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EVALUATION OF MICRO-CONCRETE FIBRE REINFORCED ROOFING TILES WITH SCM

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Abstract
Non-asbestos fiber-cement roofing tiles reinforced with cellulose pulp from sisal (*Agave sisalana*) were produced using vibrating table techniques. The product evaluation was carried out from two points of view: to determine to role of the sisal fible in the final product and to determine how to improve the carbon footprint of the tiles without compromising production or performance through the partial replacement of cement with supplementary cementitious materials (SCM). A series of concrete roofing tiles produced using cements with various levels of blending with ground granulated blast-furnace slag (GGBS) and tested using standard methods of testing corrugated tiles. Different curing method was employed in the production based also on the carbon footprint of the curing methods. The effectiveness of each of the method of curing was investigated. The failure modes and strengths are presented and discussed.

Keywords:
SCM, roofing tiles, bending strength

1 INTRODUCTION

Although galvanized corrugated iron sheeting is currently the most widely used roofing material in Africa, concrete tiles are gaining ground as a preferred alternative for those who can afford it. The popularity of iron sheeting is mainly due to its ease of handling and large span, requiring less supporting structure and they are cheaper per square meter of roof. The disadvantages, however, are that galvanized corrugated iron sheeting is usually imported material in most developing countries; its thermal performance is very unsatisfactory (extremely hot during the day, cold at night, causing condensation problems); heavy rainfall causes serious noise problems; and the often poorly galvanized sheets tend to rust through within a few years.

Asbestos cement sheets became popular in many countries for similar reasons as galvanized corrugated iron sheeting, and also on account of their better thermal performance and fire resistance. Asbestos also shared some of the set-backs such as difficulty in transportation due to its brittle nature. The most serious set-back for asbestos cement sheets is the health risks of mining and processing asbestos. This eventually led to the banning of the use of asbestos in construction.

Concrete roofing tiles have all the advantages of the asbestos cement sheets without the disadvantages. They are now produced by small businesses in many countries around the world. The key to the success of this technology was the development of equipment and techniques to produce the tiles on a small scale. These are produced as Fibre Concrete Roofing (FCR) tiles. It consists of concrete tiles made of cement mortar mixed with a small amount of natural or synthetic fibre. They can also be produced without fibre; micro concrete roofing (MCR) tiles are made by using fine aggregate instead of fibre. The technology provides an inexpensive and reliable roof cladding and suits especially the needs of developing countries and offers the following advantages:

- The raw materials are available locally and thus foreign exchange is saved.
- The appropriate technology that is involved allows for decentralized and small scale production.
- The technology involves little investment.
- The production is labour intensive rather than capital-intensive, thus it creates jobs.
- During sun radiation, compared to metal sheeting, rooms covered with FCR/MCR remain cooler because of better thermal insulation and ventilation.
- During rain, compared to metal sheeting, FCR/MCR produces much less noise.
- The product is environmentally well adapted.
- The technology is easy to learn.

This paper presents investigation based on tiles produced using a simple technology. The tiles were studied for the effects of different factors including:

- Effect of sisal fibre as reinforcement;
- Effect of curing condition;
- Effect of ground granulated blast-furnace slag (GGBS) as partial cement replacement;
- Permeability tests on the samples

The durability of FCR/MCR is basically as good as for ordinary concrete tiles, which have shown service lives exceeding 50 years. However, lower strength of the material compared to modern concrete tiles and AC-sheets was sometimes achieved because of the small production units involving a risk of bigger variations in quality and because of the lack of standards.

When the technology was first developed it was decided to make large roofing sheets similar in size and shape to the corrugated asbestos or galvanized iron sheets used on many buildings. These were reinforced with natural fibres such as sisal or coir. The fibre-cement mortar mix was simply spread out by hand on a flexible plastic sheet in a large mould.

Afterwards the sides of the mould were taken away and the sheet with the mortar on top was gently pulled over onto a corrugated mould where it took its shape.

In practice, long-term problems were experienced with decay of the fibres and cracking of the sheets after only a few years, and so the production of fibre-reinforced concrete roofing sheets has been abandoned in many countries.

