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Jute Fibre Reinforced Concrete Materials for Building Construction

Beton armé de fibres de jute pour la construction de logements

Mit Jutefasern bewehrter Beton als Baustoff für den Wohnungsbau

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SUMMARY
This paper reports the findings of an experimental investigation conducted on the engineering properties of jute fibre reinforced cement composites. Different lengths of fibres at varying volume fractions were used as reinforcement for cement based matrices to determine the mechanical, thermal and acoustic properties of the composites. The results of this investigation have shown the feasibility of using jute fibres for producing low-cost building materials.

RÉSUMÉ
Cette contribution décrit un projet de recherche sur les caractéristiques d'un béton armé de fibres de jute. L'influence de différentes longueurs des fibres et de différents pourcentages volumétriques sur les caractéristiques mécaniques, thermiques et acoustiques est étudiée. Les résultats ont mis en évidence que le béton armé de fibres de jute peut être utilisé avec succès comme matériau de construction pour de l'habitation bon marché.

ZUSAMMENFASSUNG
Dieser Beitrag beschreibt die Resultate eines Forschungsprojekts über die Eigenschaften von mit Jutefasern bewehrtem Beton. Der Einfluss von verschiedenen Längen der Jutefasern und unterschiedlicher Volumenanteile auf die Zementmatrix wurden untersucht und die mechanischen, thermischen und akustischen Eigenschaften bestimmt. Die Forschungsresultate haben gezeigt, dass der Einsatz von Beton mit Jutefasern als Baustoff für preisgünstige Wohnungen geeignet ist.

1. INTRODUCTION

In developing countries, there has been an acute shortage of cheap but durable building materials for the construction of low-cost housing. The use of jute fibre reinforced cement composites may offer a possible solution in this respect.

Jute is abundantly grown in Bangladesh, China, India, Indonesia and Thailand. It is extracted from a woody type of plant which grows to about 2 m high with a stem diameter ranging from 20 mm to 30 mm. Its bark consists of bundles of fibres running longitudinally down the stem. When harvested, the cut-stems are tied into bundles and kept submerged under water for 20 to 30 days. The tissues of the stems are then decomposed under bacterial action. The resulting soggy mass consisting of strands of overlapping fibres are then stripped off manually, washed in water and dried under the sun.

Jute fibre being cheap, strong and durable, is a prospective reinforcing material for cement-based matrices. Virtually, no studies have been carried out so far to utilize jute fibres for reinforcing concrete materials. This study was initiated to explore the feasibility of utilizing this indigenous fibre for producing fibrous composite in an attempt to solve, to some extent, the acute shortage of low-cost building materials in developing countries.

2. PROPERTIES OF JUTE FIBRES

Typical properties of jute fibres are given in Table 1 [1,2]. The basic requirements of any fibre for producing good quality fibrous concrete are high tensile strength, high elastic modulus, good bond at the fibre-matrix interface, adequate geometric stability, chemical resistance and durability.

Property	Range of values
Fibre length, mm	180 - 800
Fibre diameter, mm	0.10 - 0.20
Specific gravity	1.02 - 1.04
Bulk density, kg/m^3	120 - 140
Ultimate tensile strength, N/mm^2	250 - 350
Modulus of elasticity, kN/mm^2	26 - 32
Elongation at fracture, percent	2 - 3
Water absorption, percent	25 - 40

Table 1 Typical properties of jute fibres

3. PRODUCTION TECHNOLOGY

Uniform dispersion of fibres in a cementitious matrix distributes stresses and improves microcracking. Therefore, the fibres are to be distributed in such a way as to allow them to perform their desired functions and to achieve a composite action between the fibres and the matrix by ensuring adequate interfacial bond. It is well-established [2] that the most exploitable form of fibre-cement composites is to be made by using randomly distributed short discontinous fibres. It is usually possible to incorporate only a small volume of discrete fibres in the matrix, and also economic and other considerations dictate that the use of fibres be optimized. The optimum length and volume fraction of jute fibres are found to 25 mm and 3 percent, respectively [1].

