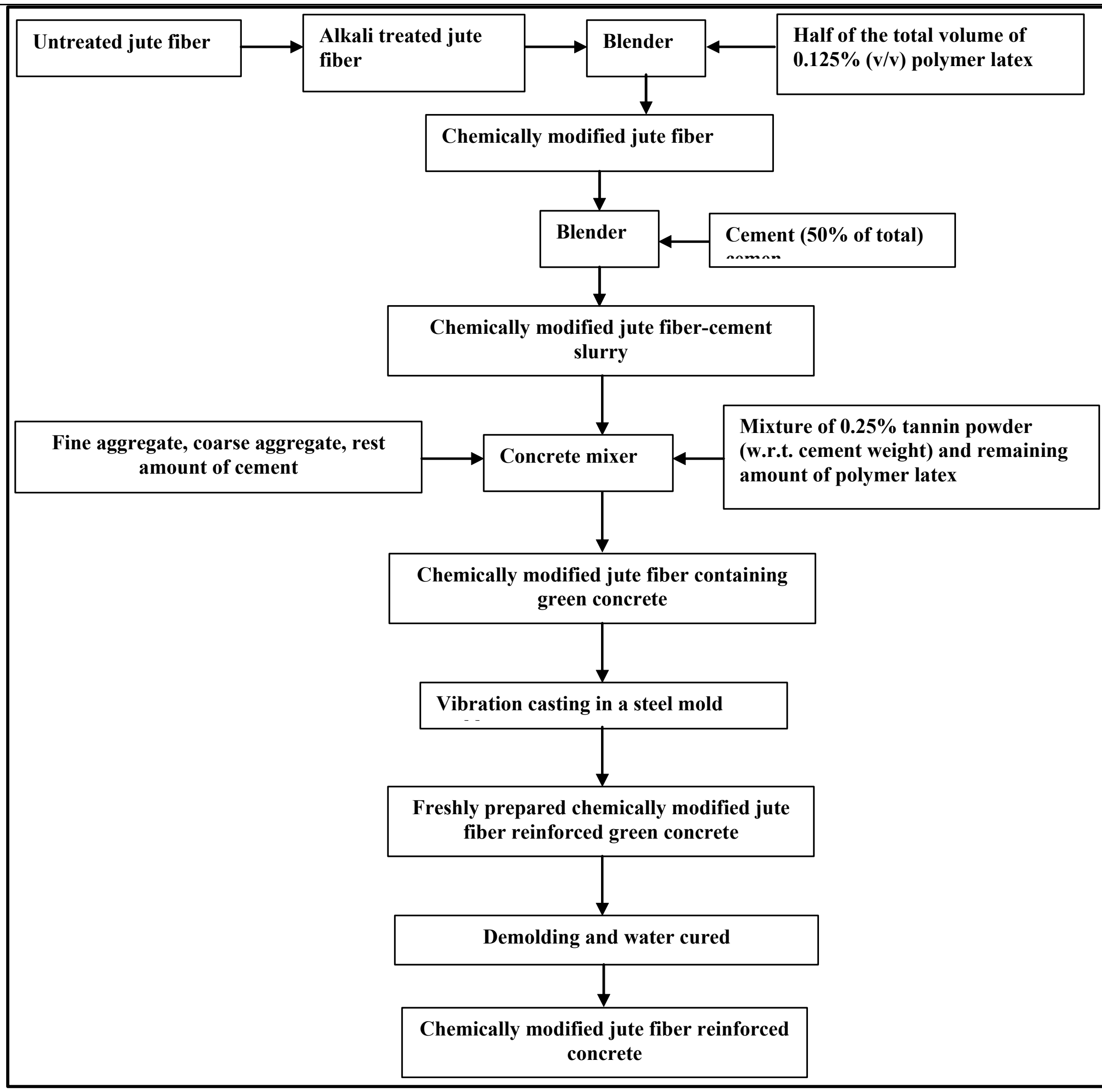


Fig. 7. Schematic flow diagram of chemically treated jute fiber reinforced concrete fabrication (by Process-B)

C.4. Physical and mechanical properties of unmodified and modified jute fiber reinforced cement mortar

C.4.1 Bulk density

Increase in jute fiber content significantly decreases the bulk density of the mortar. The reason might be the replacement of cement mortar (dense materials) by light jute fiber. The apparent bulk density of the jute cement mortar made by Process-A is lower than that of the mortar made by Process-B with the same amount of raw jute (1%) (Table 6a). The variation of apparent bulk density of polymer modified jute fiber reinforced cement mortar is depended upon loading of jute fiber and polymer latex, which is added to prepare polymer latex modified cement mortar. From Table 6b it is found that the bulk density of modified mortar increases with increase in polymer latex.

Table 6a. Physical and mechanical properties of unmodified jute fiber reinforced cement mortar prepared by Process-A/Process-B

Sample code	Flow table Value (mm)	Bulk density (Kg/m^3)	Compressive strength (MPa) after			Flexural strength (MPa) after		
			28 days curing	42 days curing	90 days curing	28 days curing	42 days curing	90 days curing
Control	**155 ± 5**	**2283 ± 10**	**28.3 ± 2.3**	**29.8 ± 2.4**	**34.5 ± 2.1**	**7.1 ± 0.3**	**7.2 ± 0.3**	**7.4 ± 0.3**
A1UJRM	**127 ± 9**	**2100 ± 30**	**25.8 ± 1.5**	**26.8 ± 1.5**	**29.8 ± 1.6**	**6.4 ± 0.3**	**7.0 ± 0.3**	**7.7 ± 0.4**
A2UJRM	**115 ± 7**	**2100 ± 80**	**24.0 ± 1.5**	**26.0 ± 1.5**	**28.0 ± 1.6**	**6.2 ± 0.3**	**6.5 ± 0.2**	**7.1 ± 0.2**
A3UJRM	**110 ± 6**	**1900 ± 40**	**18.2 ± 1.5**	**21.0 ± 1.5**	**21.5 ± 1.5**	**4.7 ± 0.3**	**5.0 ± 0.3**	**6.3 ± 0.3**
A4UJRM	**110 ± 8**	**1800 ± 50**	**15.4 ± 1.6**	**16.4 ± 1.5**	**19.7 ± 1.5**	**1.6 ± 0.3**	**2.5 ± 0.3**	**3.9 ± 0.3**
B1UJRM	**156 ± 6**	**2270 ± 10**	**30.8 ± 1.5**	**32.1 ± 1.5**	**35.8 ± 1.7**	**7.6 ± 0.3**	**8.5 ± 0.3**	**10.0 ± 0.5**
B2UJRM	**157 ± 8**	**2220± 50**	**30.1 ± 1.6**	**31.5 ± 1.6**	**35.0 ± 1.5**	**7.2 ± 0.3**	**8.0 ± 0.4**	**9.0 ± 0.5**
B3UJRM	**159 ± 9**	**2190 ± 10**	**20.0 ± 1.6**	**21.5 ± 1.5**	**25.0 ± 1.6**	**6.6 ± 0.4**	**7.0 ± 0.4**	**7.5 ± 0.4**
B4UJRM	**161 ± 8**	**2100 ± 10**	**17.0 ± 1.4**	**18.0 ± 1.6**	**19.4 ± 1.6**	**6.1 ± 0.3**	**6.4 ± 0.4**	**6.7 ± 0.4**

C.4.2. Flow table value

The workability of control and jute reinforced mortar were measured by flow table index test according to IS: 4031. In our investigation flow table value was decreased with increase in jute fiber loading for the preparation of jute cement mortar at constant water cement ratio. From Table 6a it can be observed that jute cement mortar made by Process-B shows good flow value than that made by Process-A, with same jute content (1%). The effectiveness of polymer latex on flowability of jute fiber reinforced cement mortar depends upon its concentration. From the Table 6b it is found that the flow table value is increased with increase in polymer latex concentration at same W/C ratio. Increase in polymer latex concentration decreases the water requirement in cement mortar preparation to produce constant satisfactory workable mortar. Addition of 0.5 % polymer latex to the cement mortar decreases the W/C ratio 0.6 to 0.54 and maintains the flow table value of 155 ± 2 mm.

Table 6b. Physical properties of polymer latex modified jute fiber reinforced cement mortar fabricated by Process-B

Sample code	Polymer latex (%)	Water/Cement ratio	Flow table value (mm)	Bulk density (kg/m^3)
Control	-	0.60	155 ± 5	2283 ± 12
B1LJRM	0.063	0.60	157 ± 8	2285 ± 12
B1LJRM	0.125	0.60	161 ± 6	2288 ± 15
B1LJRM	0.250	0.60	164 ± 5	2291 ± 14
B1LJRM	0.500	0.60	167 ± 8	2298 ± 13
B1LJRM	0.063	0.60	157 ± 8	2285 ± 12
B1LJRM	0.125	0.58	156 ± 8	2290 ± 11
B1LJRM	0.250	0.56	156 ± 8	2296 ± 14
B1LJRM	0.500	0.54	151 ± 7	2301 ± 12
B2LJRM	0.125	0.60	162 ± 8	2269 ± 12
B3LJRM	0.125	0.60	164 ± 9	2259 ± 10
B2LJRM	0.125	0.58	157 ± 9	2272 ± 11
B3LJRM	0.125	0.58	156 ± 5	2263 ± 14

C.4.3. Microstructure analysis of jute fiber reinforced mortar composite

The fracture surface topography of the cementitious matrix reinforced with jute fibers was analyzed using SEM after mechanical testing of mortar samples. In Fig. 8 it can be observed that a homogeneous dispersion of jute fibers in cementitious matrix at lower jute content and considerable amounts of these fibers are well attached to the matrix. However, the higher amount of fibers showed inhomogeneous dispersion in the cementitious matrix and poor anchoring, which created bulk flaw and stress was concentrated on that flaw and crashed at lower stress.

C.4.4. Compressive strength

Compressive strength of JRM cubic specimens of dimension 70.6 mm x 70.6 mm x 70.6 mm was measured by a 1000 kN Hydraulic Universal Testing machine as per IS: 516. Compressive strength is a function of fiber loading, fiber length and curing time and it also depends upon the process by which composites were made (Table 6a). The compressive strength decreases with increases in fiber loading and length. Optimal compressive strength of jute

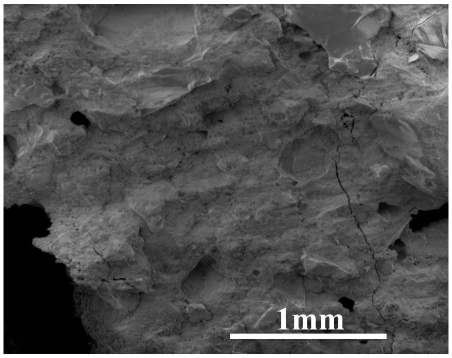


Fig. 8a. Fracture surface of control cement mortar

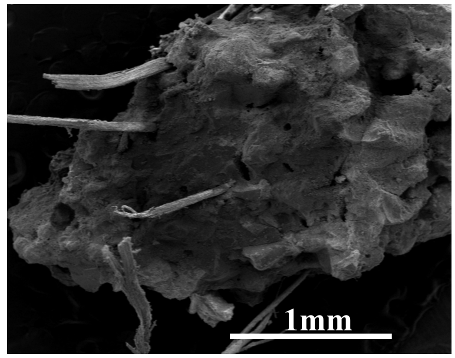


Fig. 8b. Fracture surface of 1% jute fiber reinforced cement

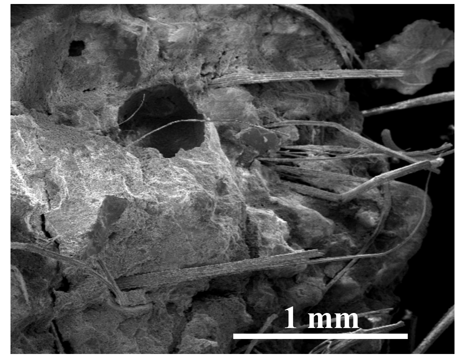


Fig. 8c. Fracture surface of 4% jute fiber reinforced cement

cement mortar was obtained with shorter fiber length of 5 mm (Fig. 9a). Increase in length of the fiber increases fiber agglomeration in composite specimens. The fiber ball makes the specimen porous and lead to obtain lower strength. The maximum compressive strength was achieved by 5 mm 1% jute fiber containing mortar fabricated by Process-B.

