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Thermal Insulating Concrete Tiles

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ABSTRACT

This Paper studies the shape of high-thermal insulating concrete tiles used for roof tiling. The theoretical part consists of a comparison between this invented tiles and ordinary terrazzo tiles. The analysis depends on the values of thermal conductivity of the material used. The results showed that when these tiles are used for roof tiling, the temperature difference between the outside of roof surface and the inside room can be reduced about six times compared with the use of ordinary terrazzo tiles. In addition, these specimens were fabricated and tested for rupture and absorption tests. The test results showed that, they had a good resistance to the applied test loads, and high resistance to water absorption. The authors believe that, the results are remarkable, highly applicable and should be taken into consideration in building constructions.

Keywords: *Concrete tiles, Terrazzo tiles, Thermal insulating, power saving*

LIST OF SYMBOLS

k: thermal conductivity of the material (watt/m.°k)
R_1: thermal resistance, when the 90 mm tiles are used (m^2. °k /watt)
R_2: thermal resistance, when the 30 mm terrazzo tiles are used (m^2. °k /watt)
ΔT_1: difference in temperature between the external invited tile surface and the internal ceiling surface (Cº).
ΔT_2: difference in temperature between the external surface of traditional terrazzo tiles and the internal ceiling surface (Cº).
y: depth of neutral axis of the tile section measured from the tensioned face (mm).
I: moment of inertia of the section about neutral axis (mm^4).
M: ultimate bending moment of the section (N.mm)
σ: maximum tension stress of the section (MPa).

1. INTRODUCTION

The key to maintaining a comfortable temperature in a building is to reduce the heat transfer out of the building in the winter and reduce heat transfer into the building in the summer. Heat is transmitted across confined air spaces by radiation, convection and conduction [1, 2]. Conduction is the direct flows of heat throw a material resulting from physical contact. The transfer heat by conduction is caused by molecular motion in which molecules transfer their energy to adjoining molecules and increase their temperature.

Heat transfer by conduction is governed by a fundamental equation known as Fourier's law [2- 5].

$Rate\ of\ heat\ flow = -k \times area \times temp.\ gradient$. K value is a measure of a heat conductivity of particular materials, and it is called thermal conductivity. The lower of the k-value for a material, the better it insulates [6].

The k of insulation materials is the most important property that is of interest when considering thermal performance and energy conservation measures. ASTM standards C168-97 define thermal conductivity (k-value, w/m.°k) as the time rate of steady state heat flow through a unit area of a homogeneous material induced by a unit temperature gradient in a direction perpendicular to that unit area [7].

In Arab gulf countries, especially in Iraq, nominally, the tiles used are either concrete 800 mm x 800 mm x 40 mm or 300 mm x 300 mm x 30 mm laid on roofs with cement mortar. But due to large range of temperature difference between the outside and the comfortable temperature both in summer and winter, a heavy use of air conditioning system is needed in order to reduce his temperature differences, which demands high power consumption and therefore, a high cost to both private and national income. Thus, the need for proper insulating material is mandatory. People with high standard of living apply insulation of the roofs by using insulating styro pore sheets with various thicknesses; some other use soil as an insulation layer below the tiling. But the problem with this is that when water penetrates through the joints to the insulating layer, it will cause the tiles to be isolated from the insulating sheets and make them come up, and this will render failure. As for the soil (when used), the

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penetrated water causes grass to grow and hence swelling of earth which will also render failure of roofing. It is the intension of this research to show that an invented shape of concrete tile provides a high thermal insulation. This will increase the temperature difference between the external tile surface and the internal room ceiling surface. Also the work indicates that the tile resists the applied service loads and has a low absorption percentage of rain water. If water penetrates through tiles joints, it will not cause harm to the roofing system as the tiles (with about 30 kg) are solidly fixed with cement mortar through their parameters on the reinforced concrete roofs.

2. THEORY

2.1 Thermal Insulation

The theory on which this research is based depends on the invented shape of the concrete tile with the cross section shown in Fig. (1).

