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Development Of Test Methods For Fibre Reinforced Roofing Tiles

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Abstract- ***A series of sisal fibre reinforced concrete roofing tiles were produced and tested using both standard methods and non-standard methods of testing corrugated Roman II tiles. The concrete was blended with ground granulated blast-furnace slag to various degrees to determine the optimum blend. The effectiveness of solar chamber curing was studied. The curing method was based on the utilization of solar energy to produce moisture movement in a sealed system with a chamber temperature that is significantly higher than the normal level in the surroundings. The failure modes and strengths of the tiles under bending load were presented and discussed. The effect of admixtures was also investigated on some of the samples. The viability of the techniques studied for commercial production of concrete roofing tiles was discussed.***

Keywords- Roofing tiles, GGBS, sisal fibre, solar chamber curing.

I. INTRODUCTION

Building materials sometimes account for as much as 75% of the cost of low cost houses. The natural resources used for the production of the more traditional building materials are being depleted at an alarming rate. Growth in industries world-wide has generated abundance of wastes and by-products coupled with the disposal problems of these wastes. There is urgent need to utilize more industrial wastes and by-products as construction materials.

The properties of concretes containing ground granulated blast- furnace slag (GGBS) have been well-established by research and field experience in several countries. However its use in roofing tile production is not well established. The major effects of using ground slag can be summarized as follows:

1. Higher ultimate and usually lower early strengths.
2. The ratio of flexural to compressive strength is increased.
3. Decreased variability in concrete strengths.
4. Lower permeability, decreased chloride penetration.
5. Improved sulfate and sea-water resistance.
6. Decreased alkali-silica reactions.
7. Decreased temperature rise from hydration.
8. Improved workability.

The material properties of ground granulated blast- furnace slag (GGBS) sourced from the ZISCO-STEEL plants in Redcliff, Zimbabwe was investigated for use in commercial roofing tile production. Both the strength and the material properties of fibre-reinforced roofing tiles made by blending with GGBS has been investigated. The ZISCO-STEEL company in Zimbabwe produces granulated blast-furnace slag at rate of 500 kg per tonne of hot metal. This gives about 340,000.00 tonnes of slag annually.

II. THE ROOFING TILE MATERIALS

The materials used in producing the tiles are Portland cement, sand, water and natural fibre. The basic mix is 1:3, cement:sand ratio with the addition of 1 % sisal fibre by weight. Many natural fibres can be used in concrete. The most common ones are sisal, jute, and henequen or coconut coir. It is important that the fibres are flexible and not brittle; fibres should not be oily or contain substances such as sugar which affects the hydration of cement. The sisal fibres used as reinforcement in the tiles originates from sisal plants which are grown

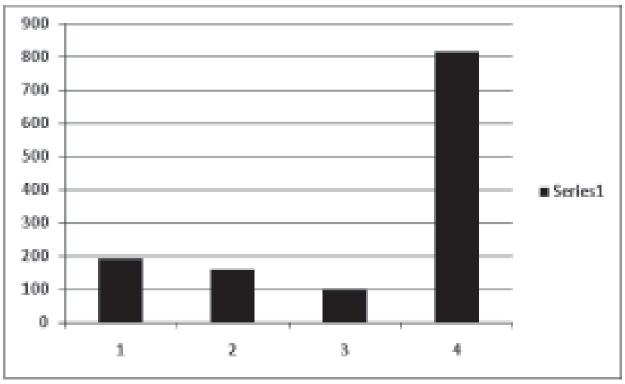

Figure 1. Tensile strength of Date palm fibres and Sisal fibres

General mechanical properties of sisal fibres are as follows:

- Elongation 4 – 9%
- Young's modulus 7 – 20 GPa
- Tensile Strength 500 – 800 MPa

It has been shown that the durability problems in the use of sisal fibre as reinforcement in tiles in various locations are due to alkali attack of the fibres by the pore water present in the cement matrix. Alkali attacks on fibres can be reduced by reducing the alkalinity of pore water in concrete. One method of doing this is by replacing part of the cement with a pozzolanic material such as GGBS. The GGBS extensively in Zimbabwe. Sisal is reportedly one of the strongest natural fibres available. The strength is comparable to that of bamboo fibres. The preparation was done by scraping the sisal leaves, drying and chopping them to a length of 30 mm, ready for use. The typical properties of sisal fibre in comparison with other natural fibres have been given by [4], [5], [6] and [7]. comparative Tests reported by Jager et al determined the following average tensile strength for fibres tested and further illustrated in Figure 1:

1. Date palm fibre – fine 164,15 N/mm²
2. Date palm fibre – middle 139,87 N/mm²
3. Date palm fibre – corse 115,27 N/mm²
4. Sisal fibre 840,09 N/mm²

used in these investigations originated from ZlSCO-STEEL plants in RedcliFf and were marketed by FOSROC. The chemical composition is shown in Table I.

