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Development of Coir-Fibre Cement Composite Roofing Tiles

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Abstract

In order to optimize the cost of construction, engineers have always been on the lookout for efficient and light roofing which requires minimum maintenance and labor to install. Coir is a green building material and has potential as a raw material for the production of roofing materials like corrugated sheets and tiles. The main objective of the paper is to produce cost effective roofing tiles without compromising their quality by replacing cement up to 15% using coir fibre. On the basis of the results, a composite with a fibre volume of 10% was considered to be the optimum composite. A comparison of material costs indicated that this composite tile was substantially cheaper than the ordinary cement concrete tile.

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1. Introduction

In almost all developing countries, there is a great shortage of roofing material. Local materials are often used, like soil, stone, grass and palm leaves. These roofs require a lot of maintenance and are not always resistant to heavy rain. Materials like Corrugated Iron Sheets (CIS) and asbestos cement sheets have replaced traditional materials.

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Roofing materials tend to be the biggest expense for individual home builders.

The disadvantages of CIS roofs in tropical areas are that they give a poor indoor climate and make a lot of noise when it rains. They also require a lot of energy to produce. Asbestos cement sheets should not even be considered, because of the health hazard associated with making them. Ceramic tile roofs are good. However, if the kiln does not allow adequate temperature control during firing, the quality of the finished tiles can be very much uneven. Concrete tiles have partially replaced ceramic tiles for purely economic reasons but what limits the use of concrete tiles is their weight on the roof, which requires a strong load bearing structure. Therefore, changing an existing system of roof also requires strengthening of the roof framework. They can be made lightweight by incorporating natural fibres into its composite matrix.

Coir fibre is one of the natural fibres abundantly available in tropical regions, and is extracted from the husk of coconut fruit. Coir is stiff coarse fibre and is being found between the husk and the outer shell of a coconut. It is a fibre abundantly available in India the second highest in the world after Philippines. The individual fibre cells are narrow and hollow, with thick wall made of cellulose. There are two varieties of coir; (i) brown coir extracted from a varieties ripe coconut which contains more lignin and less cellulose and are stronger but less flexible. (ii) White coir extracted from coconut before they are ripe, which are white or light brown in colour and are smoother and finer, but also weaker. There are many general advantages of coconut fibres e.g. they are moth-proof, resistant to fungi and rot, provide excellent insulation against temperature and sound, not easily combustible, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, springs back to shape even after constant use, totally static free and easy to clean.

Owing to these general advantages and the rich availability of the material in the South Indian tropics, Coir has found desirable applications in the field of construction with the advent of light-weight concrete technology. The cheap availability of the raw material can also reduce the production costs and hence the housing expenditure on roofing, which is otherwise the most expensive part in building construction, can be considerably truncated. The main objectives of the study are to develop coir fibre reinforced cement concrete roof tiles and to seek its pros and cons as a roofing material based on standard specifications. The structural behaviour and strength characteristic of coir fibre reinforced tile were compared with Cement Concrete roofing tiles. Main objectives of the present study are

- To develop lightweight concrete roofing tiles with coir reinforced cement concrete composite.
- To study the strength and behaviour of these tiles relative to the Cement Concrete roofing tiles.

2. Previous studies on coconut fibre reinforced composites

Cook et.al. (1978) [3] reported the use of randomly distributed coir fibre reinforced cement composites as low cost materials for roofing sheets. The studied parameters were fibre lengths, fibre volumes and casting pressure. They concluded that the optimum composite was a composite with a fibre length of 3.75 cm, a fibre volume fraction of 7.5 % and cast at a pressure of 1.67 MPa. Cost comparison revealed that this composite was substantially cheaper than the locally available roofing materials.

Research output of Ramaswamy et.al. (1983)[9] revels that, natural fibres such as jute, coir and bamboo can be used with advantage in concrete, in a manner similar to other fibres. It was also observed that, improvement in impact strength of over 25% and increased ductility under static loading and considerably lower shrinkage characteristics of the order of 50% to 70% compared to those of plain concrete, are obtained when natural fibres are added.

Bo Johansson (1995)[5] has presented a simple method to produce a roofing material with cement as the binding agent. Ramakrishna et.al. (2005)[8] studied the durability of natural fibres and the effect of corroded fibres on the strength of mortar. Coir fibres were found to retain higher percentages of their initial strength than all other fibres after the specified exposure in the various mediums.