3.1 Matrix Properties

Constituent materials of jute-fibre reinforced concrete (JFRC) are small-diameter discontinuous discrete fibres and a matrix of cement, aggregates, water and admixture (if there is any). The matrix binds the fibres together, protects them from environmental attack and takes part in transfer of stresses to and from fibres. In general, concrete matrices used with jute fibres should have a higher cement content, a lower coarse aggregate content and a relatively small size aggregates compared to conventional concretes. The dimensional stability of the matrix can be improved by adding various inert fillers and pulverized fuel-ash that modify the flow characteristics and other basic properties of the matrix [2].

3.2 Production Steps

The four major steps in the production of JFRC are fibre preparation, mixing of ingredients, placing and curing. The JFRC construction, unlike other sophisticated engineering constructions, requires a minimum of skilled labour and utilizes the readily available local materials. However, proper attention should be paid to the quality control of materials and construction.

4. FACTORS AFFECTING PROPERTIES

Properties of JFRC are affected by many factors, such as geometry, form and surface characteristics of fibres, properties of matrix, mix design, mixing and placing methods, and casting and curing techniques. In general, the mechanical, thermal and acoustic properties and durability of JFRC are functions of length, volume fraction, and aspect ratio of the fibres, properties of fibres and constituent materials, and casting pressure. Performance of JFRC, like any other material is very much influenced by the production process and quality control. As in conventional fibre reinforced concrete, the jute fibres act as crack-arresters that restrict the growth of flaws in the cement matrix. The uniform dispersion of fibres in the brittle matrix offers improvements in many of the engineering properties such as fracture, tensile and flexural strengths, toughness, fatigue and impact resistance of the composite.

4. EXPERIMENTAL INVESTIGATIONS

A series of tests was conducted to determine the mechanical, thermal and acoustic properties and also to study the durability of JFRC. Figs. 1 and 2 show the stress-strain behaviour in direct tension and load-deflection curves, respectively, of JFRC specimens [1]. Tables 3 and 4 provide quantitative information on the strength properties [1-3]. It can be observed that the inclusion of short randomly distributed fibres increases substantially the tensile, bending and impact strengths.

Mix proportion	Fibre length (mm)	Fibre volume fraction (%)	Tensile strength (N/mm^2)	Modulus of rupture (N/mm^2)	Modulus of elasticity (kN/mm^2)
1 : 0 : 0	25	2	2.36	4.14	10.80
1 : 1 : 0	25	2	2.39	4.50	16.40
1 : 2 : 0	25	2	2.24	3.92	16.00
1 : 1 : 0	38	2	2.30	4.20	17.20

Table 3 Strength properties of JFRC

Concrete type	Impact strength Nm/m^2
Plain concrete	5.80 - 6.30
Jute fibre reinforced concrete	
a. Using 38 mm long fibres	18.80 - 21.40
b. Using 25 mm long fibres	19.40 - 23.20
Mix proportion - 1:2:4, fibre volume fraction = 3 percent fibre length = 25 mm and 38 mm, curing period = 28 days	