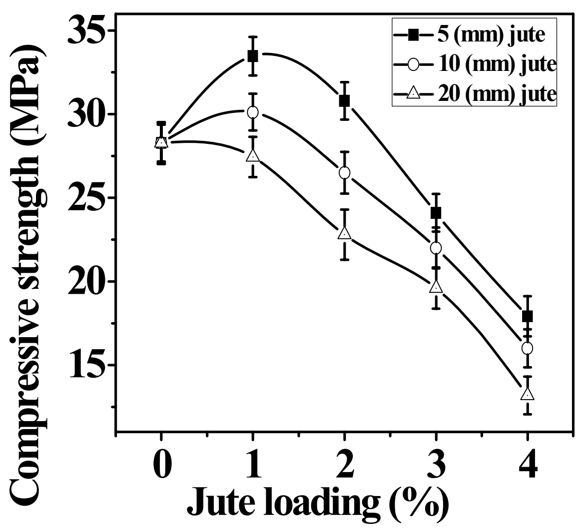


Fig. 9a. Compressive strength of mortar cubes containing different lengths and different loadings of jute fiber

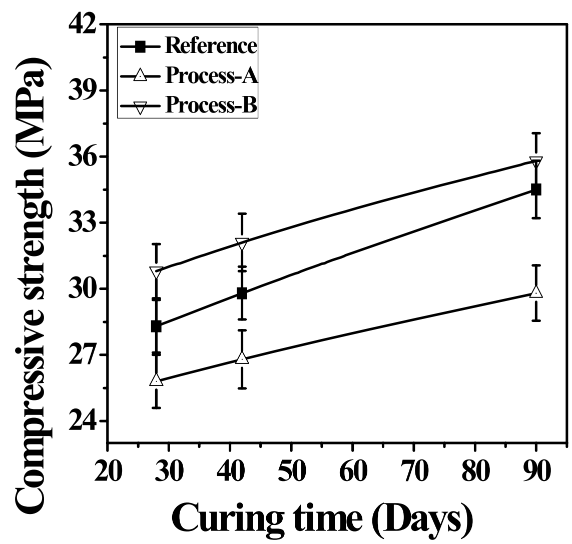


Fig. 9b. Compressive strength of 28, 42 and 90 days water cured mortar cube samples fabricated by different processes

A comparative study of compressive strength of raw jute and alkali polymer latex treated jute cement mortar containing 5 mm 1% jute, cured for different curing times is shown in Tables 6a and c. The compressive strength of jute fiber reinforced cement mortar prepared by different processes continues to increase with increase in curing days (Fig. 9b).

Table 6c. Mechanical properties of jute fiber reinforced polymer latex modified cement mortar fabricated by Process-B

Sample code	Polymer emulsion (%)	W/C ratio	Compressive strength* (MPa) after			Flexural strength** (MPa) after		
			28 days curing	42 days curing	90 days curing	28 days curing	42 days curing	90 days curing
Control	-	0.60	28.3	29.8	34.5	7.1	7.2	7.4
B1LJRM	0.063	0.60	34.4	35.9	37.3	8.5	10.2	11.6
B1LJRM	0.125	0.60	35.4	36.2	37.9	9.1	10.6	12.8
B1LJRM	0.250	0.60	28.2	31.6	33.7	8.0	9.7	11.1
B1LJRM	0.500	0.60	27.2	29.5	32.3	7.7	8.3	9.4
B1LJRM	0.063	0.60	34.4	35.9	37.3	8.5	10.2	11.6
B1LJRM	0.125	0.58	35.5	37.1	38.4	9.3	10.8	13.8
B1LJRM	0.250	0.56	29.1	32.0	34.2	8.1	9.9	11.3
B1LJRM	0.500	0.54	27.7	30.0	33.0	7.8	8.3	9.6
B2LJRM	0.125	0.60	24.2	26.4	29.1	7.1	7.5	7.8
B3LJRM	0.125	0.60	17.5	20.0	22.9	6.3	6.6	6.9
B2LJRM	0.125	0.58	25.0	27.1	30.1	7.3	7.7	8.0
B3LJRM	0.125	0.58	18.0	20.9	23.5	6.4	6.9	7.3

N.B. *Maximum standard deviation for compressive strength 1.8, **Maximum standard deviation for flexural strength 0.6.

From Fig. 9c it is found that initially the compressive strength of modified cement mortar improves with increase in polymer latex content and reaches a maximum at 0.125 % polymer latex concentration; it continues to turn down with increase in polymer latex. Thus optimum compressive strength (38.4 MPa) of cement mortar (90 days cured) was achieved by reinforcing 5 mm 1% jute fiber modified by 0.125% polymer latex. Fig. 9d shows superior compressive strength of 0.125 % polymer latex modified jute fiber reinforced cement mortar with lower W/C ratio.

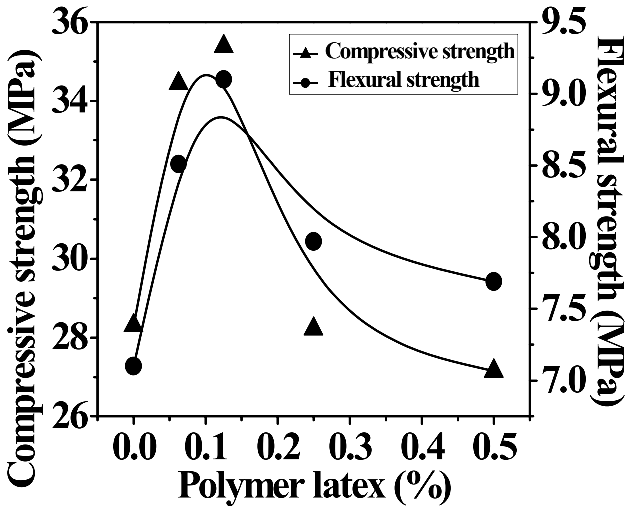


Fig. 9c. Compressive and flexural strength of jute reinforced (1%) polymer modified cement mortar (28 days cured) vs. polymer latex percent

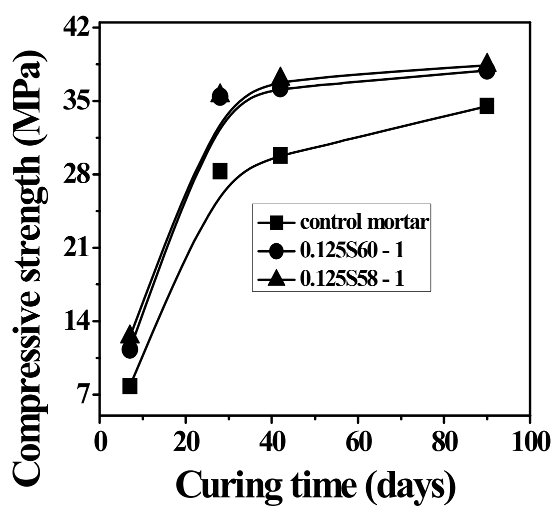


Fig. 9d. Compressive strength of 0.125% latex modified mortar containing different W/C ratio with curing time

C.4.5. Flexural strength

The flexural tests of the fabricated mortar bar test specimens of dimensions 110 mm x 20 mm x 20 mm (length x width x thickness) were carried out on the same testing system using a four point bending configuration, under a span of 60 mm according IS: 4332. The correlation between flexural strength and the major parameters of jute cement mortar bars at different curing times are shown in Tables 6a and 6c. During the test it was observed that at the beginning of loading, the behavior is elastic in nature until the first crack was generated and then the failure of specimen was gradual. The specimen did not break into pieces (i.e., retain its integrity) after occurrence of excessive vertical cracks, compared with the control mortar having no fiber. Flexural strength is gradually decreased with increase in fiber content in both processes (Table 6a). The flexural strength of 1% jute loaded and 90 days cured cement mortar made by Process-B was 35 % superior to control mortar. For both processes, improvement of flexural strength of cement mortar (with 1% jute and without jute reinforced) with the curing time are shown in Fig. 10a and same observation was found in the case jute fiber reinforced polymer latex modified mortar with different W/C ratio (Fig. 10b). A comparative study of flexural strength of raw jute and alkali-polymer latex treated jute cement mortar containing 1% jute, cured for different curing time is shown in Table 6a and 6c.

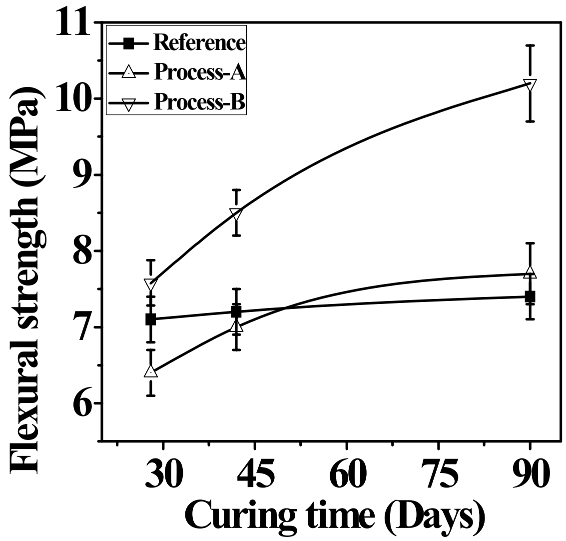


Fig. 10a. Flexural strength of mortar samples fabricated by different processes after 28, 42 and 90 days curing

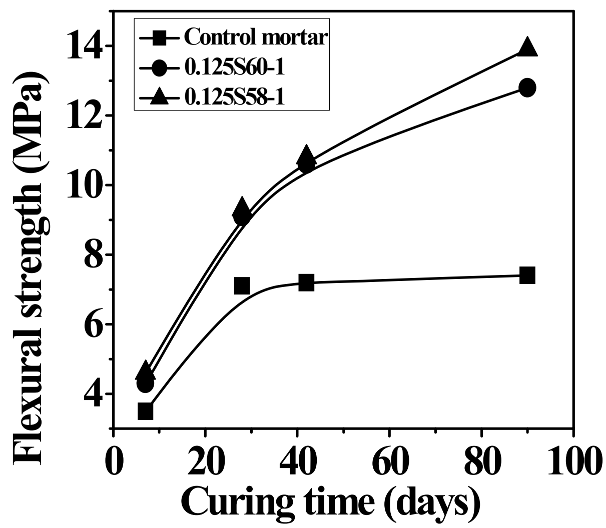


Fig. 10b. Flexural strength of 0.125% latex modified mortar containing different W/C ratio with curing time

C.4.6. Relation between density ratio and strength ratio

The wet and dry density of control cement mortar and jute fiber reinforced cement mortar were measured according to ASTM C 948, 1981. In Fig. 11 it is shown that wet density to dry density ratio of jute incorporated polymer modified cement mortar (0.6 W/C) possesses a gradual downward trend with increase in polymer latex content and an upward trend of flexural strength to compressive strength ratio. The left hand inset graph of Fig. 11 shows that both wet and dry densities of polymer modified cement mortar increase with increase in polymer latex content but the difference between wet density and dry density becomes smaller with increase in polymer latex content showing a decrease of density ratio. The right hand inset figure of Fig. 11 shows that initially compressive and flexural strengths increase with increase in polymer latex concentration and reaches a maximum at 0.125% polymer latex. So it can be assumed from the resulting trend of Fig. 11 that the extent of decrease of flexural strength is lower than that of the compressive strength with increase in polymer concentration after attaining the maximum value at a particular polymer latex concentration.

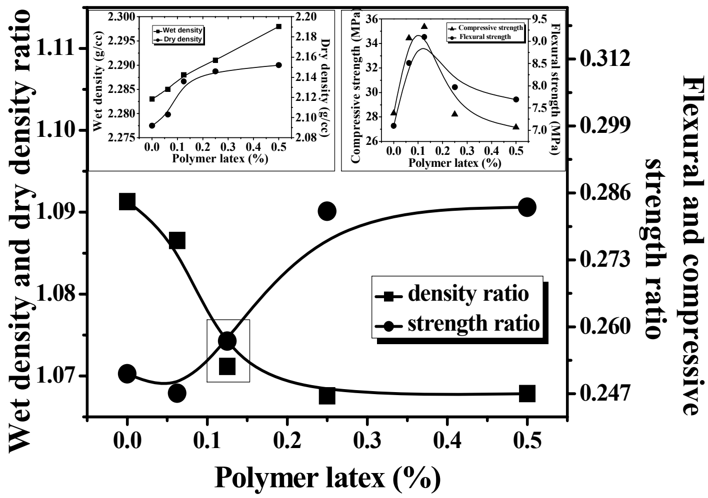


Fig. 11. Density and strength ratio of latex modified cement mortar with latex percent

C.4.7. Extensibility

Extensibility is an important property for cement composite. Extension not only reflects the impact ductility and fracture enhancements, but also is an assurance of the safety and integrity of a structural element prior to its complete failure. Extension in plain cement mortar leads to rapid crack growth. When the fibers were present in cement mortar, the cracks could not extend without stretching and debonding the fibers during the bending of a composite beam. It can be seen that the process parameter and fiber factor together play a significant role in enhancing the extension of jute cement mortar. Extensibility increases gradually with increase in fiber loading into cement mortar composite as shown in Fig. 12a. The maximum elongation was obtained for the Process-B, which was about four times more than the control mortar by incorporation of 4% jute into cement mortar. When alkali-polymer latex treated jute fibers were used to make composite, elongation of mortar was increased. This is due to an increase in elongation at break after chemical treatment of jute fiber, and that effect was reflected into the composite also (Fig. 12b).

