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The Improvement of Thermal Insulating Concrete Panel

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ABSTRACT

The Iraqi houses flattening the roof by a concrete panel, and because of the panels on the top directly exposed to the solar radiation become unbearably hot and cold during the summer and winter. The traditional concrete panel components are cement, sand, and aggregate, which have a poor thermal property. The usage of materials with low thermal conductivity with no negative reflects on its mechanical properties gives good improvements to the thermal properties of the concrete panel. The practical part of this work was built on a multi-stage mixing plan. In the first stage the mixing ratio based on the ratios of the sand to cement. The second stage mixing ratios based on replacing the coarse aggregate quantities with the Alabaster aggregates, and the third stage the mixing ratios based on the replacement of wood ash instead of the sand. While the fourth stage mixing ratios based on decreasing the thermal conductivity and increasing mechanical properties by adding a multilayer of a plastic net. The result shows that using a concrete panel with components (cement, sand, coarse aggregate, wood ash, and Alabaster aggregates) with a mass ratio of (1:1:2:1:1) and 3-plastic layers, gives the best improvement of the thermal properties. Where, the thermal conductivity is reduced by 42% and the specific heat increased by 41.2% as compared to the traditional concrete panel mixing ratio, with mechanical properties are agreed with the Iraqi standards.

Key Words: wood ash, Alabaster aggregates, plastic layers.

تحسين العزل الحراري للبلاطه الخرسانية

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الخلاصة

يؤدي الاشعاع الشمسي الساقط على البلاطة الخراسانية التي تستخدم في تسطيح السقوف العراقية ساخنة خلال الصيف وبارده خلال فصل الشتاء. ان مكونات البلاطة الخرسانية التقليدية هي السمنت والرمل والحصى (الركام) والتي تتميز بخصائص حرارية رديئة. ان تعزيز الخصائص الحرارية للبلاطة الخرسانة باستخدام مواد ذات موصلية حرارية منخفضة دون أن تعكس سلبا على خصائصها الميكانيكية ممكن ان تحسن الخواص الحرارية للبلاطة بشكل كبير. تم في هذا البحث اجراء خطة خلط متعدد المراحل. تعتمد المرحلة الأولى في نسبة الخلط على نسبة الرمل إلى الاسمنت. أما نسب الخلط في المرحلة الثانية فتعتمد على استبدال كميات الحصى الخشن بمجاميع من ركام المرمر وترك اوزان الأسمنت والرمل ثابتة اعتمادا على المرحلة الأولى. اما في المرحلة الثالثة فتعتمد نسبة الخلط على إستبدال رماد الخشب بدلا من الرمل في حين ان المرحلة الرابعة اعتمدت على نقصان الموصلية الحرارية وزيادة الخواص الميكانيكية بإضافة شبكة او عدة شبكات مصنوعة من اللدائن. لقد ظهرت نتائج أن استخدام لوح الخرسانة مكون من (السمنت والرمال والركام الخشنة ورماد الخشب و مجاميع المرمر) وبنسبة (1: 1: 2: 1: 1) مع ثلاث طبقات من شبكات اللدائن. واعطي هذا السقف الرقم 4 والذي بين احسن اداء حراري للمبنى حيث ان الموصلية الحرارية انخفضت بنسبة 42٪ والخزن الحراري ازداد بنسبة 41.2٪ مقارنة بالبلاطة الخرسانية التقليدية. وتم الحصول على خواص ميكانيكية مقبولة اعتمادا على المواصفة العراقية.

الكلمات الرئيسية: رماد الخشب، مجاميع المرمر،طبقات بلاستك

1. INTRODUCTION

The thermal performance of the concrete panel envelope is determined by the thermal properties of the materials used in its construction characterized by its ability to absorb or emit solar radiation in addition to the volumetric heat capacity and thermal resistance. The concrete panel is usually cemented construction that made of fine aggregates (sand) and coarse aggregates with a ratio of water to cement. Enhancement of thermal performance of the concrete panel using materials has low thermal conductivity and high specific heat, such as wood ash, Alabaster aggregates and waste PET (polyethylene terephthalate). In another side, the enhancement of thermal properties of the concrete panel should not negatively reflect on its mechanical properties.