Table 4 Impact strength of JFRC

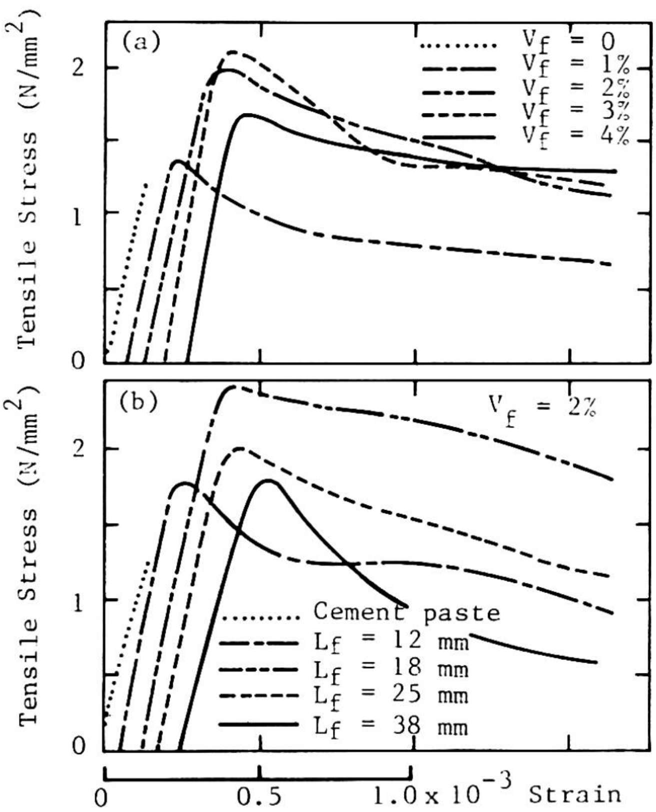

Fig. 1 Stress-strain behaviour of JFRC in direct tension

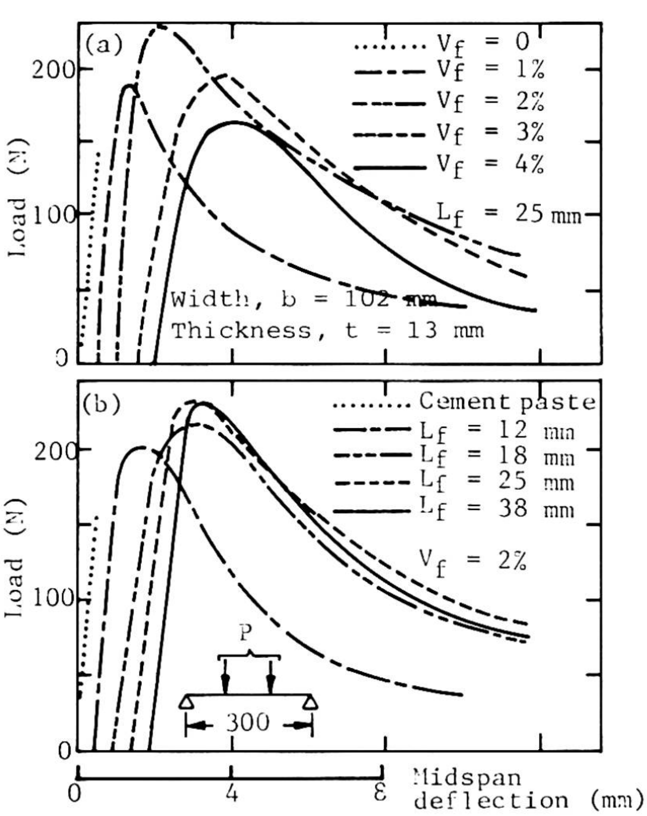

Fig. 2 Load-deflection curves of JFRC

Fibre type	Cement/sand ratio	Fibre volume fraction (%)	Fibre length (mm)	Slab thickness (mm)	Thermal conductivity (W/m^oK)
Jute fibre	1 : 0.5	2	25-38	25	0.61
		3	25-38	25	0.68

Table 5 Thermal conductivity of JFRC corrugated slabs

Volume Fraction	Thickness (mm)	Sound absorption coefficient (percent) at a frequency of					
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
3%	5	3.4	4.0	5.0	6.0	17.0	29.0
	10	4.5	6.7	5.6	7.0	22.4	42.6
	13	4.5	7.0	5.6	7.2	20.5	32.8
4%	5	5.2	8.5	6.0	9.2	15.2	46.0
	10	4.7	4.2	6.2	11.5	21.3	35.0
	13	4.7	4.5	5.3	7.7	24.6	26.0

Table 6 Sound absorption coefficient of JFRC

Properties	Asbestos cement plain roofing sheets	JFRC plain roofing sheets
1. Flexural strength, N/mm^2 (SFS* = 20)	17.80	18.50
2. Impermeability	excellent	excellent
3. Water adsorption, percent	20.60	16.50
4. Coefficient of thermal conductivity, W/m^oK	0.36	0.34
5. Sound transmission of 833 Hz signal, percent	26 (when dry) 40 (when wet)	24 (when dry) 35 (when wet)
6. Combustibility (BS 476-Part 4)	Non-combustible	Non-combustible
7. Linear expansion, percent	0.24	0.22
8. Density, kg/m^3	1,540	1,780

