ENGINEER - Vol. XXXIX, No. 03, pp. 35-41,2006

Engineering Properties of Micro Concrete Roofing Tiles

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Abstract: There are several types of roofing material available in Sri Lanka such as clay tiles, cement fiber sheets, zinc aluminium sheets and mortar tiles. Since there is an increase in demand for housing, it is desirable to have alternative roofing materials in order to produce better selection for the construction industry. One such roofing material is a Micro Concrete Roofing (MCR) tile. Although this tile has been introduced to Sri Lanka some time ago, this has not been very popular among house builders. Therefore a comprehensive study was carried out on strength and durability aspects of MCR tiles. The results of the detailed experimental research together with the cost study have shown that MCR tiles can be used as a roofing material with much confidence. This study also revealed that the performance of MCR tiles is comparable with conventional roofing materials.

Keywords: Roofing, Micro concrete tiles

1. Introduction

Roofing materials play a vital role in house construction. Many types of roofing materials are used in different parts of the world [1]. Calicut clay tiles and cement fibre sheets are commonly used roofing materials in the Sri Lankan building industry where high demand has caused over exploitation of natural resources.

When the conventional roofing materials are concerned, flat clay tile is very popular among the builders. It is the most popular shape of the clay tiles, which is also called 'Calicut tile', 'Mangalore tile', or 'French tile' [2] [3]. The other popular roofing material in Sri Lanka is Cement fibre sheets.

In addition to the manufacturing and construction cost, there is an environmental cost associated with all building materials. This may be in the form of over exploitation of natural resources and environmental problems associated with the production process.

If there is a high demand for any material, the cost to the environment will also go up. In order to ease the burden on conventional materials due to high demand, there is a timely need to investigate the performance of alternative roofing materials. One such material is Micro Concrete Roofing (MCR) tiles which can be manufactured with a chip concrete mix. The raw materials used to manufacture these tiles are cement, quarry dust and chips. Quarry dust and chips are by products of the metal crushing industry. This paper describes a detailed investigation carried out on MCR tiles in order to determine the overall performance as a roofing material. The strength and durability testing have given very satisfactory results which help engineers and architects to recommend this tile with much confidence.

The roof construction costs at least 20% of the total cost of a house [1]. Therefore, a detailed cost study was carried out to compare the MCR tiles with other roofing materials. It revealed that the cost of MCR tiles is comparable with the other roofing materials.

The roof contributes a lot to the aesthetics of any building. Therefore, the recommended roofing angle is very important for the building planners. With water spray testing, a suitable range for the roof slopes was also determined for the MCR tiles.

The weight of the entire roof structure is a significant factor for structural engineers. This study has shown that a MCR tiled roof would have a weight comparable with that of a Calicut tiled roof.

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2. Objectives

The objectives are to investigate the strength, durability and cost aspects of MCR tiles and to suggest improvements to meet comparable performance with the conventional roofing materials.

3. Methodology

In order to achieve the above objectives, the following methodology was adopted:

1. Investigation of the manufacturing process and mix proportions used.
2. Strength testing was conducted on a selected sample according to SLS9: Part 2: 2001[4] and SLS 1189: Part 2:1999 [5].
3. A model roof was constructed and subjected to an imposed load test and a water spray test according to the accepted standards.
4. A detailed cost study was carried out and the cost of MCR tiles was compared with that of conventional roofing materials.

4. Manufacturing process of MCR tiles

The raw materials used to produce MCR tiles are cement, sand (or quarry dust) and 4 - 6 mm chips (small aggregates). The chip concrete mix of 1: 1: 1.5 cement, sand (or quarry dust) and chips gives a good combination of raw materials which is easy to mould since it retains the shape at the wet stage [6]. The thickness of the tile is 8 mm or 10 mm depending on the strength required. The experimental study was conducted with 8 mm tiles manufactured with 1 cement, 1 quarry dust and 1.5 chips. The raw materials are mixed in a mechanical mixer until a uniform colour is obtained and water is mixed with the raw materials until it obtains a uniform consistency. A plastic sheet is placed on the vibrating table and the chip concrete mix is spread on it. Then the mix is vibrated for about 30 seconds. The green mix is carefully moved on to a mould so that it takes the corrugated or ridge tile shape of the mould. Then the mould is stacked for 24 hours. Thereafter the tile is removed from the mould and stacked vertically in a water tank. Curing should be done continuously for 7 days. Figure 1 shows the shape and dimensions of the MCR tile used for testing.