Peñamora, et.al. (2005)[7] explains the manufacturing process of Coir Fibre Cement Boards (CFB) created from a mix of cement and coir fibre in 70:30 ratio. Fibres are extracted from husks, soaked in water, mixed and blended with pre-weighed cement, pressed and finally trimmed before drying and conditioning. They also illustrated its application in wall panel, roofing, flooring, partitioning and formwork systems. Mohd Hisbany Bin Mohd Hashim (2005)[11] did an experimental study to develop a new material for wall boards in a composite of cement, gypsum and coconut fiber as reinforcement. An experimental study was conducted by Li et.al. (2006)[12] on coir mesh reinforced mortar (CMRM) using non-woven coir mesh matting. The results indicate that the addition of coir mesh to mortar significantly improves the composite post-cracking flexural stress, toughness, ductility, and toughness index, compared to plain mortar materials.

Asasutjarit et.al. (2007)[2] studied the properties of panels strengthened with treated coir fibres. It was observed that the treatments (immersion in cold and hot water) increased the efficiency of coir fibres as a compound strengthening, increasing the interfacial adherence between the coir and the matrix.

Indian Coir, a Reference Book by the Coir Board (2007)[4] gives the details of coir, coir products and coir composites. It lists out the physical properties of coir, pointing out that coir composites are antifungal and termite-resistant. Coir-Cement, Coir-Veneer, Rubberized Coir, Coir-Gypsum Board and Coir-Husk composites, their structural and mechanical properties are also given in detail. Development of coir-cement composite panels, blocks, sheets and flooring tiles is also explained.

Sivaraja.M. et al. (2009)[10] studied the durability of natural fibre concrete composites using mechanical strength and micro structural properties and concluded that, natural fibres enhance the strength and flexural performance of concrete. The effect of curing ages on mechanical properties such as compressive strength, split tensile strength, modulus of rupture , flexural performance and micro structural properties have been ascertained and discussed through this paper. It was found that, at all the curing ages, both the natural fibres such as coir and sugarcane fibres enhance all the three mechanical strength properties such as compressive strength, split tensile strength, modulus of rupture and flexural performance. Though the natural fibres enhance the strength properties at earlier curing ages, the rate of increments are lower than conventional concrete specimen at later curing. Ali (2010)[6] studies the versatility of coconut fibres in civil engineering as a construction material. They are reported to be ductile and energy absorbent material and also have the potential to be used in composites for different purposes and as reinforcement in composites for non-structural components. Cost comparison revealed that this composite was substantially cheaper than the locally available roofing materials.

Abdullah et.al. (2011)[1] reports the effect of natural fibre content on the physical and mechanical properties as well as fracture behaviour of composite cement reinforced with coconut fibre. It was observed that the composite reinforced with 9 wt. % of coconut fibre demonstrated the highest strength of modulus of rupture and compressive strength. Indian Plywood Industries Research & Training Institute and Coir Board, Bangalore explains the procedure adopted for treated coir sheets. The basic steps involved are procuring the coir felt, dimensioning the coir fibres, compressing the fibres, application of preservative and bonding resins, stabilization and drying coir mats, hot pressing them to make hard sheets and finishing of the sheets.

3. Methodology

After selecting suitable materials like cement, sand and coir fibres , material properties were determined. In order to replace cement with coir fibre, initial studies were conducted to finalise the % replacement of cement with fibres. After finalising the same, tile specimens were prepared using specially prepared mould. Accelerated curing was given to the specimens using oven. Tests were conducted as per Indian Standard specification for tiles.

4. Material properties

Details of materials used for the preparations of the roofing tiles are discussed in the following sections.

4.1 *Cement*

Portland Pazolona cement was used throughout the experimental programme. The different laboratory tests were conducted as per IS 4031:1991 to determine the properties of the cement used. The obtained properties of cement are shown in Table 1. The properties of cement conform to the IS 1489(Part 1):1991 specifications.

Table 1.Properties of ppc

Property	Value
Standard Consistency of Cement	**35%**
Compressive strength at 7 Days	32.80 MPa
Compressive strength at 28 days	45.50 MPa

4.2 *Fine aggregate*

Manufactured sand (Fig. 1 (a)) passing through 4.75mm IS sieve was used for the study. The different tests as per IS 2386:1963 (Part III) were conducted on fine aggregate. The properties of fine aggregates are given in the Table 2. The particle size distribution curve for fine aggregate is shown in Fig 1(b). The properties of fine aggregates conforms to the IS 2386:1963 Specifications.