*SFS = specific surface area = surface area of fibre per unit surface area of sheet 6 mm thickness containing 1 kg cement = 20

Table 7 Comparison between the engineering properties of JFRC and asbestos cement plain roofing sheets [4]

Characteristics and properties	Asbestos cement corrugated roofing sheets	JFRC corrugated roofing sheets
1. Pitch of corrugation, mm	146	146
2. Depth of corrugation, mm	48	48
3. Length of sheets, m	1.5 - 3.0	1.5 - 3
4. Width of sheets, m	1.05	1.00
5. Weight, kg/m^2	13.5	11.8 - 12.57
6. Breaking load for a span of 60 cm, N/m	-	55
7. Breaking load at a span of 100 cm, N/m	50	30
8. Thermal conductivity, $kcal/cm/m^2$	0.24	0.14
9. Water permeability through finished surface in 24 hours	-	almost nil
10. Acid resistance as per I.S.:	9.30×10^3	9.40×10^3

Table 8 Comparison between the engineering properties of JFRC and asbestos cement corrugated roofing sheets

Tables 5 and 6 show the thermal conductivity and sound absorption coefficient of JFRC corrugated slabs, respectively. These values compare very well with those of asbestos cement boards and sheets as shown in Tables 7 and 8.

5. DISCUSSION OF PROPERTIES

JFRC behaves as a homogeneous material within certain limits. The random distribution and high surface-to-volume ratio (specific surface) of the fibres results in a better crack-arresting mechanism. With low fibre contents that are normally used in cement composites (from 2 to 4% by volume), the strain at which the matrix cracks is little different from that of plain concretes. However, once cracking occurs, the fibres act as crack-arresters, and absorb a significant amount of energy as they are pulled out from the matrix without breaking. These properties are useful in precast industry where accidental damage from impact creates large waste. The inclusion of short jute fibres in cement-based matrices, nevertheless, increases the first crack strength and once the matrix has cracked, the fibres carry a major portion of the tensile stress in the composite material.

Besides its ability to sustain load, JFRC is also required to be sufficiently durable. To ensure durability, care should be taken to select suitable constituent materials in appropriate proportions and good quality jute fibres of specified length and volume fraction for producing a homogeneous and fully compacted mass. Poor dimensional stability of jute fibres due to moisture changes gives rise to durability problems and various protective treatments have been found to improve the situation [4]. The embrittlement of jute-fibre reinforced building materials has been observed in some applications [2,4]. The reason for such embrittlement has been found to be the alkaline pore-water in the composite which dissolves the fibre component. This can be counteracted by replacing 40 to 50% of the cement content by silica fume. The use of high alumina cement also reduces the alkalinity and thus slows down the rate of embrittlement. Sealing the pores with wax or resin, or use of suitable impregnating agents have also been observed to reduce embrittlement to a satisfactory level [4].

The performance properties like permeability, water absorption, thermal expansion, and shrinkage usually vary with fibre concentration [3,4]. These can be significantly reduced by coating the surfaces with suitable paints or by using suitable admixtures.

6. APPLICATIONS

JFRC products like sheets (both plain and corrugated) and boards are light in weight and are ideal for use as roofing and ceiling, and as wall panels for the construction of low-cost housing. Their special usages include applications where energy absorption is the primary requirement or where impact damage is likely to occur such as shatter and earthquake resistant construction. Other conventional applications include rafts and beams for cellular foundation, pavements, slabs and various types of shell structures. All potential applications of JFRC depend, of course, on the ingenuity of the designers and the builders taking advantage of the static and dynamic strength parameters, energy-absorbing characteristics, material performance properties, acoustic and thermal behaviour.

7. CONCLUSIONS

Use of JFRC may help to a great extent in providing low-cost housing in the countries of the Asia-Pacific region like Bangladesh, China, India, Indonesia and Thailand where jute fibres are abundantly available. It requires only a low degree of mechanisation and a small number of trained workers. The use of such building materials is particularly atractive to these countries because of their shortage of capital and skilled manpower. This will also avoid draining of hard-earned foreign exchange and alleviate unemployment problems.

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