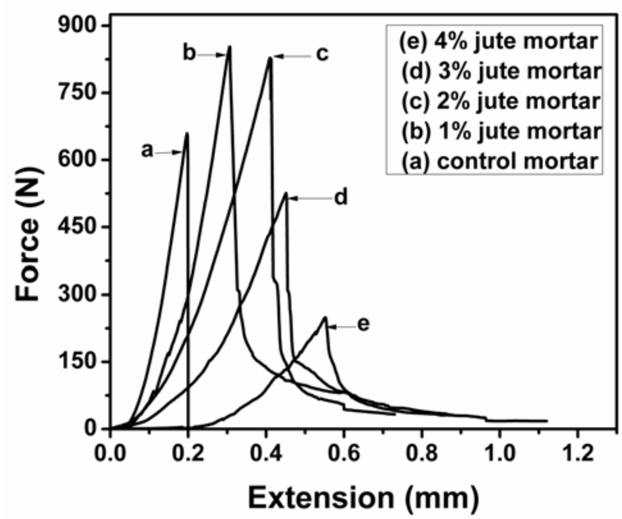


Fig. 12a. Load deflection curve for mortar containing different percent of jute

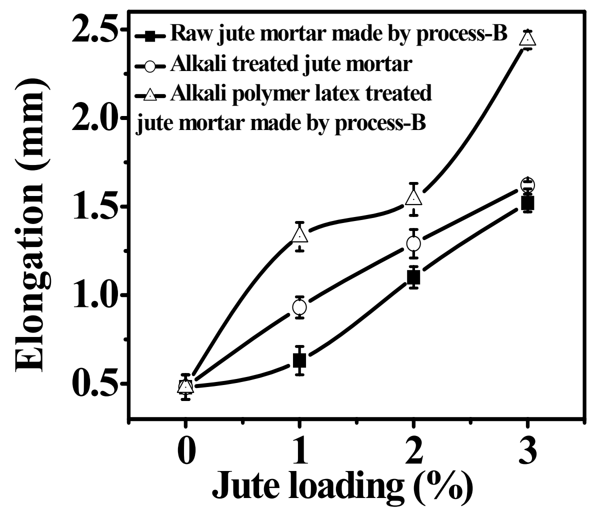


Fig. 12b. A comparative study of elongation vs. loading of raw jute, alkali treated jute, alkali and polymer latex treated jute mortar

C.5. Physical and mechanical properties of unmodified and modified jute fiber reinforced concrete

C.5.1. Slump test

The workability of the fresh concrete was measured by slump test according to IS: 1199. Slump value, an index of workability of fresh concrete, was adversely affected by jute content. In Process-B, since water soaked fiber was used there was no further water absorption by jute from concrete mix and this makes the fresh concrete to have a good workability. The workability of reinforced concrete was affected by chemical modification of jute fiber. Chemically modified jute fiber reinforced concrete has higher slump value compared to that of untreated jute fiber reinforced concrete with same water cement ratio (Table 7).

C.5.2. Specific gravity

Specific gravity of the concrete was measured according to ASTM C948-01. The incorporation of jute fiber into the cement-concrete matrix decreases the specific gravity of the composite, because the specific gravity of jute fiber (1.6 g/cm^3) is much smaller than that of reference concrete (2.43 g/cm^3). From Table 7, it can be seen that as the jute fiber loading increases specific gravity of the composites decreases.

Table 7. Physical and mechanical properties of JFRC composites

Mix code	Fiber[a] (wt %)	W/C ratio	Curing (days)	S.G.[b] (Kg/m^3)	Slump value[b]	Compressive strength[b] (MPa)	Flexural strength[b] (MPa)
Control	0.0	0.6	28	2545 ± 55	65 ± 5	27.5 ± 1.5	2.6 ± 0.2
Control	0.0	0.6	42			29.0 ± 2.0	2.7 ± 0.3
Control	0.0	0.6	90			30.0 ± 1.0	2.7 ± 0.4
B0.5UJRC	0.5	0.6	28	2544 ± 58	65 ± 4	31.0 ± 1.0	2.7 ± 0.1
B0.5UJRC	0.5	0.6	42			32.5 ±1.5	2.8 ± 0.2
B0.5UJRC	0.5	0.6	90			34.0 ± 2.0	2.9 ± 0.3
B1UJRC	1.0	0.6	28	2543 ± 60	70 ± 5	32.0 ± 1.5	2.9 ± 0.2
B1UJRC	1.0	0.6	42			34.0 ± 2.0	3.0 ± 0.2
B1UJRC	1.0	0.6	90			37.5 ± 2.5	3.2 ± 0.4
B2UJRC	2.0	0.6	28	2538 ± 57	72 ± 3	29.0 ± 2.0	2.2 ± 0.3
B2UJRC	2.0	0.6	42			31.0 ± 2.5	2.3 ± 0.1
B2UJRC	2.0	0.6	90			33.5 ± 1.5	2.5 ± 0.2
B3UJRC	3.0	0.6	28	2533 ± 61	75 ± 6	26.5 ± 1.5	2.2 ± 0.2
B3UJRC	3.0	0.6	42			28.0 ± 1.0	2.1 ± 0.3
B4UJRC	3.0	0.6	90			31.0 ± 1.0	1.8 ± 0.1
B4UJRC	4.0	0.6	28	2528 ± 54	78 ± 5	22.5 ± 1.0	1.6 ± 0.2
B4UJRC	4.0	0.6	42			24.0 ± 1.5	1.8 ± 0.3
B4UJRC	4.0	0.6	90			26.5 ± 2.0	1.9 ± 0.4
B1LJRC	1.0	0.6	28	2544 ± 52	75 ± 4	37.0 ± 1.5	3.8 ± 0.2
B1LJRC	1.0	0.6	42			39.0 ± 2.0	4.0 ± 0.3
B1LJRC	1.0	0.6	90			42.0 ± 1.3	4.2 ± 0.1
B1LTJRC	1.0	0.5	28	2546 ± 42	80 ± 5	43.0 ± 1.2	4.1 ± 0.2
B1LTJRC	1.0	0.5	42			44.0 ± 1.5	4.3 ± 0.1
B1LTJRC	1.0	0.5	90			48.0 ± 1.2	4.5 ± 0.3

[a] w.r.t. the weight of cement, [b] Mean ± standard deviation, B refers to process-B; 0.5,1,2,3,4 are jute loading percent w.r.t. weight of cement; UJ refers to Untreated Jute; LJ refers to alkali and polymer Latex modified Jute; LTJ refers to alkali and polymer latex and tannin modified jute; RC refers to Reinforced Concrete.

C.5.3. Microstructure analysis of jute fiber reinforced concrete composite

The fracture surface topography of the cementitious matrix reinforced with jute fibers was analysed using optical microscope after mechanical testing of samples. Fig. 13 shows the microstructure of concrete with and without jute fiber reinforcement.

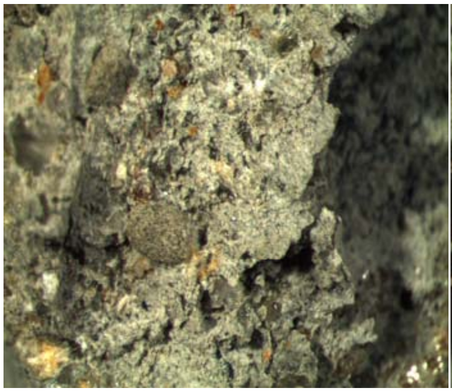


Fig. 13a Microstructure of reference cement concrete

Fig. 13b Untreated jute fiber reinforeced cement concrete

Fig. 13c Homogenious dispersion of treated jute fiber reinforced cement concrete

C.5.4. Compressive strength

Compressive strength of jute cement concrete cubes [(100x100x100) m^3] was measured by universal testing machine according to IS: 516, 2004. The strength of composites increases with low fiber content within the range 0.5 – 1.0% compared to reference concrete and maximum strength was achieved with 1% fiber loading, irrespective of the fiber surface modification and cuing days (Table 7). But, as the fiber content exceeds the value of 1% compressive strength of composite decreases significantly. The compressive strength of JRC continues to increase with cuing days, which is irrelevant with fiber loading percent. For 1UJRC fabricated by Process-B, compressive strength increases 17% at an age of 90 days curing w.r.t. to that of the 28 days cured composites (Table 7). From Table 7, it is observed that LJRC achieves higher compressive strength than that of UJRC composites, both having 1% fiber content. The compressive strength is further increased when tannin was used as admixture during fabrication of concrete. Thus optimum compressive strength (60 % increment w.r.t. reference concrete) was obtained at 90 days cured, 1% chemically modified jute fiber reinforced tannin modified concrete composites, fabricated by Process-B. During compressive failure experiment, there was a catastrophic destruction of the composites, without jute fiber, after crack initiation. But in the case of jute fiber reinforced cubes, a dampening effect was observed.

C.5.5. Flexural strength

Four point bending flexural strength of the fabricated composites [(100x100x500) m^3] was measured by universal testing machine according to IS: 516, 2004. The four point bending strength of the JRC specimens increased initially with an increase in jute fiber content and the maximum strength was achieved at 1% fiber loading (Table 7). During bending test, when a crack was generated in the matrix, the randomly distributed jute fibers provided a bridging effect to the matrix. At this portion of the tensioned composite all the stresses were transferred from the matrix to the fiber and may be this phenomenon is responsible for carrying the increased loads. A further increase in fiber content shows a reduction in the flexural strength and at 4% fiber loading, the strength reduces to 1.6-1.9 MPa. The flexural strength increases with increasing curing days. Optimum flexural strength (73% increment w.r.t. reference concrete) was obtained at 90 days cured, 1% chemically modified jute fiber reinforced tannin modified concrete composites, fabricated by Process-B.

Achievement

- ✓ **Technique of short jute fiber (optimum length: 5 mm) dispersion in concrete is developed.**
- ✓ **Maximum compressive and flexural strength is achieved with optimized 1 wt% jute fiber loading in cement composite, i.e., about 4 kg jute fiber per one cubic meter concrete and 5.5 kg jute fiber per one cubic meter cement mortar.**
- ✓ **Workability of jute fiber incorporated wet concrete mix is improved by using tannin admixture.**
- ✓ **Compressive and flexural strengths of chemically treated jute fiber reinforced cement concrete are improved by 60 and 66% respectively than that of the concrete without jute fiber reinforcement.**
- ✓ **Compressive and flexural strengths of chemically treated jute fiber reinforced cement mortar are improved by 11 and 86 % respectively than that of the mortar without jute.**

SECTION D

Industrial field trial for product development

D.1. Identification of products

The identified areas of jute fiber reinforced cement products in this project are:

1) Jute fiber reinforced cement concrete for precast non-pressure (NP) sewerage pipes.

2) Jute fiber reinforced cement concrete for prestressed electric poles.

3) Jute fiber reinforced precast cement concrete for pavers block.

4) Jute fiber reinforced precast cement fly ash roofing sheet

D.2. Prototype development of jute fiber reinforced concrete pipe

D.2.1. Preparation of concrete for pipe fabrication

According to IS 458, 35 M graded concrete is required for fabrication of NP pipe. The calculated mix design to prepare 35 M concrete is cement: sand: stone chips :: 1: 1.5: 2.7, however, here stone chips of two different sizes (20 and 12.5 mm) were used in 70: 30 ratio. The water cement ratio for concrete preparation was 0.4 - 0.42 and the slump value was 25 ± 5 mm. For each set of concrete composites 1% jute fiber was incorporated.