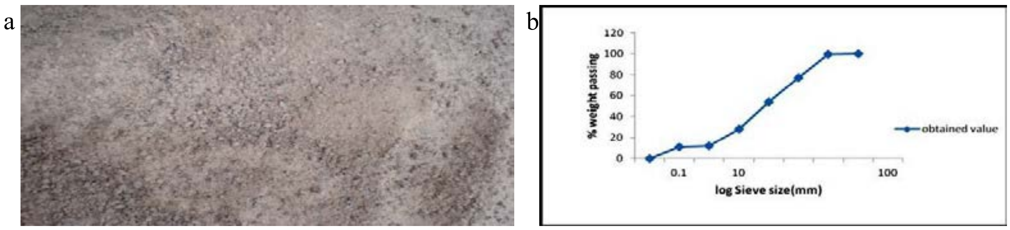

Fig 1. (a) Manufactured Sand used in the study (b) Grading curve of fine aggregate

Table 2. Properties of fine aggregate

Property	Value	Recommended Value (for river sand)
Sieve Analysis	Grading zone I	Zone I, Zone II, Zone III
Bulk density	1.82 g/cc	1.42 g/cc-1.65 g/cc
Specific Gravity	2.20	2.5-2.66
Porosity	17.3%	-
Void ratio	0.21	-
Fineness Modulus	3.16	2-3.5

4.3 *Coir fibre*

Processed coir yarns are cut to fibres (Fig.2) of length 1 inch (25 mm approx.) and diameter of the order of a few micrometers were used .

Fig. 2 Coir fibre used in the study

5 . Experimental Investigation

5.1 *Preparation of cube specimen*

A mix proportion of 1:4 was selected for the experimental study. Based on previous studies, proportions of coir considered for replacement of cement were 10% and 15% by weight of cement.15% mix resulted in a harsh mix where as the 10% mix produced satisfactory results. Hence the mix was selected with cement mortar of 1:4 with 10% replacement of coir fibre and water cement ratio of 0.6(CF 10). Cube specimens were prepared and 7 day and 28day compressive test was done. Test results shown in Table 3 show that results are comparable with that of control specimen (CF0).

Table 3. Compressive strength test results

Specimen Details	Average Compressive Strength (in MPa)	
	7 day	28 day
Control Specimen, CF0	31.06	42.30
CF10	29.10	40.10
CF15	23.40	28.80

5.2 *Casting of tile specimen*

Tile specimen moulds of size 320mm x 280mm x 15mm (Fig.3 (a)) were manufactured for the preparation of tiles. The prepared mould with cover is shown in Fig 3 (b). Five such moulds were manufactured for the study.

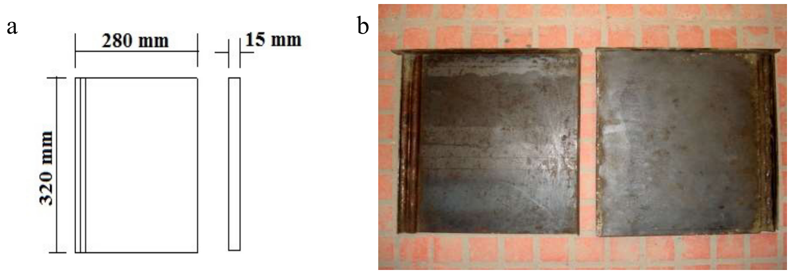

Fig. 4 (a) Tile Specimen dimensions,(b)Tile Moulds with cover

The required quantity of cement, fine aggregate, coir fibres (10% replacement of cement) and water were weighed and a cement composite mix was prepared. The mixing was continued until a uniform mix of required consistency was obtained. The mix was then filled in the prepared moulds after placing a plastic sheet on the mould for easy demoulding. A table vibrator (Fig. 4) was used to compact the mix within the mould. After compacting, the mould cover was removed carefully and the top surface was levelled using a trowel, whenever necessary. Then the specimens were kept undisturbed for 24 hours.

Fig 5. Tile under Vibration

5.3 *Curing of specimens*

After 24 hours, the moulds were stripped off and the specimens were kept in a chamber (hot air oven) at 45^0 C to accelerate curing as shown in Fig 6 . The specimens were cured for 5 days. While curing, the tiles should not be allowed to dry out and hence, moisture was applied on the surfaces of the tiles on each day.

Fig. 6. Specimens in hot air oven for dry (or temperature) curing

5.4 *Testing of specimens*

Strength parameters were tested against the standard specifications given by IS 654:1992 (tests on Mangalore Pattern Tiles). Following are the details of the tests(Stress controlled) conducted: The paper presents the results of preliminary investigation. Durability studies were not conducted. From literature[13]it is known that the presence of lignin and hemicelluloses coir fibres are found to retain around 40-60% of their tensile strength when subjected to alternate wetting and drying . These tiles are better suitable as floor tiles.