The next development was production of fibre-reinforced concrete roofing (FCR) tiles. With tiles (typically about 500 x 250 x 6 or 8mm) the performance of the fibre is less critical than with sheets. The fibres are added largely to control damage caused by impact during handling. Once placed on the roof, tiles are unlikely to crack if the fibres decay. In addition, FCR tiles are vibrated during their production which gives them added strength and durability. It has also been found possible to make fibre-reinforced semi-sheets (of size 600 x 600 x 8mm) by the same method without any adverse effects.

The difficulty of introducing this relatively new roofing system is that potential users do not know the advantages and the fact that the roof is generally not strong enough to be walked on (Ramakrishna, 2011).

Tests carried out on adobe masonry by Jaega (2010) have shown that the energy absorption capacity of adobe blocks is enhanced by the inclusion of sisal fibre in the material. The application of natural fibres such as sisal as a reinforcement of clay bricks causes a marginal reduction of the compressive strength, but increases the capacity to absorb energy or toughness significantly. Out of the tested fibres, Sisal has been determined as the best suitable natural fibre, whereas the application of Date palm fibres also causes a considerable enhancement of the energy absorption. Figure 1 shows a sketch of the stress-strain behaviour of both unreinforced and sisal fibre reinforced adobe block under compression.

2 MATERIALS FOR TILE PRODUCTION

The materials used in producing the tiles are Ordinary Portland Cement (including GGBS replacement), sand, water and fibre. The standard mix is 1:3 cement:sand ratio with 1% fibre by weight of cement. Typical fibre content is between 0,25% and 2%. The optimal content is 1% as considered by several researchers [ramakrishna 2011, Beaudoin 1990, Cook 1978].

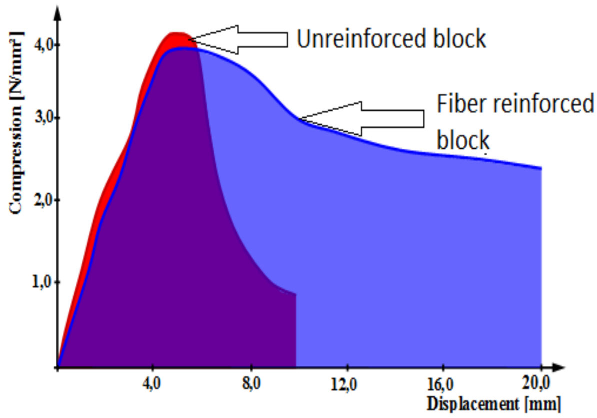

Figure 1: Typical stress-strain curves of unreinforced and Sisal-fibre reinforced clay in compression [Jager 2010]

Sand of regular grading is essential for the production of MCR and FCR. The sand should not be of one particular size only but well distributed sizes. If the sand from one source contains too much material of any one size it should be mixed with a sand of different grading from another source. River sand may be mixed with a clean finer pit sand to provide the correct sand grading. The sieve analysis of the sand shows a fine sand mix as shown in Table 1.

Table 1. Particle size distribution of the fine aggregates

Size range	% Passing
>2.36	100
1.18 mm – 2.36 mm	85
600 µm – 1.18 mm	65
300 µm – 150 µm	35
< 15 µm	15
Relative density	2.62

Unprocessed natural fibres can be used for reinforcement of tiles. Fibres such as coconut coir, sisal, sugarcane bagasse, bamboo, jute, wood and vegetable fibres have been tested in a number of countries. However problems like decay have been reported with the long-term durability of some of the products. To avoid much influence of the fibre in the long-term property of the tiles, fibre content was limited to 2%. Typical properties of natural fibres are shown in Table 2

It has been shown that durability problems in the use of sisal fibre in tiles are associated with alkali attack on the fibres in the long term. Gram (1988) suggested that the durability of the fibres can be improved by reducing the alkalinity of the pore water by replacing part of the cement with a pozzolanic material. The GGBS used in this experiment originated from the steel plants in Redcliff in Zimbabwe. The chemical compositions of the GGBS are shown in Table 3 below.