5. Experimental Programme

Randomly selected tile samples were tested in the laboratory to determine the strength and durability aspects of MCR tiles. This included spray test, water absorption test, imposed load test, and impact load test. All the tests were conducted according to the accepted Sri Lankan standards for roofing materials.

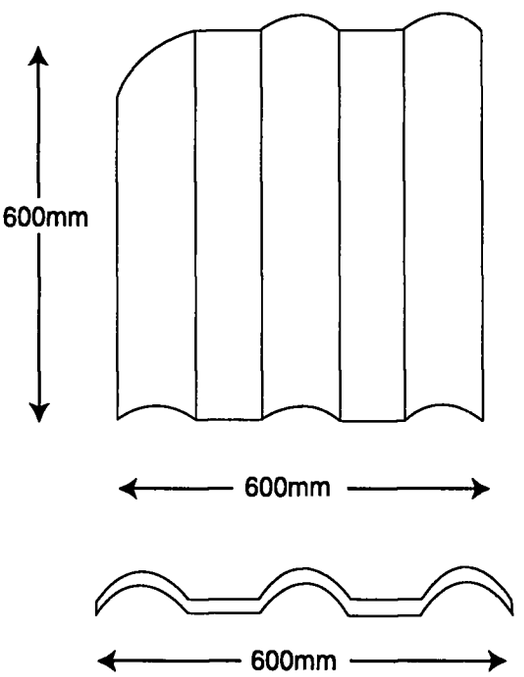
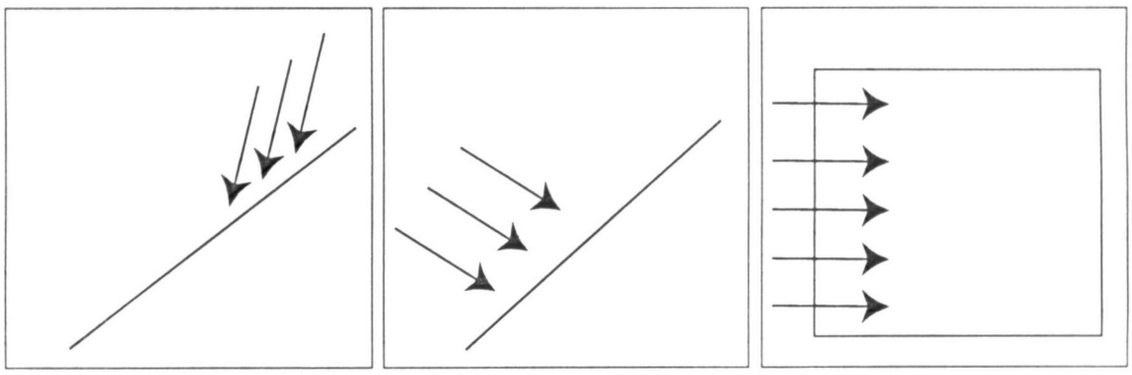


Figure 1: Dimensions of the MCR tile

5.1 Water spray test

It is important to see whether these tiles can provide resistance against heavy rains experienced Sri Lanka. It is essential to make the roof leak-free so that occupants will not have any problem during the life span of the building. This was conducted according to SLS 1189: Part 2: 1999 [5] and water was sprayed to the roof in three different directions. A high-pressure water jet was used to simulate the heavy rain conditions and applied on a model roof with different roof angles. Figures 2a and 2b show the directions of water spray applied. Roof angles and the results obtained are given in Table 1. The roof angle was varied from 14^0 to 25^0 and it was found that roof angles beyond 22^0 can give better results. Therefore, it is recommended to use a roofing angle of 22^0 and above.



DIRECTION 1 DIRECTION 2 DIRECTION 3
(Water spray from the front)

Figure 2a: Directions of water spray application

Table 1: Results of the spray test

Roof angle	Direction 1	Direction 2	Direction 3
14°	X	X	X
17°	√	X	X
20°	√	X	√
22.5°	√	√	√
25°	√	√	√

Note: '√' - No water spray resulted 'X' - water spray resulted

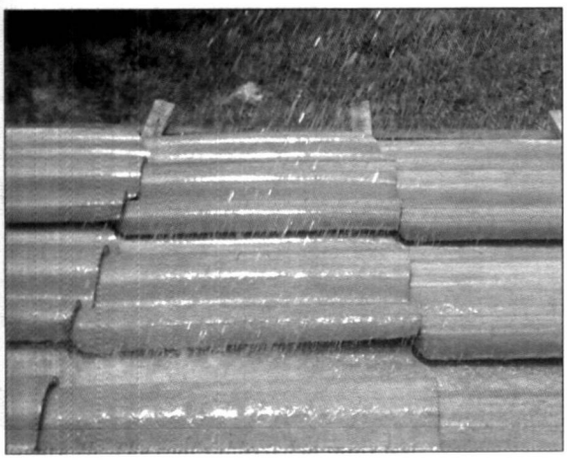


Figure 2b: The roof subjected to spray test

5.2 Imposed load test

A model roof constructed with MCR tiles was tested for an imposed load simulating a person attending to any maintenance work on the roof.