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	$420m^2/kg$
Minimum Glass Content	95%
Loss of Ignition	2.5%

Table 1: Chemical and physical composition of the GGBS

A sketch of the Roman II tiles produced by Parry Associates [1] is shown in Figure 2 and is also shown on a roof structure during construction in Figure 3. 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 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%.

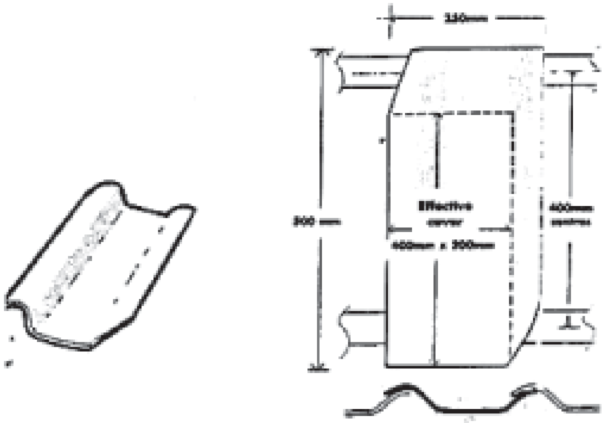

Figure 2. The Parry Associates Roman II tile shown in 3-d and basic dimensions in plan.

Figure 3. Roof construction using Roman II tiles.

III. EXPERIMENTAL

A Curing chamber

A low cost curing technique was used which involves the use of a sealed chamber covered with a polythene sheet and exposed to direct sunlight. Figure 4 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

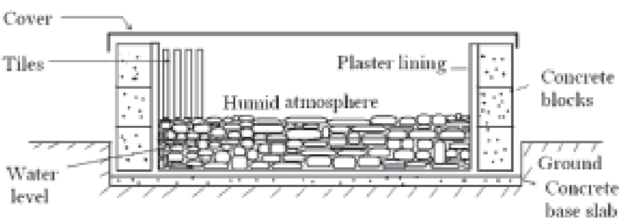

Figure 4. Sketch of the cross-section of the curing chamber.

B Water Permeability

Water permeability tests were carried out in accordance with the qualitative procedure described in [6]. A similar method is also used at the Parry Instamac production yard for testing the permeability tiles. Four tiles were selected from each sample for the test. Two small weirs were formed on each tile 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. The difference between the night temperatures was much lower.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 2.

GGBS content (%)	No admixture	COMPLAST P211	COMPLAST P430	COMPLAST P509
0	Pass	Pass	Pass	Pass
10	Pass	Pass	Pass	Pass
20	Pass	Pass	Pass	Fail
30	Pass	Pass	Fail	Fail
40	Pass	Pass	Fail	Fail
50	Pass	Pass	Fail	Fail
60	Pass	Pass	Fail	Fail
70	Pass	Fail	Fail	Fail
80	Fail	Fail	Fail	Fail

C Strength Tests

Tests for the strength in bending were carried out using three methods:

i) The method described in BS 550 part 2: 1971 (set-up 1, see Figure 6);
ii) The method described in the Parry Instamac manual (set-up 2, see Figure 8);
iii) A modification of the Parry Instamac method (set-up 3, see Figure 10).

In addition to the physical testing, a numerical finite element modeling based on the experimental test data have been carried out to simulate the plane of weakness and failure mode of tiles under three different experimental set-ups. Figure 5 shows solid tetrahedron finite element mesh for tile. Figures 5 - 11 shows the simulation of experimental set-ups and corresponding numerical deformed shape of the tiles. The failure modes obtained from the FEM numerical modeling is in good agreement with the test failure modes. The material content and geometry of the tile did not influence the failure modes.

The BS method recommends that six tiles be 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. A sketch of the arrangement is shown n Figure 6. The loading was applied at the rate of 800 N/minute. The mode of failure is modeled in Figure 7.

The second test arrangement investigated was the in-house method developed by Parry Instamac Zimbabwe. In the method, load was applied evenly across the center of the tile as sketched in Figure 8. The wooden platen of 25 mm width is designed to march the profile of the top surface of the tile as shown in Figure 8 with the failure mode shown in Figure 9.

A third testing arrangement was used in which both the supports and the bearer for load application were designed to match the surface profile of the tile. This can be considered a modified version of the Parry Instamac method. This test arrangement is shown in Figure 10 and the mode of failure shown in Figure 11.