Table 2: Typical properties of natural fibre (Source: The concrete Institute, South Africa)

Fibre Type	Coconut	Sisal	Sugar cane bagasse	Bamboo	Jute	Flax
Fibre Length, mm	50 – 100	N/A	N/A	N/A	175 - 300	500
Fibre diameter, mm	0,1 – 0,4	N/A	0,2 – 0,4	0,05 – 0,4	0,1 – 0,2	N/A
Relative density	1,12 – 1,15	N/A	1,2 – 1,3	1,5	1,02 – 1,04	N/A
Modulus of elasticity, GPa	19 - 26	13 - 26	15 - 19	33 – 40	26 – 32	100
Ultimate tensile strength, MPa	120 – 200	275 - 570	180 - 190	350 – 500	250 – 350	1 000
Elongation at break, %	10 – 25	3 - 5	N/A	N/A	1,5 – 1,9	1,8 – 2,2
Water absorption, %	130 - 180	60 - 70	70 - 75	40 - 45	N/A	N/A

N/A Properties not readily available or applicable

Table 3: Chemical and physical composition of the GGBS

Component	% by weight
CaO	36.4
SiO_2	30.4
Al_2O_2	16.9
MgO	11.5
S	2.0
Na	0.78
Mn	0.6
FeO	0.5
K	0.02
Mo	0.02
Fineness	420 m^2/kg
Minimum Glass Content	95%
Loss of Ignition	2.5%

To produce the tiles, sand was first dry-mixed with cement before water is added. Colour is obtained by adding various coloured synthetic iron oxide pigments at the mixing stage at around 3% of cement mass. The tiles are produced with a vibrating machine powered by a multi-vibe vibrator. The moulds are designed to give the tile three-dimensional corrugated form. A series of tiles were produced by replacing part of the Portland cement in the control sample with GGBS in varying proportions. Samples containing the following percentages of GGBS in the binder were produced: 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80%. The tiles have a large overlap, deep valley and close fit to ensure that the roofs are leak proof without the need for underfelt or plastic sheeting. They are normally available in three thicknesses: 6 mm, 8 mm and 10 mm. The newly produced tiles were de-moulded after 24 hours. Care is taken to avoid breakages. The manufacturing processes have been further described by Uzoegbo (1997). In addition, the batching of the quantities of sand, cement, and water needs to be done accurately - to ensure that there is enough cement and that the mix is not too wet. Figure 2 shows a sketch of the Roman tile in plan and cross section.

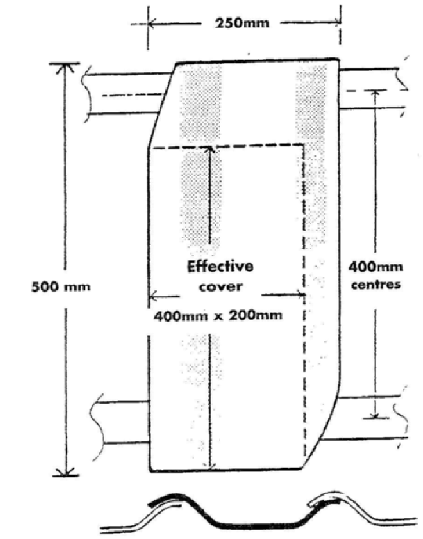

Figure 2. Sketch of Roman tile plan and cross section.

3 CURING OF TILE SAMPLES

A low cost curing technique was used which involves the use of a sealed chamber covered with a black polythene sheet and exposed to direct sunlight. Figure 3 shows a cross section of the chamber. The water level in the curing chamber was maintained at just below the surface of the gravel such that the tiles were not directly in contact with static water; Static water tends to leave map traces on tiles.

The build-up of temperature inside the sealed chamber combined with the high relative humidity resulting from the water to provide the required moisture for curing. A high temperature and high humidity condition therefore prevails within the chamber. The probe of a digital thermometer was inserted in the chamber before it was sealed. An average temperature of 28°C was obtained in the curing chamber over the seven-day curing period in September compared with the average ambient temperature of 22°C outside the chamber. The registered day temperatures inside the chamber were up to 60% higher than the ambient temperature (see Figure 4). The difference between the night temperatures was much.