In the model roof, a rafter (50 mm x 100 mm) at a spacing of 600 mm and a reeper (50 mm x 25 mm) at a spacing of 475 mm were used. For this test a person weighing 70 kg walked on the roof. As a safety precaution the model roof was constructed very close to the ground level so that any chances of the person suffering injuries, in case of damage to the test roof, could be minimized. Figure 3 shows how the imposed load was applied. This gave very satisfactory results, which confirmed that the selected rafter and reeper spacings are adequate.

Figure 3: The roof subjected to Imposed load test

5.3 Impact load test

This test was carried out for a sample of MCR tiles according to SLS 9: Part 2: 2001 and SLS 1189: Part 2: 1999 [4], [5]. This test is important to determine the maximum load carrying capacity of the tiles.

The tile under test was placed on two transverse rigid flat parallel supports with the top surface upwards. A strip of expanded polystyrene was inserted in the gaps between the tile and the supports.

Although the spacing recommended for cement fibre sheets in SLS 9: part 2: 2001 is 1100 mm, a spacing of 482 mm was used, as the tile is only 600 mm in length. The loading bar was placed on the tile at mid span. Loads were applied at the rate of 10 kg (sand bags) until the failure point was reached. The testing arrangement is shown in Figure 4. Three tiles were tested in each batch. Table 2 shows the results of impact load test. The average breaking load can be taken as 450 kg (some tiles exceeded 450 kg).

Table 2: Impact load test results

Tile	Breaking load
Sample A	> 450 kg
Sample B	> 450 kg
Sample C	430 kg

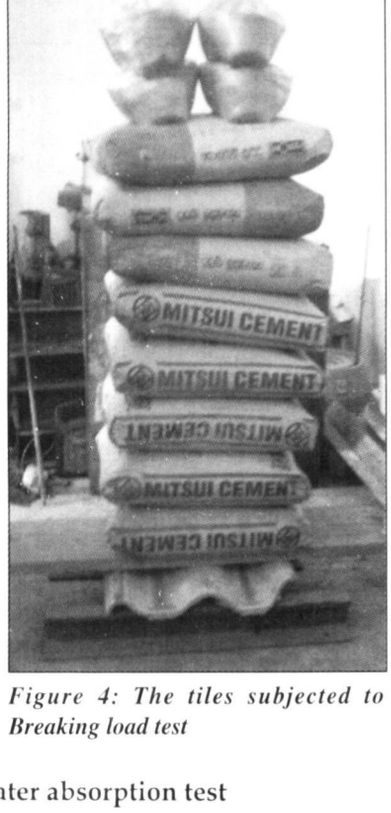


Figure 4: The tiles subjected to Breaking load test

5.4 Water absorption test

A randomly selected sample of tiles was used for the water absorption test. Firstly, the tiles separated from each other by at least 25 mm, using wooden bars were placed in an oven. This would allow proper heating. Tiles were kept in the oven for 24 hours, and cooled at room temperature for another 24 hours. Then the tile weight was noted. This is the dry weight of the tile (M_1) [5]. Then the tiles were placed in soaking trays with the top surface downwards, and water was poured into the tray so that the water level was 5 mm above the top surface of the tile as shown in Figure 5. The tiles were left in the water for 24 hours. Then the tiles were removed from water and the surface was wiped with a cloth. Then each tile was weighed and the wet weight was recorded (M_2). The water absorbed by the face of each tile is given by $(M_2 - M_1)/A$, where A is the area of the tile face in m^2. Table 3 gives the results of the test and the average value of water absorption is found to be 7.5 kg/m^2. This is much less than the permitted value given in the accepted Standard [7].

5.5 Total water absorption test

A sample of tiles was dried and cooled as explained in Section 5.4. Then the tiles were immersed in water so that their faces are parallel to the surface of water [5]. Thereafter the tiles were kept under water for a period of 24 hours as shown in Figure 6. Then the surface water was removed by using a wet cloth. Then the wet weight of each tile was recorded (M_3). The total water absorption by each tile is given by $(M_3 - M_1) / M1 \cdot 100$ [7]). The results are given in Table 4. The average total water absorption is 8.63 %. The permitted water absorption stated in the Standards is 28% [5]. Hence the water absorption of MCR tiles is at a satisfactory level.