Figure 5: FEM model of tile

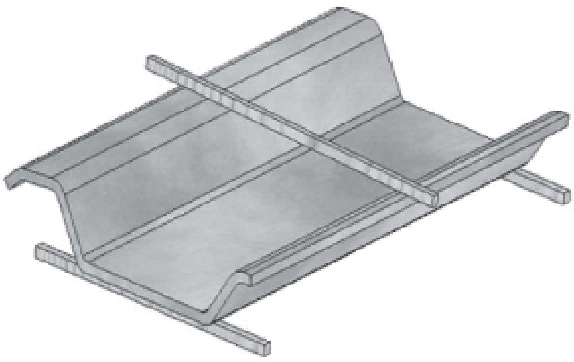

Figure 6: Test arrangement to the Parry Instamac test method (set-up 1)

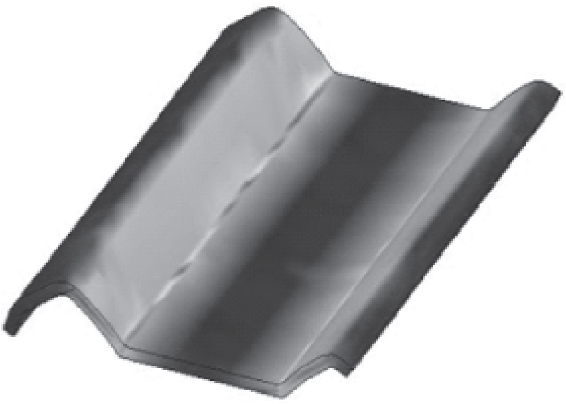

Figure 7. Failure mode from finite element simulation of experimental Set-up 1

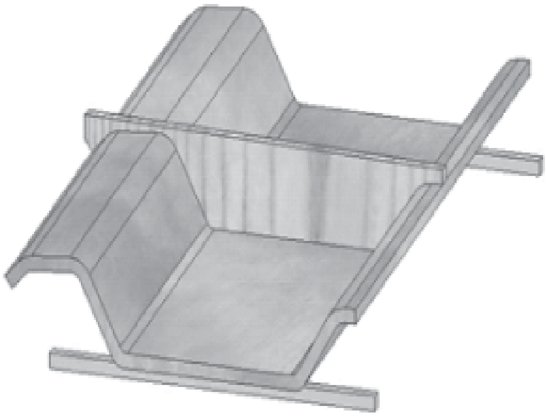

Figure 8. Finite element simulation of experimental Set-up 2

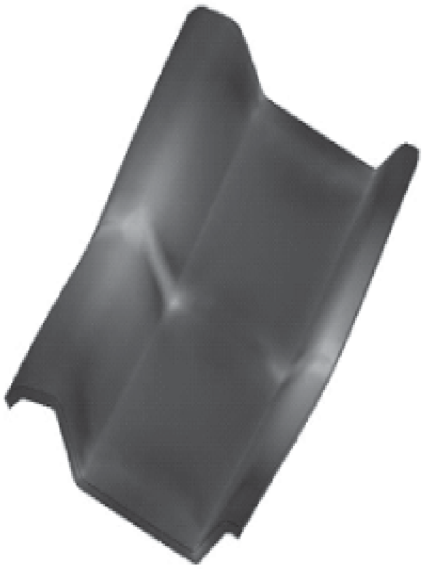

Figure 9. Failure mode from finite element simulation of experimental Set-up

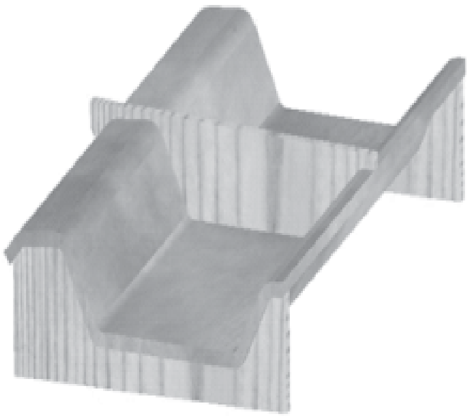

Figure 10. Finite element simulation of experimental Set-up 3

Figure 11. Failure mode from finite element simulation of experimental Set-up 3

IV. RESULTS AND DISCUSSIONS

A comparative result shown in Figure 12 shows that a much lower strength was obtained from the BS method compared with the other two test methods. This is due to the nature of the loading and the shape of the tile. The platen rests on the tile at two points where the loads are applied as point loads. The tiles fail in direct tension or by the development of local stresses at corners rather than in bending. The Parry Instamac method of testing is used In the European Standard [8] on roofing tiles.

The BS method is designed to suit press extruded tiles. These tiles are comparatively flatter in cross section and have the same overall height at several points. The rest of the results were obtained from tests to the BS method. Figure 13 shows average test results at 28 days for the tiles with 6 mm and 8 mm thickness using the BS method of testing.