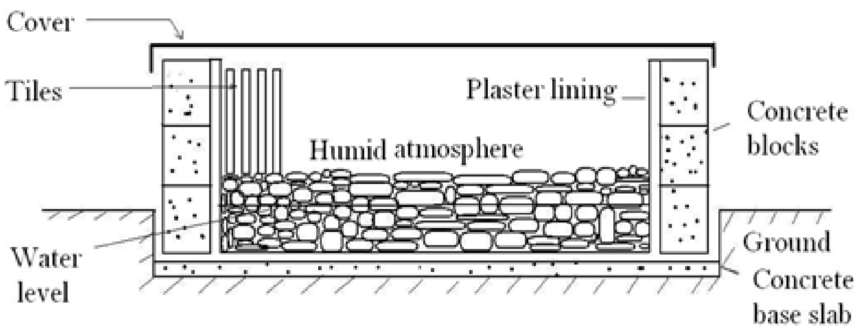

Figure 3: solar chamber curing tank

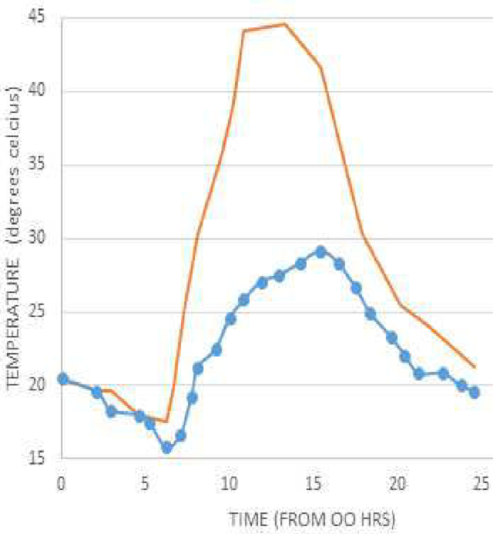

Figure 4. Temperature profile inside and outside of the curing tank.

4 WATER PERMEABILITY TESTS

Water permeability tests were carried out in accordance with the qualitative procedure described by Johansson (1995). Four tiles were selected from each sample for the test. Two small weirs were formed on each tile and water was allowed to stand in a pool for a period of 24 hours. A tile was considered to have failed the test if after the 24-hour period it was found that water was dripping from, or there was free water on the underside. The results of the water permeability tests are shown in Table 4.

Table 4. Results of permeability test

GGBS content (%)	Result
0	Pass
10	Pass
20	Pass
30	Pass
40	Pass
50	Pass
60	Pass
70	Pass
80	Fail

5 FLEXURAL STRENGTH TEST

The method employed for the strength test is the three point test as illustrated in Figure 5. Six tiles were selected for testing from each sample. The tiles were immersed in water or 24 hours and tested soon after removal from water. The tile to be tested was supported on two bearings or supports. The distance between the supports was two thirds of the length of the tile. The load is applied centrally through a third bearer using a rod of 38 mm diameter. The loading was applied at the rate of 800 N/minute. The mode of failure is by cracking right across the tile in line with the loading platten.

The results from the flexural tests are shown in Figures 6 - 8. Tests were conducted for the following variables:

- Thickness of the tiles
- Percentage GGBS used as partial replacement for cement in the tile production
- Effect of natural fibre on the strength
- Strength at 28 days and at 90 days.

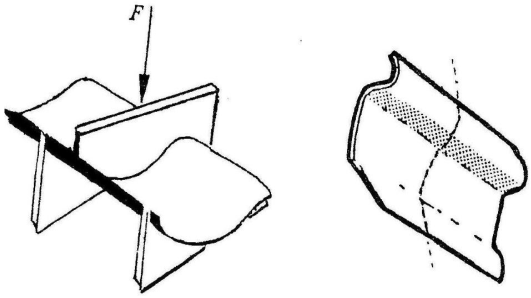

Figure 5. Loading arrangement for flexural tests

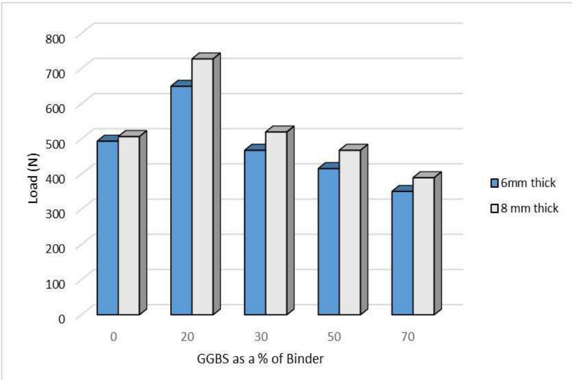

Figure 6: Effect of tile thickness on flexural strength.