D.2.1.1. Characterization of lab based concrete composites required for pipe fabrication

No noticeable change has been observed in physical properties of the concrete made for pipe fabrication shown in Table 8a. From the Table 8b it is observed that maximum mechanical strength (compressive strength: 60.7 MPa and flexural strength: 6 MPa) was obtained by incorporating 1% chemically treated jute fiber in tannin modified concrete.

Table 8a. Physical properties of lab based concrete composites (cured for 28 days) for pipe fabrication

Sample	W/C ratio	Type of jute	Bulk density	Water absorption (%)	Apparent porosity (%)
Control	**0.4**	**-**	**2635 ± 57**	**4.5 ± 0.5**	**11.4 ± 1.2**
Raw jute concrete	**0.42**	**Untreated**	**2520 ± 36**	**7.1 ± 1.5**	**16.8 ± 3.5**
Chemically treated jute concrete	**0.42**	**Alkali and latex treated**	**2597 ± 36**	**6.3 ± 0.8**	**15.5 ± 1.9**
Chemically treated jute concrete modified with tannin	**0.4**	**Alkali and latex treated**	**2588 ± 65**	**5.0 ± 1.3**	**12.2 ± 2.9**

Table 8b. Mechanical properties of lab based concrete composites for pipe fabrication

Sample	Compressive strength(MPa)			Flexural strength(MPa)		
	7 days	14 days	28 days	7 days	14 days	28 days
Control	**31.0 ± 1.4**	**44.7 ± 1.5**	**48.7 ± 2.3**	**4.6 ± 0.2**	**5.4 ± 0.3**	**5.4 ± 0.2**
Raw jute concrete	**24.5 ± 2.1**	**49.7 ± 0.6**	**51.7 ± 1.5**	**4.2 ± 0.2**	**5.0 ± 0.1**	**5.8 ± 0.3**
Chemically treated jute concrete	**26.0 ± 1.4**	**51.7 ± 1.0**	**54.3 ± 1.6**	**3.7 ± 0.1**	**4.1 ± 0.1**	**5.7 ± 0.2**
Chemically treated jute concrete modified with tannin	**21.5 ± 4.9**	**51.7 ± 4.0**	**60.7 ± 1.2**	**4.5 ± 0.2**	**5.5 ± 0.3**	**5.9 ± 0.3**

D.2.2. Fabrication of jute fiber reinforced concrete pipe (NP3)

We collaborated with a local precast pipe manufacturing company M/S Rural Concreting Company of Ghatal Pvt. Ltd., West Midnapur District, West Bengal. This company has all facilities of manufacturing and testing of precast concrete pipes of different diameters. We visited the company and fabricated jute fiber reinforced cement concrete pipes in this unit with our mix design formulation and process. Fig.14 shows schematics of process steps followed during the actual fabrication of jute reinforced concrete pipes.

Chemical modification of jute fiber

Mixing of cement with modified jute fiber

Jute cement slurry

Addition of jute cement slurry into mixer

Mixing

Fresh jute-concrete mix

Steel cage into pipe mold

Casting of concrete pipe

Prepared jute-concrete pipe

Fig. 14. Fabrication of chemically modified jute fiber reinforced precast concrete pipe

D.2.3. Fabricated concrete pipes with and without modified jute fiber reinforcement

Three different concrete sewerage pipes were made with the mix design which is developed in this research. Fig. 15a shows the concrete sewerage pipes without any jute fiber reinforcement. Jute fiber reinforced concrete sewerage pipes is shown in Fig 15b, and Fig. 15c shows concrete sewerage pipes fabricated by chemically modified jute fiber reinforcement.

Fig. 15. (a) Pipes without jute fiber reinforcement, **(b)** pipes with untreated jute fiber reinforcement, **(c)** pipes with chemically modified jute fiber reinforcement

D.2.4. Standard testing of manufactured jute fiber reinforced concrete pipes

There are two standard tests of concrete sewerage pipes. The first one is hydrostatic test of concrete sewerage pipe and second one is the three edge bearing test. Both of these tests were performed in M/S Rural Concreting Company of Ghatal Pvt. Ltd. Fig.16a and 16b show the testing of concrete sewerage pipes.

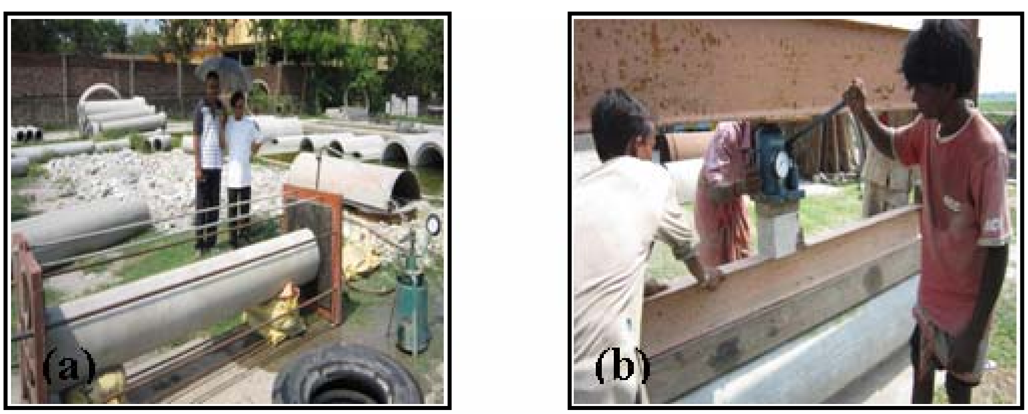


Fig. 16. (a) Hydrostatic testing of pipes, (b)Three edge bearing test of pipes.

Tables 9a and 9b show that jute fiber reinforced precast concrete pipe achieved better properties than that of the standard pipe. The chemically modified jute fiber reinforced NP3 concrete pipe achieves higher strength than that of conventional NP4 concrete pipe by incorporating only 20.5 kg of steel cage instead of 29.9 kg. Thus, the chemically modified jute fiber reinforced NP3 concrete pipe is cost effective as well as strong.

Table 9a. Comparative study of the properties of modified jute fiber reinforced precast concrete pipes (PJRCP) with standard pipe of class NP2

Property		Properties of concrete pipe (IS 458)	Properties of PJRCP	Remarks
Diameter (mm)		**300.0**	**300.0**	**-**
Length (m)		**2.5**	**2.5**	**-**
Thickness (mm)		**30.0**	**30.0**	**-**
Strength of three edge bearing test	**Load to produce 0.25 mm crack (KN/linear meter)**	**13.5**	**14.0**	**Jute fiber reinforcement in concrete pipe leads to 3.4% increment in load required to produce 0.25 mm crack.**
	Ultimate load (KN/linear meter)	**20.2**	**21.9**	**Jute fiber reinforcement in concrete pipe leads to 8.4% increment in ultimate load.**
Time (s) for holding water during hydrostatic test at 0.07 MPa pressure		**150**	**186**	**Pressure was gradually raised up to 0.07 MPa and held for 186 s. No formation of water beads or leakage was found on the surface of pipe.**

Table 9b. Comparative study of chemically treated jute fiber reinforced modified concrete pipe with standards

Properties	Specifications and properties of NP3 concrete pipe (IS: 458)	Specifications and properties of NP3 concrete pipe (our pipe without jute fiber)	Specifications and properties of our NP3 pipe reinforced with chemically modified jute	Specifications and properties of NP4 concrete pipe (IS: 458)
Diameter (mm)	**600**	**600**	**600**	**600**
Length (m)	**2.5**	**2.5**	**2.5**	**2.5**
Thickness (mm) (IS 458)	**85**	**85**	**85**	**85**
Grade of concrete	**35 M**	**35 M**	**35 M**	**35 M**
Amount of steel (Kg/pipe)	**20.5**	**20.5**	**20.5**	**29.9**
Average Load to produce 0.25 mm crack (kN)	**71.9**	**100 ± 3.5**	**154.5 ± 3.4**	**115.8**
Average Load to produce 0.25 mm crack (kN/linear meter)	**28.7**	**33.3 ± 1.6**	**61.8 ± 1.4**	**46.3**
Average Ultimate breaking load (kN)	**107.8**	**--**	**247.1 ± 5.6**	**173.5**
Average Ultimate breaking Load (kN / linear meter)	**43.1**	**--**	**98.9 ± 2.2**	**69.4**

D.3. Prototype development of jute fiber reinforced concrete electric pole

D.3.1. Preparation of concrete composites for pole fabrication

According to IS 1678, 45 M graded concrete is required for fabrication of pole. The calculated mix design to prepare 45 M concrete is cement: sand: stone chips (12.5 mm) :: 1: 1: 2. The cement used for pole preparation is OPC (Ambuja) of 43 grade. The water cement ratio for concrete preparation was 0.32-0.34. For each set of concrete composites 1% jute fiber was incorporated.

D.3.1.1. Physical characterization of ordinary portland cement (OPC)

Consistency, initial and final setting times of cement pastes with and without jute fiber was measured by Vicat Apparatus according to IS: 4031.

From Table 10 it is observed that the initial and final setting times of raw jute fiber reinforced cement paste rise from the control cement paste.

Table 10. Setting time of ordinary Portland cement paste

Sample code	Jute loading (%)	Polymer emulsion (%)	Amount of water/400g cement(ml)	Standard consistency (W/C)	Initial setting time (min.)	Final setting time (min)
Control	0	0.000	124.5	0.31125	172	252
RJC	1	0.000	129.0	0.32250	196	280
RJC	2	0.000	133.5	0.33375	205	295
RJC	3	0.000	143.5	0.35875	225	340
RJC	4	0.000	172.0	0.43000	--	353
LJC	1	0.125	133.0	0.33250	192	288
LTJC	1	0.125	124.5	0.31125	335	415

N.B. RJC: raw jute cement, AJC: alkali treated jute cement, LJC: alkali and latex treated jute cement, LTJC: Alkali and latex treated jute cement modified with tannin.

When polymer latex modified jute fibers were incorporated into cement matrix, the initial and final setting time was decreased than that of the raw jute fiber reinforced cement. But addition of organic admixture (tannin) delays the setting time of cement paste. As the jute fiber percent in cement matrix increases, the initial and final setting times of cement paste increase.

D.3.1.2. Characterization of concrete for pole fabrication

From Tables 11a and 11b it can be observed that maximum mechanical strength (compressive strength: 81 MPa and flexural strength: 8 MPa) was obtained by incorporating 1% chemically treated jute fiber in tannin modified concrete.

Table 11a. Physical properties of lab based concrete composites (cured for 28 days) for pole fabrication

Sample	W/C ratio	Type of jute	Bulk density	Water absorption (%)	Apparent porosity (%)
Control	0.32	-	2566 ± 25	4.4 ± 0.4	10.9 ± 1.1
Raw jute concrete	0.34	Untreated	2555 ± 22	5.8 ± 0.5	14.1 ± 1.1
Chemically treated jute concrete	0.34	Alkali and latex treated	2576 ± 13	5.5 ± 0.3	13.5 ± 0.6
Chemically treated jute concrete modified with tannin	0.32	Alkali and latex treated	2587 ± 29	4.8 ± 0.4	11.9 ± 1.1

Table 11b. Mechanical properties of lab based concrete composites for pole fabrication

Sample	Compressive strength (MPa)			Flexural strength (MPa)		
	7 days	14 days	28 days	7 days	14 days	28 days
Control	57.0 ± 1.5	63.3 ± 3.8	64.1 ± 4.0	4.9 ± 0.1	5.9 ± 0.1	6.4 ± 0.2
Raw jute concrete	46.0 ± 4.1	60.6 ± 3.5	68.3 ± 3.5	4.2 ± 0.2	6.2 ± 0.2	6.6 ± 0.3
Chemically treated jute concrete	52.0 ± 4.6	59.0 ± 4.4	72.3 ± 2.5	5.2 ± 0.2	7.0 ± 0.1	7.0 ± 0.2
Chemically treated jute concrete modified with tannin	32.0 ± 2.1	67.6 ± 5.6	81.0 ± 1.2	6.1 ± 0.1	7.6 ± 0.2	8.0 ± 0.3

D.3.2. Fabrication of jute fiber reinforced prestressed concrete electric pole

We collaborated with a local prestressed concrete pole manufacturing company, M/S HB Housing industries, West Midnapur District, West Bengal. This company has all facilities of manufacturing and testing of prestressed concrete poles. We visited the company and fabricated few jute fiber reinforced concrete poles of 6 m length with our mix design formulation and process. Fig. 17 shows the photographs of different process steps followed during the actual fabrication of jute reinforced concrete poles.