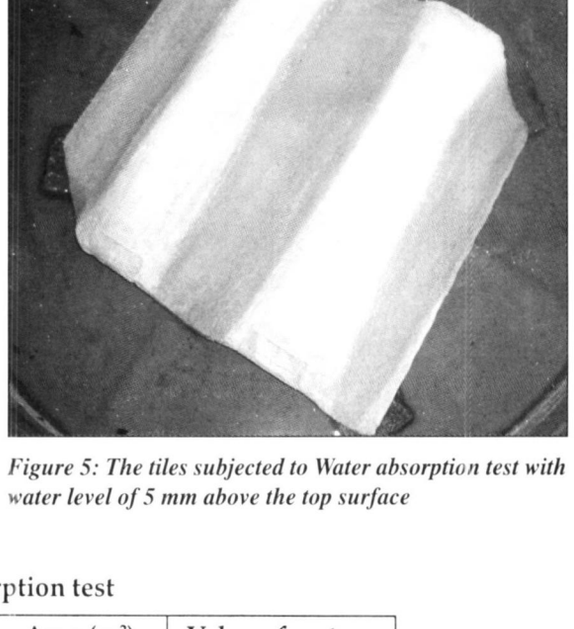


Figure 5: The tiles subjected to Water absorption test with water level of 5 mm above the top surface

Table 3: Results of surface water absorption test

Tile	Dry mass (kg) M_1	Wet mass (kg) M_2	Area (m^2) A	Value of water absorption = (M_2 – M_1)/A
A	11.60	12.25	0.1125	5.78
B	11.40	11.85	0.1006	10.33
C	11.20	11.75	0. 0847	6.49

Table 4: Results of total water absorption test

Tile	Dry mass (kg) M_1	Wet mass (kg) M_3	Total absorption of water $(M_3-M_1)/M_1$ (%)
A	11.60	12.50	7.76
B	11.40	12.45	9.21
C	11.20	12.20	8.93

5.6 Comparison of roof weight of MCR tiles with other roofing materials

Roof weight is one of the main contributory factors for the total load of the structure. Therefore when an alternative material is introduced, it is important to compare the weight of such material with commonly used roofing materials.

The weight of the roof is taken by considering the covering material and the framework together. The MCR roof weight is compared with Cement fibre sheets and Calicut tile roof in Table 5. Roof area of 1 m2 is considered in the calculations.

The roof weight comes to the same value as that of the Calicut tiled roof. Therefore MCR tile is a comparable material with conventional roofing materials when the structural weight is concerned.

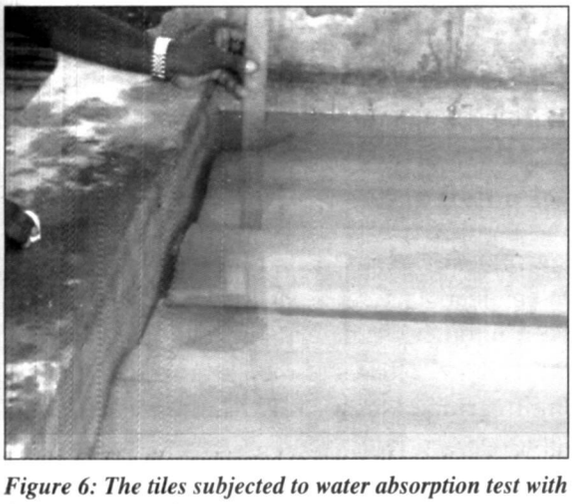


Figure 6: The tiles subjected to water absorption test with fully immersed tile

6. Cost Study

The cost study was conducted using material cost evaluation and a work study (labour cost). In addition to the tile production cost and framework cost, it is necessary to take the energy cost into account. In clay tile production, the burning process needs a temperature inside the kiln approximately in the range of 650 to 850^0 C. Burning process takes nearly a week and consumes about 60 cubic yards of fire-wood to produce about 11,000 to 15,000 tiles at a time [8]. For the MCR tile production, energy is consumed to produce the ingredients and electrical energy is used to vibrate the chip concrete mix. A major portion of energy is utilized in the cement manufacturing. A comparison of embodied energy of different roofing materials is currently in progress and will be published in a separate paper.