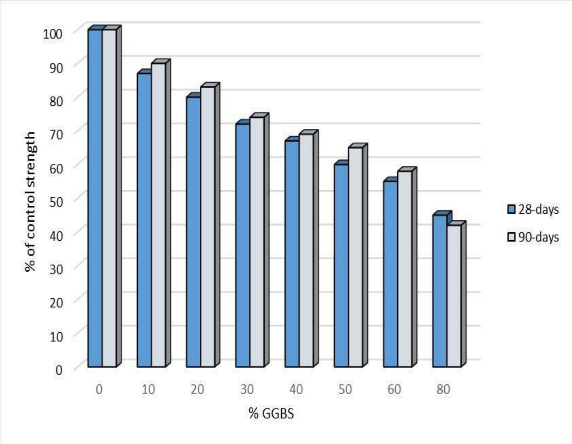

Figure 7: 28 day versus 90 day flexural strength as % of control for samples cured at room temperature

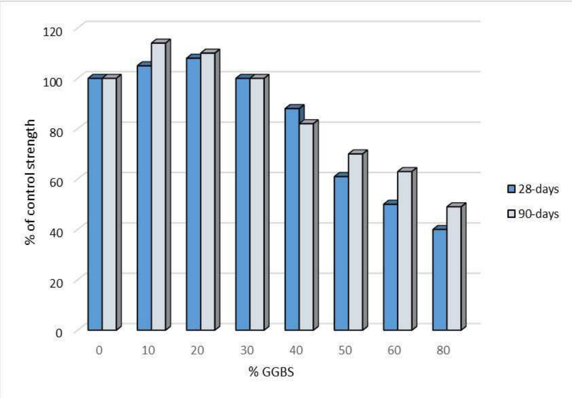

Figure 8. Flexural strength as a % of control sample for tiles cured in solar tank

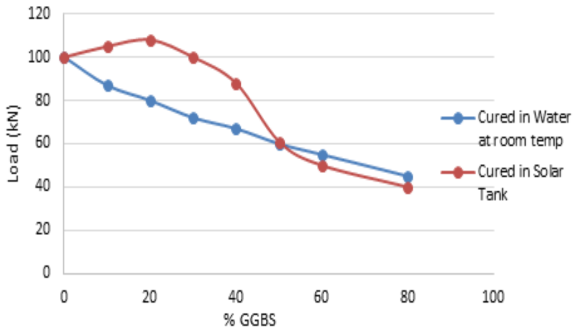

Figure 9. Comparison of 28 day Strengths for samples cured in water vs. cured in tank

6 DISCUSSION AND CONCLUSIONS

The thickness of the tiles has a small but significant influence on the strength of the tiles (See Figure 6). The 90-day strength is in a similar range with the 28-day strength but slightly higher. Tests carried out on the tiles show that the sisal fibre does not contribute to the long-term strength of the tiles. It is, however, very useful in early stages of the production to prevent cracking. Tests results show that the solar tank curing method used in this work is very effective particularly in connection with the application of SCM (supplementary cementitious material). The temperature in the chamber was on average about 10^{o} C higher than the ambient temperature. Combine the high temperature with humid environment and the most suitable environment for hydration of cement and pozzolanic activity was created. The strength of the tiles was significantly improved by partial replacement of the cement with GGBS (see Figures 6, 7 and 8) up to 20% cement replacement with GGBS.

In contrast the samples immersed in water at room temperature showed different results. The strength of the tiles decreased with increase in GGBS content. Permeability in Table 4 and strength results in Figures 7 and 8 show that up to 50% cement replacement with GGBS could be done without any compromise on property.

Tests show that the sisal fibres did not have significant contribution to the long-term strength of the tiles. The fibres play an important role in early strength and the handling of the tiles without breakages in early age.

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