5.4.1 *Water absorption test:*

The test specimen were dried in an oven at a temperature of about 105-110 C prior to the test. Dry weights were measured after atmospheric cooling and were immersed in clean water at room temperature (24-30ºC) for about 24 hrs (Fig 7). The specimen was then removed from water and surface dried and weighed. The increase in weight with respect to the original dry weight was taken as the water absorption for that sample. Mean water absorption of the three samples was taken as the water absorption of the prepared mix. A sample set of results obtained is given in table IV. IS specifications for MP tiles advocates that its water absorption should not be more than 18% (for class AA) and 20% (for class A) of its weight. As per Peñamora and Melencion.[7] a cement concrete tile should not absorb more water than 6% of its dry weight during 24 hrs in a water bath. A slightly higher value of water absorption% is mainly due to the presence of coir fibres

Fig 7 .Specimens in water for water absorption test

Table 4. Test results of water absorption

Dry weight	2.525 kg
Wet weight	2.683 kg
% Water absorption	6.25 %

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5.4.2 *Breaking Load test:*

Three tiles were tested after soaking them in water at 27^0 C for 24 hrs in the wet condition using 30 T- UTM. The tiles were placed evenly flat-wise on the bearers set with a span of 27 cm, resting on the bottom surface (Fig 8). The load was applied in a direction perpendicular to the span, at a uniform rate of 450 to 550 N/min.

Fig. 8. Testing of specimen in UTM

The individual breaking load of the three tiles was recorded in wet condition separately and the average was taken as the load carrying capacity. Test results are shown in Table 5. Tests are also conducted to find the strength of temperature cured specimen. As per literature, the required bending strength is an average load of at least 60kg for the five tiles, and a minimum load of 50kg for any single tile. During testing it was observed that tiles with coir fibres exhibit better ductility comparing with those of ordinary concrete tile. Also the load carrying capacity was increased by 25%. This increased strength can only be substantiated as due to the reinforcing material(coir) used here which will act as crack arresters.

Table 5 sample test results for breaking load

Specimen details	Average Breaking Load (in kg)
CF0	48
CF10	60

5.4.3 *Permeability test:*

Permeability test was conducted as per the procedure given in [3]. The test was conducted in a rectangular trough, open at the bottom, the dimensions being equal to the size of tile under test. The tile was fitted at the bottom of the trough and the space between the tile and the sides of the trough were plugged water-tight with a suitable material like wax, bitumen, etc. Water was poured into the mould so that it stands over the lowest tile surface to a height of 5 cm. The water in the trough was allowed to stand for a period of 24 hours. The bottom of the tile was carefully examined to see whether the water has seeped through the tile. The experimental set up is shown in Fig 9.

In the study, three specimens were tested and two of them showed a little dampness at the bottom. The water absorbent behaviour of the tile, attributed to the presence of coir fibres in it. The same test was carried out by coating the tiles with cement mortar. It was observed that the tile does not indicate any dampness.

Fig. 9. Permeability test

6. Cost estimation

The cost estimation of the Tile is given in Table 6. Approximate cost for one Mangalore Pattern tile is Rs. 30 and that of a Cement Concrete tile ranges within Rs.60-90 for various sizes. Only the cost of replaced cement could be saved here. When process gets mechanized, percentage coir fraction can be increased and hence more savings.can be ensured.

Table 6 estimation of the project

Sl No.	Materials	Quantity (for 100 tiles)	Rate (Rs)	Amount (Rs)
1.	CEMENT	59.4Kg	340/Bag	403.93
2.	COIR	6.6Kg	150/Kg	990.00
3.	M-SAND	240Kg	2/Kg	480.00
4.	LABOUR			2000.00
		For 100 tiles		3873.93
		For 1 tile		**38.74**

7. **Conclusion**

- An eco-friendly product was developed using locally available material.
- In the present study, only 10% replacement of cement was possible. But the percentage can be increased with mechanization of the manufacturing process.
- Addition of more fibres will result in reduction in self-weight and cost.
- Properties like breaking load and ductility were improved with the addition of fibres. From the difference in cracking pattern of tiles which used coir fibre and those without coir fibre it was observed that the cracks are more sharp in the latter. This can be justified because of the presence coir fibres in the roofing tile it has shown a cracking pattern with less sharpness and this physical observation lead to this conclusion

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