The effect of the additive on both thermal and mechanical properties of building materials was introduced by many searchers such as **Yesilata, et al., 2009**, investigated the effect of adding polymeric based waste material on the insulation property of the ordinary concrete. **Akçaözoğlu, et al., 2013,** studied the effect of replacement of traditional aggregate by a waste PET (polyethylene terephthalate) in the form of lightweight aggregate WPLA (waste PET lightweight aggregate), on thermal conductivity, density and compressive strength properties of the concrete composite. **Foti, 2013,** reported that there is an increment in thermal insulation of the concrete due to both adding pieces of waste rubber of tires and plastic fiber. **Saikia and de Brito, 2014,** which is reduced the density of fresh concrete by increasing the content of the plastic aggregate due to the particle density of plastic aggregate is very low. **Elinwa, et al., 2005,** concludes that the bulk density can be reduced significantly by replaced the cement partially by wood ash. While **Udoeyo, et al., 2006,** added wood waste ash at different ratios as a supplement to a concrete of mix proportion 1:2:4:0.56 (cement, sand, coarse aggregate, water, and cement). The additional effect of wood ash to the concrete roof mixture on the thermal conductivity and diffusivity of various samples was introduced by **Taoukil, et al., 2011,** they demonstrated that the embodiment of wood aggregates in the concrete increases its thermal insulation capacity significantly, as well as adding an equal mass percentage of wood aggregates. **Taoukil, et al., 2013,** studied the influence of moisture content on the thermal proprieties of the wood-concrete composite. **Chowdhury, et al., 2015,** studied the ability of replacement the uncontrolled burning of the sawdust by partial cement in the traditional concrete, acquired the sawdust from the wood polishing unit. **Yun, et al., 2013,** it is the replacement of coarse aggregate with the lightweight aggregates (Argex, Asanolite, Stalite) in the concrete mixture**. Fabien, et al., 2017,** showed that the aggregate size has a significant influence on the permeability and mechanical behavior of concrete.

In this work, the compound effect of adding insulation materials; wood ash, PET, and alabaster aggregates type marble-onyx to the concrete mixture component on thermal and mechanical properties have been studied, while previous work investigated the effect of adding each material to the concrete component separately on thermal and mechanical properties. As well as, the types of additive and the mass ratios in this work are different from that of previous work.

2. EXPERIMENTAL WORK

This work deals with different materials, some of them are similar to the local materials used in the common concrete classified as base materials and others selected as a low thermal conductivity properties classified as additives:

The base materials are the ordinary Portland cement, which is chosen from the product of the Kufa Cement Plant conforming to the Iraqi Standards No. 5 of 1984. Fine Aggregates (sand) are chosen from the Akheidhar area which is identical to the Iraqi standards (45-1980). The Coarse Aggregates were brought from the al-Naba'i quarries with identical to the Iraqi standards (45-1980). While the additive materials are the wood ash, which is representing the waste or wood residues that brought from carpentry plants and burned, then sift using a sieve with (75Mc) size to lift the large blocks and impurities. Alabaster aggregates represent an onyx-marble type used as a retrieve alabaster aggregates residue from the factories and markets, which are smashed, then sift through a sieve with a maximum size of 14 mm. The (PET) net with a square hole shape is made from polyethylene terephthalate and the thickness of the wire made of it is 3 mm and its length is 18 mm. This net used as a multilayer mesh with different orientations. The molds that used to pour the samples are designed depending on the thermal and mechanical testing. The molds with size (20×15×5) cm are used to pour the samples that used to measure the thermal conductivity and density, the molds with size (8×8×5) cm are used for the samples that used to measure the specific heat, the samples that used to measure the emissivity are poured by the molds with size (10×10×5) cm, the molds with size (15×15×5) cm are used for the samples that used to measure temperature distribution. Finally, the samples that prepared for he mechanical fracture test (flexural strength and the water absorption) are poured by the molds made with dimensions (20×60× 5) cm.