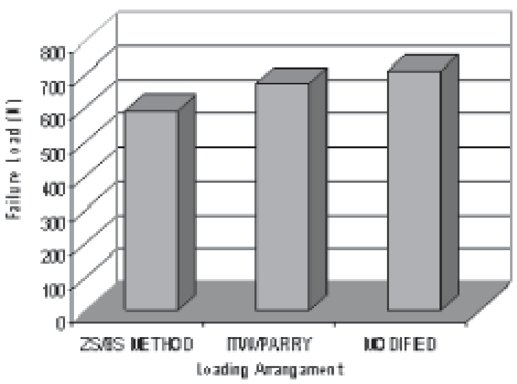

Figure 12. Average strength from three testing arrangements

It is generally observed that the best strength results were obtained for GGBS content of 20% for samples cured in the chamber under the high temperature and humidity conditions See Figure 13. For samples cured at room temperature the strength generally decreased with an increase in GGBS see appendix 1.

In section 1.11.1 of the BS 550, it is required that the breaking load in Newtons for the Roman II tiles in this test shall not be less than 3.2 times the effective width, The effective width is 200 mm, therefore the required minimum breaking load is 640 N. This requirement is easily met in samples containing up to 30% GGBS at 28 days. The other samples could generally fulfill the BS requirement at older ages.

Another difference between the two test methods is the fracture mechanism. In the BS testing method the tile cracks and fails along the length of the tile (see Figure 7). In the Parry Instamac method failure was across the width as shown in Figures 9. The two methods, therefore, give cracks that are at right angles to each other. The crack pattern indicates that the Parry Instamac method is more representative of a true flexural test.

On demoulding the tiles after 24 hours, some breakages were observed particularly for tiles containing high percentages of GGBS. It became obvious that more stripping times were required for samples with high GGBS content. Samples with 30% GGBS or less did not experience handling breakages.

Some samples made without fibres were also tested to investigate the effect of the natural fibres on the strength of the tiles. It was observed that the fibres did not have a significant effect on the ultimate strength of the tiles, there were considerable handling problems and breakages, however, in the samples that were not reinforced with fibres.

The permeability test showed a general tendency of an increase in permeability with GGBS content. The use of an admixture slightly increased the strength due to the decrease in a water requirement in producing a workable mix, but the tiles containing admixtures generally failed the permeability tests.

The investigations have shown that the strength of the roofing tiles can be improved by replacing a limited amount of the cement with GGBS if the curing technique described above is used. It has also been demonstrated that the testing arrangement described in the BS 500 does not give a true bending strength of the tiles. To obtain a more accurate measure of the strength in bending of the Roman II tiles, it is necessary to apply the load through a platen that matches the surface profile.

The use of water reducing admixtures is not beneficial to the tiles in terms of durability and water permeability

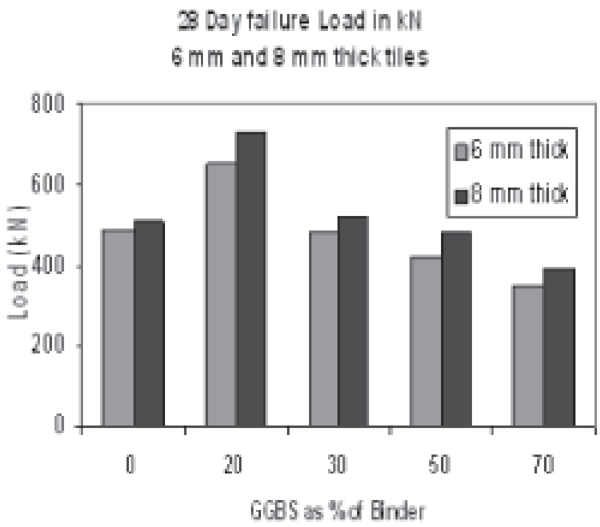

Figure 13. Failure loads at 28 days for 6 mm and 8 mm thick samples

V. CONCLUSIONS

Tests results have shown that the curing method used in this work is very effective as shown in the result Tables in the appendix. The humid environment within the curing chamber provided adequate moisture for the hydration and strength development of the tiles. The conventional system of curing the tiles which involves the soaking of tiles in water for about seven days has several disadvantages:

- The curing temperature is relatively low (about 20^{o}C);
- Cement film floating on water causes blisters workers hands like glass;
- Water needs to be changed after each batch;
- Water leaves map traces on drying out.

The strength of the tiles is significantly improved by replacing a limited amount of the cement with GGBS provided curing was carried using the technique described in this report. The strength of tiles with an irregular surface depends on the profile of the platen. The European Standard on tiles (EN 194) recommends the use of platen that matches the surface profile of the tiles. The addition of superplasticizing admixture does not generally improve the quality of the tiles as the permeability property was compromised.

A comparison with similar samples cured by complete immersion in water at room temperature is shown in the appendix. The results indicate reduced rate of strength development over the curing period investigated for samples. cured in water at room temperature.

ACKNOWLEDGMENTS

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