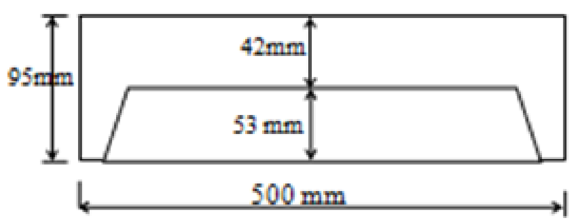

Fig. (1): the invented cross section of the tile

Assuming 20 mm thick mortar is to be used to fix the tile on the reinforced concrete roof. K-values for variable materials are taken from Ref. [3], with:

(1) a 42 mm thick plain concrete of k-values = 1.8 watt/m. $^{\circ}$k

(2) a 73 mm thick trapped air (formed of 53 mm air contained within the tile plus 20 mm mortar underneath) of k-value = 0.025 watt/m. $^{\circ}$k

These values approximately are as same values which are listed in Refs. [1, 2]. Thermal resistance of 95 mm tile and the underneath mortar 15 mm ceiling plaster = R_1

$$R_1 = \frac{0.042}{1.8} + \frac{0.073}{0.025} + \frac{0.15}{2.2} + \frac{0.015}{0.58} = 3.0374\, m^2 .^{\circ} k / watt$$

Thermal resistance of the traditional 30 mm terrazzo tiles + the underneath 20 mm mortar + 150 mm reinforced concrete slab + 15 mm ceiling plaster = R_2

$$R_2 = \frac{0.03}{1.8} + \frac{0.02}{1.8} + \frac{0.15}{2.2} + \frac{0.015}{0.58} = 0.1218\, m^2 .^{\circ} k / watt$$

If ΔT_1 is the difference in temperature between the external invented tile surface and the internal ceiling surface, and ΔT_2 is the difference in temperature between the external surface of the traditional terrazzo tiles and the internal ceiling surface, therefore:

$$\Delta T_1 : \Delta T_2 = 3.0371 : 0.1218 = 24.935 : 1$$

Taking care of the reduction of insulation due to the concrete ribs; By multiplying by $(415/500)^2 = 0.69$, where the 415 mm is average internal dimension of the tile specimen, and reduction of the fact that walls and openings of the room are not 100% multiplied by 0.7. Also, taking care of the bad workmanship, by multiplying by 0.5, the ratio becomes:

$$(24.935 \text{ x } 0.69 \text{ x } 0.7 \times 0.5) : 1 = 6 : 1$$

which is a high ratio. This means that if temperature difference with terrazzo tiles is only 5 Cº, the difference in temperature with these invented tiles will be (5 Cº x 6 = 30 Cº). That is if the maximum outside surface temperature of tile in summer = 55 Cº, the internal ceiling temperature with ordinary terrazzo tiles = 50 Cº, then the internal ceiling temperature with the new tiles will be (25 Cº). This means a great reduction in the daily running hours of air conditioning units and a very short yearly running duration. That's if insulation is applied to walls as well as the roof, it will only be necessary to use air conditioning for nearly three months a year (i.e. January, July and August) instead of nine months (i.e. January, February, March, May, June, July, August, September and December). Also instead of daily running of 18 hours as an average, it will only about 3 to 4 hours as a daily average. This will result in a yearly saving of electric power. If the normal yearly national consumption of power = W mega watts, then the yearly power saving will be given by:

$$W \times \left[1 - \left(\frac{3}{9} \times \frac{4}{18} \right) \right] \times 100 = 92.5\,\%\, W$$

When, these insulating tiles are used for roofing.

2.2 Experimental

A mould was manufactured, made of 3 mm folded steel plate, designed to be 500 mm x 500 mm x 95 mm depth. Another mould of smaller dimensions was made to fit inside the pervious mould so that the cast concrete inside will have a cavity of 53 mm depth. The cavity is the essence of the design.
Three specimens were cast using mentioned pair of moulds and an electrical table vibrator with 1250 mm x 625 mm with frequency 2880 rpm. These specimens were made of 1:2:4 concrete with water cement ratio of 0.45.