Fig. 17. Fabrication of chemically modified jute fiber reinforced prestressed concrete pole

D.3.3. Fabricated concrete poles with modified jute fiber reinforcement

The two concrete electric poles reinforced with chemically modified jute fiber were fabricated in the prestressed concrete pole manufacturing company, M/S HB Housing industries and those are shown in Fig. 18.

Fig. 18. Chemically modified jute fiber reinforced prestressed concrete pole

D.3.4. Standard testing of fabricated jute fiber reinforced concrete pole

The standard test of concrete electric pole is cantilever test. This test was performed in the prestressed concrete pole manufacturing company, M/S HB Housing industries. Fig. 19a shows the cantilever test of chemically modified jute fiber reinforced concrete electric pole and Fig. 19b shows that the maximum flexibility before failure of concrete pole.

Fig. 19a. Cantilever testing of modified jute fiber reinforced concrete electric pole

Fig.19b. Maximum flexibility before failure of modified jute fiber reinforced concrete electric pole

Table 12 shows that jute fiber reinforced prestressed concrete pole achieved better mechanical properties than that of the standard pole. The chemically modified jute fiber reinforced concrete pole shows higher deflection property than that of conventional concrete pole. Thus, the chemically modified jute fiber reinforced concrete pole can be used in coastal areas.

Table 12. Comparative study of chemically treated jute fiber reinforced modified concrete pole with standard

Standard values of concrete pole (IS ; 1678, 1998)			Chemically modified jute fiber reinforced concrete pole (our product)		
Load (kg)	**Ultimate load (%)**	**Deflection (mm)**	**Load (kg)**	**Ultimate load (%)**	**Deflection (mm)**
200	40	50	200	40	39
250	50	62	250	50	56
300	60	75	300	60	66
350	70	90	350	70	83
400	80	110	400	80	103
425	85	125	425	85	125
450	90	145	450	90	143
475	95	155	475	95	164
500	100	167	500	100	199
Ultimate load	600	--	Ultimate load	620	525

D.4. Prototype development of jute fiber reinforced concrete pavers block

D.4.1. Fabrication of jute fiber reinforced concrete pavers block

According to IS 15658 for fabrication of concrete pavers 35 M graded concrete is required. The mix design of concrete paver is cement: sand: stone chips :: 1: 3: 4. Here the size of stone chips used was 3-6 mm. The water cement ratio for concrete paver preparation was 0.2. For each set of concrete composite 1% jute fiber was incorporated.

For prototype fabrication of concrete pavers blocks, we collaborated with a local precast pipe manufacturing company M/S Rural Concreting Company of Ghatal Pvt. Ltd., West Midnapur District, West Bengal. This company has all facilities of manufacturing of precast concrete paver blocks. We visited the company and fabricated jute fiber reinforced concrete paver blocks in this unit with our mix design formulation and process.

Fig. 20 shows few photographs of process steps followed during the actual fabrication of jute reinforced concrete paver block.

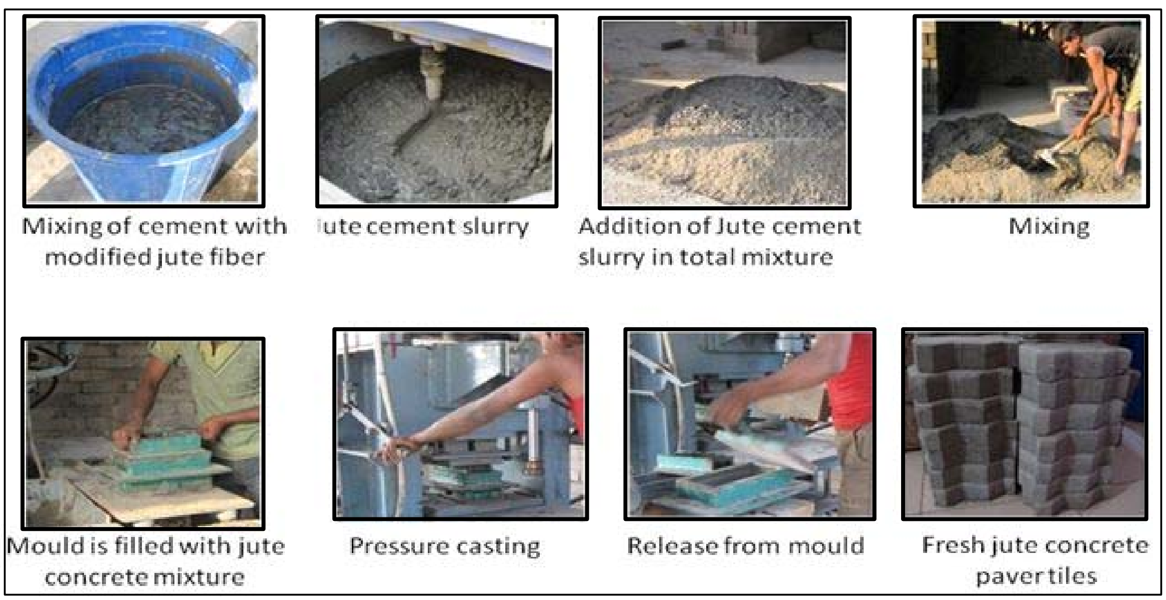


Fig. 20. Fabrication process of chemically modified jute fiber reinforced concrete pavers block

D.4.2. Concrete paver blocks with and without modified jute fiber reinforcement

Three different concrete paver blocks were made with the mix design, which was developed in this research. Fig. 21a shows the concrete pavers block without any jute fiber reinforcement. Jute fiber reinforced concrete pavers block is shown in Fig. 21b. Fig. 21c shows concrete pavers block fabricated by chemically modified jute fiber reinforcement.

Fig. 21a. Paver without jute fiber reinforcement

Fig. 21b. Pavers with untreated jute fiber reinforcement

Fig. 21c. Pavers with chemically modified jute fiber reinforcement

D.4.3. Standard testing of fabricated jute fiber reinforced concrete pavers block

There are two standard tests of concrete pavers block. The first one is compressive strength test of concrete pavers block and the second one is flexural strength test. Both these tests were performed in the IIT Kharagpur laboratory. Figs.22a and 22b show the testing of concrete paver blocks.

Fig. 22a. Compressive test of jute reinforced concrete paver block

Fig. 22b. Flexural test of jute reinforced concrete paver block

Tables 13a and 13b show that jute fiber reinforced precast concrete paver tiles achieved better properties than that of the control paver tiles without jute. The chemically modified jute fiber reinforced concrete paver shows 54 % and 69 % higher compressive and flexural strengths respectively than that of control concrete pavers block.

Table 13a. Physical properties of concrete paver blocks (cured for 28 days)

Sample	W/C ratio	Type of jute	Bulk density	Water absorption (%)	Apparent porosity (%)
Control	0.15	-	2.88	8.09	20.9
Raw jute concrete	0.2	Untreated	2.67	8.29	21.11
Chemically treated jute concrete modified with tannin	0.15	Alkali and latex treated	2.88	7.08	20.66

Table 13b. Mechanical properties of manufactured concrete paver blocks (cured for 28 days)

Category	Load bearing capacity (Ton)	Compressive strength (MPa)	Flexural strength (MPa)
Control	41.2 ± 2.8	20.2 ± 1.4	3.48 ± 0.2
Raw jute reinforced paver	52.9 ± 6.1	25.9 ± 3.0	5.23 ± 0.3
Chemically treated jute reinforced paver modified with tannin	69.5 ± 2.2	34.1 ± 1.1	5.37 ± 0.2

D.5. Development of jute fiber reinforced cement flyash roof sheet

Cement-fly ash sheet composites were fabricated by reinforcing with chopped jute fibers (5 mm length) and jute felts [300x300 (cm^2)] of 250, 400 and 600 gsm. At first the chopped jute fibers and jute felts were soaked into water for 24 h.

For chopped jute fiber reinforced cement-fly ash sheet composites the cement and sand ratio was 1:1.5, 10 to 50% cement was replaced by fly ash and different weight percent of water soaked jute fiber were mixed with required amount of water (112.5% w.r.t. cement weight) to make slurry, following the above process. The fresh mix thus obtained was cast in molds [(300x300x6) mm^3)] under 5 metric ton pressure for 2 h at ambient temperature. After 24 h the samples were demolded followed by moisture curing for 28 days.

For jute felt reinforced cement-fly ash sheet composites, cement and fly ash (2:3) were mixed with 112.5% of water w.r.t. cement. The water soaked jute felts were then laminated on both sides by cement-fly ash mixture and was placed in the molds [300x300x6 (mm^3)] under 5 metric ton pressure for 2 h at ambient temperature. After 24 h the samples were demolded and were moisture cured for 28 days. Fig. 23a and 23b shows the photographs of 28 days water cured chopped jute fiber reinforced cement-fly ash sheet composites and jute felt reinforced cement-fly ash sheet composites respectively.

Fig. 23. Photographs of 28 days water cured (a) chopped jute fiber reinforced cement-fly ash sheet composites and (b) jute felt reinforced cement-fly ash sheet composites

Achievement

- ✓ **The chemically modified jute fiber reinforced NP3 concrete pipe achieved higher strength than that of conventional NP4 concrete pipe. This means that 31.6% steel requirement can be reduced from NP4 pipe without compromising its properties. Thus, the chemically modified jute fiber reinforced NP3 concrete pipe is cost effective as well as possess better mechanical strength.**
- ✓ **The paver blocks made by reinforcing with chemically modified jute fiber show 14.6 % less water absorption than the pavers tiles made by raw jute fiber reinforcement.**
- ✓ **Compressive and flexural strengths of chemically modified jute fiber reinforced pavers tiles achieved 69 and 54 % more strength than the pavers tiles without jute fiber.**
- ✓ **Jute reinforced concrete pole achieved standard strength (IS 1678) and showed more deflection before failure.**

SECTION E

Summary and achievement

Summary and achievement of project

This work demonstrated the potentiality of jute fiber as reinforcing agent in cement composites for the use of sewer pipes, prestressed concrete pole, paver blocks. The entire investigation is summarized below.

Summary

- Systematic experimental processes were developed for proper modification of jute fiber with alkali and polymer.
- Raw/chemically modified jute fiber reinforced cement composites were fabricated, following a systematic experimental program by considering different experimental parameters like different processes, fiber content by weight %, fiber length, and curing time.
- Testing of jute fiber reinforced cement concrete composite showed appreciable improvement in mechanical properties, which encourage fabricating prototype cement concrete products.
- The following jute fiber reinforced cement concrete products had been developed so far
  - Jute fiber reinforced sewer concrete pipes
  - Jute fiber reinforced pavement tiles
  - Jute fiber reinforced prestressed concrete for electric pole
  - Jute fiber reinforced cement fly ash roof sheet
- Successful trials of fabrication and testing of 300 mm and 600 mm diameter sewer pipes were completed at M/S Rural Concreting Company of Ghatal Pvt. Ltd.
- Industrial trial for fabrication of pavers tiles and testing were performed at M/S Rural Concreting Company of Ghatal Pvt. Ltd.
- A field trial on jute fiber reinforced prestressed concrete pole casting and testing had already been done successfully at M/S H. B Housing Industries, West Midnapur.

Achievements

- ✓ Chemical modification of jute fiber improved tensile strength and elongation at break about 41 and 34 % respectively.
- ✓ Water absorption of jute fiber was reduced to 108 % from 210 % after chemical and polymer treatment.
- ✓ Technique of short jute fiber (optimum length 4-6 mm) dispersion in concrete/mortar was optimized both in dry and wet basis.
- ✓ Concrete mixing process was optimized with standard ratios of sand, cement, stone chip and water to obtain a concrete having adequate workability during casting.
- ✓ Workability of jute fiber incorporated concrete mix was improved using tannin as admixture.
- ✓ Critical fiber loading was optimized by fabricating cement concrete with different amounts of jute fiber (1-10% w.r.t. weight of cement). Maximum compressive and flexural strength was achieved at 1% fiber loading in cement composite which was about 4 kg per cubic meter concrete and 5.5 kg per cubic meter cement mortar.
- ✓ Compressive and flexural strengths of chemically treated jute fiber reinforced cement concrete (lab based) were improved by 60 and 66% respectively than that of the concrete without jute fiber reinforcement.
- ✓ Compressive and flexural strengths of chemically treated jute fiber reinforced cement mortar (lab based) were improved by 11 and 86 % respectively than that of the mortar without jute fiber reinforcement.
- ✓ Degradation study of jute fiber in cement matrices showed that the rate of degradation of treated jute fibers incorporated in cement paste was very slow whereas in case of untreated jute fibers incorporated in cement paste degraded rapidly with time. Chemically modified jute fiber in cement paste retained 97 % of its strength after 90 days aging duration. Whereas, raw jute fiber in cement paste retained 82% of its strength after 90 days aging.
- ✓ Need assessment, market survey and comparative cost analysis had been done by M/s Roots and Yards, Kolkata.