6.1 Material requirement

The weight of a tile is about 11.4 kg. When the density of chip concrete is considered as 2300 kg/m^3, this gives a volume of 4.96x10-3 m^3. Thus the volume of each constituent material can be determined using the following typical values for densities.

Bulk density of cement = 1450 kg/m^3
Solid density of cement = 3150 kg/m^3
Bulk density of aggregate = 1700 kg/m^3
Solid density of aggregate = 2600 kg/m^3

For the mix of 1:1:1.5 cement, quarry dust and chips, the material quantities are given in Table 6.

Table 5: Weight of different roofing materials

Material	50x100 mm rafter spacing	50x50 mm purlin spacing	50x 25 mm reeper spacing	Weight of frame work /m^2	Weight of covering /m^2	Total weight / m^2
MCR	600	–	475	11.36	45.60	56.96
Cement fibre sheets	750	1200	–	9.34	13.00	22.34
Calicut tiles	500	–	300	14.90	40.50	55.40

Table 6: The material requirement

	Bulk volume (m^3)	Solid volume (m^3)
Cement	50/1450=0.0345	50/3150=0.0158
Quarry dust	1x 0.0345=0.0345	0.0345x1700/2600 = 0.022
Chips	1.5x0.0345 = 0.05175	0.05175x1700/2600 = 0.0338
Water w/c = 0.5	25/1000=0.025	0.0250
Total		0.0966

Total solid volume (for one bag of cement) is 0.0966m^3. Assuming the price of cement as Rs. 500/= for a bag, Rs. 2500/= for a cube of quarry dust (Rs.893/= per m^3) and Rs.3000/= for a cube of chips (Rs.1072/= per m^3), the cost per 4.96 x 10^{-3} m^3 of concrete would cost at Rs.44/40.

The cost with 10% wastage as recommended in Building Schedule of Rates will be about Rs.50/=

6.2 Cost per tile

A work study was conducted to determine the labour component. It was found that with four skilled labourers and one unskilled labourer, 250 tiles can be produced in a day. The cost evaluation indicated a 0.6 m x 0.6m MCR tile will cost Rs. 80/= including the manufacturer's overhead component. The roof coverage by one tile is 0.5 m x 0.5 m (0.25 m^2) which will cost Rs. 320/m^2 for the roof covering alone. Table 7 gives the cost comparison of MCR tiled roof with commonly used roofing materials such as Cement fibre sheets and Calicut tiles. The total cost of MCR roof with the timber framework is evaluated to Rs. 852/m^2 whereas Rs. 814/m^2 for Cement fibre sheets and Rs. 1006/m^2 for Calicut tiles.

These chip concrete tiles can also be hand moulded for low cost housing. The cost was evaluated as Rs. 110/= per m^2 for the roof covering. This is much less than Rs. 320/=, the cost of machine moulded tiles. However, machine moulded tiles are of superior quality. The hand moulding of chip concrete tiles can be done as a self help scheme where the owner contributes to the labour component [9].

7. Conclusions and Recommendations

With the heavy demand for building materials, developing alternative technology is a timely need in Sri Lanka. Although the MCR tiles were introduced to Sri Lanka some time ago, it has not been popular among house builders. With the extensive testing done under this project, the strength and durability of MCR tiles are all proven to be well above the necessary minimum specified values given in the standards. MCR tiles can be used with a timber frame work of 475 mm reeper spacing and 600 mm rafter spacing. The weight and the cost are comparable with Calicut tiles. Hence the MCR tiles can be used as an alternative roofing material. Further studies are in progress to monitor the thermal comfort with MCR tiles and compare that with Calicut tiles and Cement fibre sheets.

Acknowledgements

The authors wish to thank Mr. Sisira Alawatta, a leading manufacturer of MCR tiles for his support given throughout the experimental programme. The technical officers of the Department of Civil Engineering, Messrs S.P. Madanayake, S.L. Kapuruge and H. P, Nandaweera assisted in this detailed experimental programme with much enthusiasm.

Table 7: Cost/m^2 in LKR/m^2 of different roofing materials

Material	50x100 mm rafter spacing (mm)	50x50 mm purlin spacing (mm)	50x 25 mm reeper spacing (mm)	Cost of frame work/m^2 (LKR)	Cost of covering/m^2 (LKR)	Total cost/m^2 (LKR/m_2)
MCR	600	–	475	532.65	320.00	852.00
Asbestos	750	1200	–	467.35	347.00	814.35
Calicut tiles	500	–	300	690.00	316.00	1006.00

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