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3. MATERIALS

Ordinary Portland Cement: The cement used in the investigation from Marden Turkish Company with fineness 3100 cm^2/gm (Blain method), initial setting time 150 minutes and final setting time was 3.5 hours (Vicat apparatus).

Sand: The river sand used having a fineness modulus 2.73 and specific gravity equal to 2.69 with good gradation

Gravel: The river gravel with maximum size of 19 mm and specific gravity to 2.7 was used as a coarse aggregate.

3.1 Rupture Test

After 28 days curing, the three specimens were tested for rupture testing machine as shown in Fig. (2).

Fig.2: Rupture testing machine

The diagrammatic placement of the specimen under the testing machine was shown in the Fig. (3) and the specimens after failure have shown in Fig. (4).

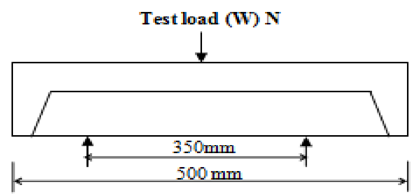

Fig.3: Tile specimen under Rupture test

Fig. 4: Specimens after failure

The loads under which the tiles failed in rupture were as follows:

1st specimen = 8830 N

2nd specimen = 9614 N

3rd specimen = 11282 N

This gives an average value of 9909 N

To evaluate this test result:

The maximum probable load on a tile will be a foot step load on the middle of the tile which is 1000 N (a maximum man load). Multiplying this by a load factor for jerking of 2.5 will give a maximum probable load of 2500N. The results of the test shows a resistance of tile nearly four times (i.e. 9909/2500 = 3.96) as much as will be needed for this supposed worst loading condition. The calculating resisting flexural stress in the tiles (σ),

$$\sigma = \frac{M \cdot y}{I} \; ; M = \frac{W \cdot L}{4} \; ; Therefore, \;\; \sigma = 8.56 \; MPa \, ,$$

Which is high value compared with the allowed of (4.25 MPa) according to specification [8].

3.2 Absorption Test

Two pieces of the ruptured tiles were immersed in water for (24) hours, then left to dry in an oven. The average absorption was 3.72% as follow:

Sample No.	1	2
Weight when immersed in water (gm)	4.958	5.061
Oven dry weight (gm)	4.778	4.882
Absorption %	3.77	3.67

This value is satisfied the limit absorption of 6.5% according to specification [8].

4. CONCLUSIONS

4.1 Thermal Insulating

The above mentioned work indicates that the invented shape Fig. (1) of a concrete tile intended to be used in tiling roofs of buildings has a high insulating feature which can change the inside room temperature of the ceiling from 50 Cº when ordinary terrazzo tiles (i.e. mosaic kashi) are used to only 25 Cº when the outside (i.e. external surface temperature is 55 Cº), provided that similar insulation is adopted for the walls and the floors. In fact, as most of the heat transfer through walls and floors won't have a great effect on the inner room temperature if insulation is not applied to walls and floors. This is due to low temperature gradient across walls and floors compared to that across the roof. To provide successful use of these tiles in tilling roofs, they were subjected to two kinds of tests:

4.1.1 Rupture Test

The aim of this test is to show that the tiles will take up the imposed load safely. The results show a high resistance for rupture, due to their shape with 95 mm high ribs in their parameter. They proved to resist 4 times as much as the maximum probable service load. Also more than twice the resistive stress (8.56 MPa) of what is considered as the minimum accepted of (4.2 MPa) according to Ref. [8]. This is obvious if it takes into consideration the high value of (y) which is 70.5 mm compared with 21 mm for traditional tiles.

4.1.2 Absorption Test

The tiles show an accepted rate of absorption of water (3.72%), compared with the maximum allowed percentage of (6.5%) according to Ref.[8]. In fact absorption is much less than this value for these tiles if we take into consideration that only the surface of the tile will be in practice subjected to rain water, while according to the executed absorption test the whole sample was immersed into water.

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