- ✓ The chemically modified jute fiber reinforced NP3 concrete pipe achieved greater strength than that of conventional NP4 concrete pipe. This means that the use of 31.6% steel can be reduced from NP4 pipe without compromising its properties. Thus, the chemically modified jute fiber reinforced NP3 concrete pipe is cost effective as well as mechanically stronger.
- ✓ Pavers blocks made by reinforcing with chemically modified jute fiber showed 14.6 % less water absorption than that of the pavers blocks made by raw jute fiber.
- ✓ Compressive and flexural strengths of chemically modified jute fiber reinforced pavers blocks achieved 69 and 54 % more strength than that of the pavers blocks without jute fiber.
- ✓ Jute fiber reinforced concrete pole achieved standard strength (IS 1678) and showed more deflection before failure.

SECTION F

Market survey and need assessment

F.1. Introduction

Need Assessment and Market Survey in this project was done by a professional organization M/S Roots & Yards, Kolkata. The need assessment on jute reinforced concrete products was first started with a precast concrete company in West Medinipur. Few big infrastructure companies were also contacted and their need was surveyed. It appeared that precast concrete had a special scope in the project. A number of other precast companies were also surveyed. One of the precast companies was chosen for field trials.

F.2. Identified products and its applications

Projected applications and advantages of jute fiber reinforced cement concrete developed in this investigation are focused in Table 14.

Table 14: Potential applications and advantages of jute fiber reinforced cement composites

Identified products	Application areas	Advantages
Jute reinforced cement concrete	a) Building materials b) Concrete sewage pipes c) Paver block d) Electric pole	Resists micro crack initiation and propagation
Jute reinforced cement mortar	a) Jute reinforced roofing sheet b) Brick wall plastering	Jute reinforcement resists peeling, cracking, crazing

F.3. Cost analysis of identified products

Cost analysis was done on two jute reinforced concrete products, viz., electric pole and sewer pipe based on our industrial trial production in M/S H. B. Housing Industries, Midnapur and M/S Rural Concreting Company of Ghatal Pvt. Ltd., Paschim Medinipur.

F.3.1. Costing of Precast concrete (PCC) poles

Specifications: Volume of concrete = 0.172 cubic meter of 8.0 m x 200 kg PCC pole

Mix design: Cement: Sand: Stone chips: water = 1: 2: 2: 0.32

Table 15: Cost analysis of one pole

Product	Qty required	Rate (Rs)	Cost of pole without jute (Rs)	Cost of pole with jute (Rs)
Cement	2 bags	280.00/bag	560.00	560.00
Sand	2.60 CFT	7.00/CFT	18.00	18.00
Graded stone chips	4.9 CFT	42.00/CFT	206.00	206.00
4 mm H. T. Wire	13.50 kg	45.00/kg	608.00	608.00
Treated jute	1 kg	60.00/kg	--	60.00
Labor cost	2 nos	142.00/head	284.00	284.00
Total raw materials and labor cost	--	--	1676.00	1736.00
Overhead @ 5%	--	--	84.00	87.00
Total manufacturing cost			1760.00	1823.00

Notable increase in properties:

The strength and flexibility of the PCC poles were substantially improved (**Table 12 in section D**) with the incorporation of treated jute in the concrete mix with the mix design mentioned in F.3.1. However, due to incorporation of jute the price/pole has been marginally increased (by Rs. 63.00) but this increase in price will be surpassed by improved performance (Table 15). Therefore, the cost of concrete electric pole with jute reinforcement may be attractive using the technology invented by IIT, Kharagpur.

F.3.2. Costing of NP3 pipes

An industrial trial production of non pressure pipes (NP), viz., NP3 and NP4 was done, at M/S Rural Concreting Company of Ghatal Pvt. Ltd. It was observed that applying treated jute the NP3 gains the property of NP4.

Specification: Medium duty according to IS 458, diameter – 600 mm, length- 2.5 m, thickness- 85 mm, concrete volume: 0.457 cubic meter.

Grade concrete: M35

Mix design: Cement: Sand: Stone chips: water = 1: 1.5: 2.7: 0.38

Table 16: Cost analysis for one pipe, diameter – 600 mm, length- 2.5 m, thickness- 85 mm

Product	Qty required	Rate (Rs)	Cost of pipe without jute (Rs)	Cost of pipe with jute (Rs)
Cement	4 bags	280.00/bag	1120.00	1120.00
Sand	305 kg	00.40/kg	122.00	122.00
Graded stone chips	540 kg	00.50/kg	270.00	270.00
8 mm M. S. Wire	20.50 kg	50.00/kg	1025.00	1025.00
Treated jute	2 kg	60.00/kg	--	120.00
Labor cost	4 nos	150.00/head	600.00	600.00
Total raw materials and labor cost	--	--	3197.00	3257.00
Overhead @ 20%	--	--	639.00	651.00
Total manufacturing cost			3836.00	3908.00

F.3.3. Costing of NP4 pipes

Specification: Heavy duty according to IS 458, diameter – 600 mm, length- 2.5 m, thickness- 85 mm, concrete volume: 0.457 cubic meter.

Grade concrete: M35

Mix design: Cement: Sand: Stone chips: water = 1: 1.5: 2.7: 0.38

Table 17: Cost analysis for one pipe, diameter – 600 mm, length- 2.5 m, thickness- 85 mm

Product	Qty required	Rate (Rs)	Amount (Rs)
Cement	4 bags	280.00/bag	1120.00
Sand	305 kg	00.40/kg	122.00
Graded stone chips	540 kg	00.50/kg	270.00
8 mm M. S. Wire	29.9 kg	50.00/kg	1495.00
Labor cost	4 nos	150.00/head	600.00
Total raw materials and labor cost	--	--	3607.00
Overhead	--	@ 20%	721.00
Total manufacturing cost			4328.00

Notable increase in properties:

NP4 property is achieved from NP3 with the application of treated jute in concrete mix. The load bearing capacity of the NP3 is observed as similar as NP4 (**Table 9a and b in section D**). Therefore, the costing seems much attractive with applied technology invented by IIT, Kharagpur.

Table 18: **Consumption of jute in kg per one cubic meter of concrete**

Product type	Mix design of concrete	Used jute (%) w. r. t. weight of cement	Amount of jute per cubic meter concrete (kg)
Base concrete	C:F.A.:C.A.:W = 1:2:4:0.6	1	4.0
Concrete pipe	C:F.A.:C.A.:W = 1:1.5:2.7:0.38	1	4.4
Concrete pole	C:F.A.:C.A.:W = 1:2:2:0.32	1	5.8
Concrete paver tile	C:F.A.:C.A.:W = 1:3:4:0.2	1	3.1
Cement mortar	C:F.A.: W = 1:3:0.6	1	5.7

C = cement; F.A. = fine aggregate; C.A. = coarse aggregate; w = water

One estimate of jute consumption in 1000 sq. ft. concrete roof of 4 inch thickness (i.e., 10 cubic meter concrete volume) having mix design of 1:2:4 (cement: sand: stone chips) is around 40 kg.

F.4. Need Assessment and Market Survey

As a marketing professional, M/S. Roots & Yards categorized the project in two parts, viz. Need Assessment in one hand and Markey Survey on the other. In a market, every product has a potential to get sold irrespective of quantum. After market survey it revealed that the types of concrete product that are used today in the construction industries are enormous. The concrete design differs from one product to the other. In view of such versatility we have, therefore, compartmentalized the technology marketing in three sectors, viz., concrete pipe manufacturing sector; concrete pole and precast concrete sectors and the infrastructure sectors. The need in these sectors has been studied. According to the needs a few companies were selected for trials. Commercial trials on precast pipes and pillars have been started in those companies. Need assessment has been estimated in the infrastructure companies too. Those infrastructure companies are also willing to have trials in their sites. In situ trials would give the actual assessment of the demand in the market at large. The field trial in the concrete pipe and pillar industries will raise the demand of the technology after necessary tests.

Concrete is most popular choice in today's urban societies. This development of technology gives thrust to cater that demand with more attractive characteristics in the concrete. Precast is having great potential in low cost housing and other applications. Precast has potentials in the door panels and accessories like seats and garden benches, in the railway platforms and bus terminus too. In those applications, precast has an obvious choice because of its manifold advantages. The pillars with added projected features with the technology intervention will have a good demand in the industries.

F.4.1. Need Assessment

We have interacted with various companies from big infrastructure to the village based micro industries like fly ash brick factories. The names of the surveyed companies are given in subsequent section of this report. Cement concrete has a growing demand with the rapid growth of urban life. Throughout the globe, cement based concrete is the most obvious choice for all today. Thus, the technology of the IIT, Kharagpur shall be much needed by the construction companies. The needs of the companies are directly proportional to the price structure. The cost benefit ratio would be calculated by the companies. The technology will be accepted by the companies if they see some commercial benefit, which is also likely to come with the application of the same. The civil construction is very expensive these days. Therefore, as far as our assessment, a technology that would give cost benefit to the customers would be taken without doubt. There is need of low cost technology intervention in the construction business. It is hoped that this technology will be able to give a new direction to those companies as far as the commercial outlook is concerned.

F.4.2. Market survey

An extensive market survey with knowledge based presentation has been conducted across India. That market behavior was enthusiastic and the companies are looking forward for the application of the technology with immediate effect. Most of the companies showed their willingness to have trials in their site itself. Many of them are in regular contact with us to come to IIT to have technical discussions with the project team. IIT has extended to do trials in two pre cast companies. From those trials it is evident that a demand may rise in the pre cast industries especially in the concrete pipe, paver tiles, fly ash bricks and electric pole manufacturing sector.

F.4.3. Companies' view on jute reinforced cement concrete products:

i) The concrete (RCC) pipes and tiles manufacturing companies

1. **Rural Concreting Company of Ghatal Pvt. Ltd.**

Status of company	Feedback from company
Manufacturer and exporter of RCC hume pipes, pavers block such as flexi pavers blocks, industrial pavers blocks, garden pavers blocks, colored pavers blocks, customized pavers blocks etc. Address: Mahamaya Lodge, Room No.-09, Judges Court Road, Medinipur, Paschim Medinipur, West Bengal-721101. Ph: 03222-297380/03225-260659 Mobile: + (91)-9434934309 / 9434109038 / 9434867586. Email: rccspunpipe@gmail.com	Successfully performed multiple industrial trials for production of jute reinforced cement concrete pipes and pavers blocks. The jute reinforcement technology in concrete pipe production can be well adopted with the existing machineries. However, installation of a counter current pan mixer will help excellent dispersion of jute even with lumpy jute caddice.

2. **A. P. M. V. Tiles**

Status of company	Feedback from company
Supplier and manufacturer of interlock tiles, floor tiles, chequered tiles, manhole covers, concrete slabs, kerb stones, bricks and hollow blocks. Address: No. 37, Navyug Market, Ghaziabad, Uttar Pradesh - 201 001.Fax: +(91)-(120)-2797745 Contact person: Mr. Manu Gupta Mobile: +(91)-9818064888/9910101767	Mr. Gupta is convinced with the presentation. He will look forward to talk more with the project group and is ready to implement technology if it seems feasible and workable

3. **Dagar Tiles**

Status of company	Feedback from company
Manufacturer of RCC pipe, industrial RCC pipes, spun pipes, concrete pipes, drainage RCC pipes, industrial RCC block, cement concrete pipes, RCC hume pipe. Address: No. 511, Sector No. 37, Noida, Uttar Pradesh - 201303. Mobile: +(91)-9811014153/9810632583 Contact person: Mr. Surindar Gupta	Interested for transfer and application of technology

4. KK Spun Pipes Private Limited

Status of company	Feedback from company
Manufacturer and supplier of RCC pipes, industrial RCC pipes, sewage RCC pipes and drainage RCC pipes, jacking pipes, lined pipes and polyethylene lined pipes, etc. Address: Tigaon Road, Ballabgarh, Faridabad, Haryana - 121 004. Ph: +(91)-(129)210483/41828557, Fax: +(91)-(129)-41828556, Contact person: Mr. Sunil Nagar, Mobile: 09958891322	**The Civil Designers took interest in technology intervention. They wish to hear the development. If feasible, they would take the technology.**

5. R. S. Spun Pipe Company

Status of company	Feedback from company
Engaged in supplying and manufacturing RCC pipes such as industrial RCC pipes, RCC hume pipes, construction RCC hume pipes, corporate RCC hume pipes, heavy duty RCC hume pipes and heavy load RCC hume pipes. Address: Hansi Tosham Road, Village - Jamalpur, District: Bhiwani Near Hansi, Hansi, Haryana - 127035.Ph: +(91)-(1254)-288232, Contact person: Mr. Lomansh Goyel, Mobile: +(91)-9812004888/9812504888	**Interested in technology. Would like to look forward for processes and application.**

6. The Poona Concrete Products Co.

Status of company	Feedback from company
Engaged in manufacturing and suppliers of all kinds of RCC pipes, HDPE lined RCC jacking pipes and RCC jacking pipes. Also supplies industrial pipes and fabricated RCC pipes. Address: Tal Khed, Pune, Maharashtra-411030. Ph: +(91)-(20)-24532914/24535813 Contact person: Mr. Tushar Dhalgad, Email:poonaconcrete@yahoo.com Mobile: +(91)-9822659340	**Took interest in the technology. Would like to come to see the advancement at IIT.**

7. Vinayak Technocast Industries

Status of company	Feedback from company
Manufacturer and exporter of RCC pipes, industrial RCC pipes, railway track RCC pipes, road RCC pipes, highway RCC pipes, construction RCC pipes, railway track etc. Address: No. 264, Zak Vahelal Road, At- Zak, Tal- Dahegam, District: Gandhinagar, Ahmedabad, Gujarat - 382330. Ph: +(91)-(2716)-296204, Mobile: +(91)-9825898758	**Interested and eager to implement the technology if feasible.**

8. Prakash Fabricators

Status of company	Feedback from company
Engaged in manufacture, export and supply of RCC pipe plant that includes RCC pipes, round RCC pipes, water supply RCC pipes and RCC pressure pipes. Also deals in supplying of bending machines, pipe bending machines and shearing machines. Address: 1034, E, Rajaram Road, Kolhapur, Maharashtra - 416 008. Ph: +(91)-(231)-2657328/2655379 Fax: +(91)-(231)-2657594, Email: info@prakashfabricators.com Contact person: Mr. Kedar Tendulkar, Mobile: +(91)-9422413610	**Interested and eager to implement the technology if feasible. Interested for technology advancements and looking forward for pipe machineries development and technology invention etc.**

9. Gandhi RCC Cement Pipe Works

Status of company	Feedback from company
Engaged in manufacturing and supplying RCC pipes, class RCC pipes, cement post pillar, cement window, cement frame, sip cot pipes and socket pipes along with hollow bricks and solid hollow bricks. Address: Opposite To Venkateshwara Kalyana, Mandapam, Poondurai Road, Erode, Tamil Nadu - 638002. Ph: +(91)-(424)-2281671/2280671.	**No feedback from company**

10. K. K. Concrete Products

Status of company	Feedback from company
Manufacturer and supplier of RCC pipes, industrial RCC pipes, concrete blocks, concrete manhole covers, concrete drains, concrete tree guards, kerb stones and concrete beams. Address: Tigaon Road, Ballabhgarh, Faridabad, Haryana - 121 004. Ph: +(91)-(129)-6452611/2210357 Contact person: Mr. Ajay Gupta, Mobile: +(91)-9350618568	**Wanted to know the pros and cons of the technology and interested to come to IIT for interaction regarding the development of the technology.**

11. New Laxmi Tiles

Status of company	Feedback from company
Deals in manufacturing and supplying RCC pipes, high strength RCC pipes and customized RCC pipes used in agricultural purposes, drainage and in pump houses. Address: Gurgaon C Sikanderpur Road, Gurgaon, Haryana - 122 001. Mobile : +(91)-9810833785/9212649950	**No feedback from company**

12. The Spun pipe & Construction Company (Baroda) Private Limited

Status of company	Feedback from company
Supplying and manufacturing reinforced concrete cement pipes and industrial reinforced concrete cement pipes. Also dealing with steel pipes, mild steel pipes and BWSC pipes. Address: A/505-506, 5th Floor, Alkapuri Arcade, R. C. Dutt Road, Vadodara, Gujarat - 390001. Ph: +(91)-(265)-2343722 Contact person: Mr. Nirav Patel, Email: spunpipe@gmail.com	**Interested for the technology. May come to IIT. If feasible, technology can be transferred**

13. Jain Spun Pipe Co.

Status of company	Feedback from company
Engaged in manufacturing and supplying RCC hume pipes, HDPE lined RCC jacking pipes, RCC jacking pipes, concrete pipes, reinforced cement concrete pipes and perforated pipes. Address: No. 274, Deepali, Pitam Pura, New Delhi, Delhi - 110 034. Fax: +(91)-(11)-27016250, Contact person: Mr. Ashu Jain Mobile: 09330177007	**Showed interest to know and adopt the technology. Wish to come to IIT and look forward for further development towards the technology transfer.**

14. Jai Spun Pipe

Status of company	Feedback from company
Manufacturer and supplier RCC pipes, industrial RCC pipes, RCC spun pipes, RCC drainage pipes, light duty RCC pipes, heavy duty RCC pipes, agricultural RCC construction pipes and irrigation RCC pipes Address: Old Khaira Road, Najafgarh, New Delhi, Delhi - 110 043. Mobile : +(91)-9212731438/9212731437	**No feedback from company**

15. Agarwal Spun Pipes

Status of company	Feedback from company
Manufacturer and supplier of industrial RCC pipes, precision RCC pipes and round pipes, manhole covers and RCC gratings. Address: T-28, Shukar Bazar, Bindapur, Matiyala Road, Uttam Nagar, New Delhi, Delhi - 110 059. Mobile : +(91)-9811308732	**No feedback from company**

16. Oriental Ceramics & Refractories Private Limited

Status of company	Feedback from company
Manufacturer and supplier of RCC pipes like RCC water pipes, drainage pipes, water drainage pipes, road pipes, industrial pipes etc. Address: Village Daun, District Mohali, Mohali, Punjab. Ph: +(91)-(172)-2278480, Mobile : +(91)-9878700162/9814009101	**No feedback from company**

17. Balaji Spun Pipe

Status of company	Feedback from company
Manufacturing and supplying RCC pipes that include RCC spun pipes, agricultural RCC spun pipes and industrial RCC pipes. Also offering other pipes like cement pipes. Address: Village Jiwra, Post Office: Aisia Kigorawas, Rewari, Haryana - 123 401. Ph: +(91)-(1274)-222488 Fax: +(91)-(1274)-222488, Mobile : +(91)-9416069069/9416214317	**No feedback from company**

18. Kreative Concrete Industries

Status of company	Feedback from company
Manufacturer, exporter and supplier of RCC pipes, RCC hume pipes, RCC split pipes, industrial RCC pipes, industrial RCC hume pipes, industrial RCC split pipes, irrigation RCC pipes, irrigation RCC hume pipes and irrigation RCC split pipes. **Address: V.P.O. Lodhwan, Damtal- Kandwal Road, Tehsil Nurpur, Kangra, Himachal Pradesh - 176 201.** **Ph: +(91)-(1893)-233081, Fax: +(91)-(186)-2245643** **Mobile : +(91)-9815183122/9815183422**	**No feedback from company**

19. Indian Hume Pipes

Status of company	Feedback from company
Manufacturing a wide range of RCC pipes such as RCC hume pipes, high strength RCC hume pipes, drainage RCC hume pipes, agriculture RCC hume pipes, durable RCC hume pipes and customized RCC hume pipes. **Address: NH - 8, 100 Km Stone, Delhi Vill. Sanjharpur, HSIIDC, Bawal, Rewari, Haryana - 123 501.Fax: +(91)-(1274)-252212** **Mobile : +(91)-9729080180/9215347047**	**No feedback from company**

20. Agra Cement Pipe Factory

Status of company	Feedback from company
Manufacturer of RCC pipes like RCC spun pipes **Address: No. E-217, Kamla Nagar, Agra, Uttar Pradesh - 282 005. Ph: +(91)-(562)-2881872, Mobile : +(91)-9927454792/9837161840**	**No feedback from company**

21. Krishna Spun Pipe Works, Kanpur

Status of company	Feedback from company
Engaged in manufacturing RCC pipes. **Address: No. 339, Vishnu Puri, Near Thana Kohna, Kanpur, Uttar Pradesh - 208002. Ph: +(91)-(512)-2640002, Mobile: +(91)-9415213664/9415039484**	**No feedback from company**

22. Mukherjee Industrial Corporation

Status of company	Feedback from company
Engaged in manufacturing and supplying RCC pipes. **Address: 18/B, Sarat Chatterjee Road, Nabagram, West Bengal - 712 246. Mobile: +(91)-9804177980**	**No feedback from company**

23. Gujarat Spun Pipe Factory

Status of company	Feedback from company
Manufacturer and dealer of RCC pipes. **Address: Gujarat Spun Pipe, Post Dhokaliya, Bodeli, Vadodara, Gujarat - 391 135, Ph: +(91)-(265)2220488/2220953 Mobile: 09825320953/9825319883**	**No feedback from company**

24. Hindustan Pipe Co.

Status of company	Feedback from company
Engaged in manufacturing RCC pipes Address: A-109, Mohan Garden, Near Uttam Nagar, Delhi. Ph: +(91)-(11)-65474376 Fax: +(91)-(11)-25356811 Mobile: +(91)-9811048990	No feedback from company

25. Hindusthan Pipe Industries

Status of company	Feedback from company
Manufacture of RCC pipes and RCC spun pipes. Address: Ethelbari, Birpara, Jalpaiguri, West Bengal - 735 204. Ph: + (91)-(3563)-264032 Fax: +(91)-(3563)-264032 Mobile : +(91)-9733445088	No feedback from company

ii) Concrete pre-stressed electric poles and other precast companies

1. H B Housing Industries

Status of company	Feedback from company
Manufacturer of pre-stressed electric poles Address: 84 Library Road, P.O: Midnapur, Dist: Paschim Medinipur. Ph: 03222 266458, Email: sujitbhakat458@yahoo.co.in Contact person: Mr. Sujit Kumar Bhakat	Industrial trials for manufacturing jute reinforced cement concrete electric poles and their testing have been performed successfully

2. Bose Abasan Prakalpa

Status of company	Feedback from company
Specialized in manufacturing precast RCC products particularly in construction areas, with modern equipments. Address: Sadarghat, P.O.Midnapore, Dist. Midnapore (W), WB. Contact person : Mr. Chandan Bose Ph: 03222-275244, Fax: 03222-261852	A couple of meetings have been arranged regarding industrial trials of jute reinforced cement concrete products.

3. Dayal Spun Pipes Pvt.Ltd.

Status of company	Feedback from company
Manufacturer of precast concrete products i.e. route indicator and pillar post RCC parming etc. Address: K.M.10 Delhi Roda Partapur. Ph: 121-2440622 , Fax: 121-2440623	The company is interested to have interaction with the project team.

4. **Precast Concrete Pipe & Products**

Status of company	Feedback from company
Manufacturer of concrete pipes and blocks, precast concrete blocks, city block, cube etc. Address: 7, Ranchhod Wadi, Near Velani Hospital, Bhuj - 370 001., Ph:+ (91)-(2832)-282225	The company wishes to look forward to the technology and wants to implement it if the technology seems feasible

5. **Laxmi Cement Products (P) Ltd**

Status of company	Feedback from company
They are manufacturer of all pre stressed poles, designer concrete products as pre stressed designer concrete door and window frames, precast manhole frames and cover etc. Address: D-5&6 Industrial Estate Mill Road, Gulbarga. Ph: +918472221766	Interested to know more about the development and wishes to interact with the project team.

6. **Bansal Building Materials Pvt. Ltd.**

Status of company	Feedback from company
Manufacturers and suppliers of building materials cement concrete hollow & solid blocks, lightweight AAC and CLC blocks, interlocking paver blocks, reflective rubber molded paver blocks, etc. Address: 302, City Centre, Sosyo Circle, U.M. Road, Surat. Ph: +912612630747, Fax: +912612632787	Would like to come to IIT for technology knowhow. Interested in the technology application if seems viable.

7. **Malda Behula Ash Bricks**

Status of company	Feedback from company
Manufacturer of bricks using fly ash. Address: Naldubi, Mangalbari, N H 34, Malda, WB. Contact person: Radheshyam Agarwala Mobile: 9434053778	They are looking forward for technology application in their brick manufacturing unit without adding any additional cost

iii) Infrastructure companies

1. **Ramky Infrastructure Ltd, East Zone**

Status of company	Feedback from company
Address: Jindal Towers, Block -A, 4th Floor, 21/1A/3, Darga Road, Kolkata – 700 017, Ph No. 033-22892527/ 28, Fax No. 033 2289 2529, Email: projectkol@ramky.com Contact person: Mr. Asit Mukherjee, Mr. Kinkar Dutta and Mr. Gupta	Want to know the detail of the technology and interact with the project team

2. **Bengal Shapoorji Housing Development Pvt. Ltd.**

Status of company	Feedback from company
Address: 3rd Floor, "Shrachi Tower",686 Anandapur, Near Ruby Hospital, EM Bypass, Kolkata –700 107 Ph: +91 33 6555 1837 / 1830, Contact parson: Mr. S Chakrabarti	Took keen interest. Looking forward for development towards implementation and test results.

3. **IVRCL Infrastructures & Projects Ltd**

Status of company	Feedback from company
Contact parson: D Deva Raja, Technical Director Email: ddr@ivrinfra.com	Interested for the technology and looking forwards for next level interaction.

4. **Simplex Infrastructures Ltd**

Status of company	Feedback from company
Simplex Infrastructures Ltd has seven business segments – Ground Engineering, Industrial, Building & Housing, Power, Marine, Roads, Railways & Bridges, and Urban infra. At present, the Company has an order book of 2 Billions USD with over 140 project locations in India and overseas. Address: 'Simplex House'27, Shakespeare Sarani, Kolkata – 700 017,Tel: (91 33) 23011600,Fax: (91 33) 2283 5966 / 65 /64, Email: simplexkolkata@simplexinfra.net Contact person: Mr. Shyamal Maity, HOD, Vice President	The vice president had shown specific interest. He wants further interaction.

5. **Bengal Shristi Infrastructure Development Ltd.**

Status of company	Feedback from company
The company promoted jointly by Asansol Durgapur Development Authority (ADDA), Govt. of West Bengal and Shristi Infrastructure Development Corporation Ltd (Shristi), in line with the approved Government model for Public Private Partnership. Office Address: Jamuna Building 28/1 Shakespeare Sarani, Kolkata 700 017, WB, Ph: 033 2281 5589, Fax: 033 2287 8379 Registered Address: City Centre Durgapur 713 216, W.B. Ph: 0343 2547018/9373	The company has taken interest with the technology and wants to have detailed presentation and looks forward for feasibility study.

6. **CCAP Limited**

Status of company	Feedback from company
CCAP Ltd (Formerly Central Concrete and Allied Products Ltd) provides various construction and infrastructure services in India. The company undertakes and executes multi-dimensional projects involving design and construction. Address: Shantiniketan Building, 8 Camac Street, 3rd Floor, Space-1, Kolkata, 700 017. Ph: 91 33 2282 0090, Fax: 91 33 2282 1553	CCAP Ltd had shown their concern about the development of the project. They want to interact with the technologists in due course and study the feasibility and test reports.

7. **Jain Group of Industries**

Status of company	Feedback from company
Address: 39, Premlata, 5th Floor, Shakespeare Sarani, Circus Avenue, Kolkata - 700017 Ph: +(91)-(33)-40027777, Fax: +(91)-(33)-40027744 Email: career@jaingroup.co.in	**They were impressed and shown interest for implementation of the technology.**

8. **Larsen & Toubro**

Status of company	Feedback from company
Larsen & Toubro Limited (L&T) is a technology, engineering, construction and manufacturing company. It is one of the largest and most respected companies in India's private sector. Kolkata address: Duck Back Building,41 Theatre Road, Kolkata – 700 071, Tel: 033-4405 4100 Contact person: Mr. N Arunagiri	**L & T authority wishes to know more about the technology from the project team.**

9. **Bridge & Roof Company (India) Ltd** (A Govt. of India Enterprise)

Status of company	Feedback from company
Serving both Private and Public Sectors in India and Overseas utilizing most modern construction equipment, technology and high degree of expertise. Address: 5th Floor, Kankaria Centre 2/1, Russel Street, Kolkata – 700071, Tel : (033) 2217-4469 to 4473, 2217-4053/4054/4056, Fax : (033) 2217-2106 / 4519 E-Mail : bridge@cal2.vsnl.net.in, info@bridgeroof.co.in Contact person: Mr. Ansuman Bhattacharya, General Manager, Civil Design, E-mail: ansuman.bhattacharya@bridgeroof.co.in	**They are willing to know the details about the technology and want to further interact with IIT, Kharagpur.**

F.5. Industrial collaboration for product commercialization

F.5.1. Rural Concreting Company of Ghatal Pvt Ltd

Collaboration with precast pipe manufacturing company M/S Rural Concreting Company of Ghatal Pvt. Ltd., West Midnapur District, West Bengal has been developed by the PI of the project. This company has all facilities of manufacturing and testing of precast concrete pipes. IIT visited the company and fabricated a few jute fiber reinforced cement concrete pipes (viz., 1 and 2 feet diameter) in this unit with its mix design formulation and process. The fabricated pipes have been kept in a curing step and testing has been done. The projected result was achieved and the mix design has been optimized. This unit agreed to manufacture concrete pipes and paving tiles using the process know how. Successive tests on concrete pipes were incorporated in the factory using the infrastructure. A couple of field trials have been incorporated in the company.

F.5.2. H B Housing Industries

H B Housing Industries agreed to have successive trials of the concrete pole. Number of meetings between the Principal Investigator and the Co-PI and the director of the company Mr Sujit Kumar Bhakat resulted the trials. The test reports are about to get published. The director, Mr Bhakat allowed to have trials on the pole. H B Housing Industries have big set up for such trials and testing. It is hoped that optimal reports would be generated after such trials.

F.5.3. Bose Abasan Prakalpa

Bose Abasan Prakalpa specializes in the manufacturing of precast RCC products. Their precast concrete products are manufactured with modern equipments. Collaboration with Bose Abasan Prakalpa in Sadarghat, Midnapore worked out very well. Mr Chandan Bose, Director, Bose Abasan Prakalpa had couple of meetings with the PI and Co-PI that resulted trial under guidance of the IIT project team. A meeting with the District Magistrate of Paschim Medinipur had been organised and there was a good discussion towards a trial of a house applying the technology evolved by IIT, Kharagpur with the association of Bose Abasan Prakalpa.

Precast concrete is a product produced by casting concrete in a reusable mold or "form" which is then cured in a controlled environment, transported to the construction site and lifted into place. In contrast, standard concrete is poured into site-specific forms and cured on site. Thus precast concrete is cost effective without any doubt. Therefore, with the technology application of IIT should give additional features to the precast. The test results will be published in due course.

Precast concrete of Bose Abasan Prakalpa

F.6. Conclusions:

Market survey gave Roots Yards good airs to submit this report. It was an extensive survey with the civil construction and infrastructure companies, with the flyash bricks factories, with the precast poles factories, with precast pipe manufacturing companies. There have been good developments in the commercial trials in the pipe and electric poles. The infrastructure companies took interest to interact with IIT. Many such trials and interactions should carry on during the project life. It is hoped that this report would be helpful to proceed further towards commercial application of this technology and transfer of the same to the industries. Roots & Yards shall be happy to get associated with this and future projects with IIT and National Jute Board and deliver sincere services towards business.

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10. Indian Standard Code Of Practice For Preparation And Use Of Masonry Mortars (First Revision) Third Reprint February 1993 UDC 691-53 : 694kil-3
11. Approximate Analytical Solutions for Diagonal Reinforced timber-framed walls with fibre-plaster coating material. M. Premrov, P. Dobrila, B.S. Bedenik. Faculty of Civil Engineering, University Of Maribor, Smetanova 17, SI-2000 Maribor, Slovenia
12. Microstructural and Mechanical Behaviour of Polyamide. Fibre-Reinforced Plaster Composites. S. Eve, M. Gomina, A. Gmouh, A. Samdi, R. Moussa, G. Orange. Journal of the European Ceramic Society 22 (2002) 2269–2275. www.elsevier.com/locate/jeurceramsoc
13. Strengthening of Masonry Walls against Out-of-Plane Loads Using Fiber-Reinforced Polymer Reinforcement. Kiang Hwee Tan and M. K. H. Patoary. Journal of Composites for Construction ASCE / January/February 2004
14. Indian Standard Corrugated and Semi-Corrugated Asbestos Cement Sheets-Specification (Third Revision), Second Reprint November 1998, UDC 691.328.5415. Bureau of Indian Standards.
15. Indian Standard Asbestos Cement Flat Sheets Specification, (First Revision). UDC 691.328.5-415, Bureau of Indian Standards.

SECTION G

Patents and publications

G.1. Patents

1. Chemically modified jute fiber reinforced high strength concrete and process thereof. Chakraborty, S., Kundu, S.P., Roy, A., Basak, R.K., Sen, R., Basu Majumder, S., Adhikari, B. Patent file no: 425/KOL/2011.
2. Casting of concrete pipe reinforced with chemically modified jute fiber and method of casting such fiber reinforced concrete pipe. Kundu, S.P., Roy, A., Chakraborty, S., Basak, R.K., Sen, R., Basu Majumder, S., Adhikari, B. Patent file no: 426/KOL/2011.

G.2. Conferences

1. Processing and Fabrication of Chemically Modified Jute fiber Reinforced Cement Concrete Composite, 2010. Chakraborty, S., Kundu, S.P., Roy, A., Basak, R.K., Basu Majumder, S., Adhikari, B. National seminar on Recent Advances in Chemical Engineering (RACE 2010) in GIET Gunupur, Odisha.
2. Brain storming seminar on 'Jute fiber reinforced cement concrete composite', 8th June, 2011, Adhikari, B., Basu Majumder, S., Roy, A., Kundu, S.P, Chakraborty, S. National Institute of Research on Jute & Allied Fibre Technology (NIRJAFT), Kolkata, West Bengal.

G.3. Workshop

1. A workshop on 'Research and development focus on jute MM IV Projects', was organized by Departments of Civil and Mechanical Engineering and Materials Science Centre of Indian Institute of Technology Kharagpur. It was held on 21st December, 2009 at Gargi Hall, IIT Kharagpur, West Bengal. The presentation given by the Co-PI of this project, Prof. S. Basu Majumder, on the topic, 'Jute fiber reinforced cement concrete composites', received an overwhelming response. The delegates gave their valuable suggestions.

G.4. Papers

1. Statistical analysis of tensile strength of alkali treated jute fiber. Roy, A., Chakraborty, S., Kundu, S.P., Basak, R.K., Basu Majumder, S., Adhikari, B. (to be communicated)
2. A novel process to introduce hydrophilic jute fiber in cement mortar with improved physico-mechanical properties. Chakraborty, S., Kundu, S.P., Roy, A., Basak, R.K., Basu Majumder, S., Adhikari, B. (to be communicated)

3. Combined effect of polymer latex and jute fiber on the physico-mechanical properties of cement mortar. Chakraborty, S., Kundu, S.P., Roy, A., Basak, R.K., Basu Majumder, S., Adhikari, B. (to be communicated)
4. Alteration of cement setting and hydration in presence of jute. Chakraborty, S., Kundu, S.P., Roy, A., Basak, R.K., Basu Majumder, S., Adhikari, B. (under preparation)
5. Performance of chemically modified jute fiber as an effective reinforcement to cement concrete composites. Kundu, S.P., Roy, A., Chakraborty, S., Basak, R.K., Basu Majumder, S., Adhikari, B. (under preparation)
6. Fabrication and characterization of modified jute fiber reinforced concrete and precast concrete sewer pipe. Kundu, S.P., Chakraborty, S., Roy, A., Basak, R.K., Basu Majumder, S., Adhikari, B. (under preparation)

G.5. Cumulative Reports

Twelve cumulative reports and flier on the project ‘Development of jute fiber reinforced cement concrete composite’ were submitted during May, 2008 – March, 2011.