The practical work of the research built on a multistage mixing plan, each stage depends on thermal testing (thermal conductivity test, specific heat test, density test) results of the stage before. In the first stage, the mixing ratio depends on the ratio of sand to the cement making the cement as a base quantity because of its high thermal conductivity and also as glue to the mixture with keeping the coarse aggregate weight is constant. This is to measure the effects of the cement and sand ratios on the concrete panel thermal properties. The second stage mixing ratios based on changing the coarse aggregate quantities with the Alabaster aggregates leaving the cement and sand weights in a constant ratio according to the first stage thermal testing results. This is to reduce the thermal effects of the coarse aggregates on the thermal conductivity property. In the third stage, the mixing ratio created depends on the adding the wood ash instead of the sand to reduce of the thermal conductivity of the concrete depending on the low thermal properties of the ash with keeping the other quantities weights are constant. While the fourth stage mixing ratio based on decreasing the thermal conductivity and increasing the mechanical properties by adding a multilayer of plastic net with different orientations in the mixture as shown in **Fig. 1**, the layout of the mixing ratio plan is illustrated **Table 1**.

3. THE EXPERIMENTAL TESTS

3.1 Thermal Conductivity Test

Thermal conductivity measurements were made by using the quick thermal conductivity meter QTM 500 device at the National Center for Structural Testing. The QTM based on the ASTM C1113-90 was the principle of the measurement is based on the probe consists (type PD-11) of single heater wire and thermocouple by using A hot-wire method. When a constant electric power (energy) is given to the heater, the temperature of the wire rises in exponential progression and the temperature rising curve is plotted in a linear line with time axis as shown in **Fig. 2**. The angle of this line increases if the sample has less thermal conductivity and decreases if its higher thermal conductivity. Therefore, the thermal conductivity of the sample can be determined from the angle of the rising temperature graphic line by Eq. (1).

$$\lambda = k.R.I.\frac{ln(\frac{t2}{t1})}{(T_2 - T_1)} - H \quad (1)$$

Where, λ is Thermal conductivity of sample (W/m.K), I is the current (A), K and H are the Probe constant, R is electric resistance of probe heater (Ω/m), t1and t2 are time after heating started (s) and T_1andT_2 are temperature at t1and t2 (^oC).

3.2 The Specific Heat Test

The specific heat of the samples aged for 7 days was tested by a laboratory device that is shown in **Fig. 3** and the following equation is used to calculate the specific heat:

$$CP_m = \frac{Q_2 - Q_1}{m.(T_2 - T_1)} \quad (3)$$

Where:

$$Q_1 = I_1.V.t_1 \quad (3.1)$$

$$Q_2 = I_2.\mathrm{V}.t_2 \quad (3.2)$$

Where m is a mass of concrete panel (kg), I is the current (A), V is the voltage drop (V), Q_1 and Q_2 are the heat flow at time t_1 and t_2 respectively.

3.3 The Flexural Strength Test

The fracture test was carried out for the samples aged 28 days, at the National Center for Structural Testing in Baghdad. The test runs according to the Iraqi standards No. 1107 on 2002.

The flexural test deals with a rectangular sample under a three-point load bending as shown in **Fig. 4**. From the recorded data which are load F at the failure (fracture) sample, the flexural strength can be determined according to the Eq. (4) **Vol, 2000**. where L=580mm ,c=25mm ,w=200mm .

$$\sigma_f = \frac{3.L.F}{2.w.c^2} \tag{4}$$

Where, σ_f is flexural strength (KN/mm^2), c is half of the specimen thickness(mm), L is length of the support (outer) span(mm),F is fracture load(KN),w is width of the specimen(mm)

3.4 The Water Absorption Test

The water absorption test, for the specimens aged for 28 days, was done at the National Center for Structural Testing in Baghdad. The samples are placed in the water and take out one day before the test. The water absorption test based on drying the specimen at a temperature of approximately 105°C to a constant weight (weight A), then immersing it in the water for (24 hours) and weighing it again (weight B). The increase in weight as a percentage of the original weight is expressed as its absorption (in percent) as expressed in Eq. (5). The water absorption of the test samples should not be greater than 10%, according to the Iraqi standards No. 1107 on 2002

$$Water\ Absorption\ percentage\ = \frac{B - A}{A} * 100\% \tag{5}$$

3.5 The Surface Emission Test

The measurement of the surface emission is made in the Department of renewable energies in the Ministry of Science and Technology in Iraq. For samples (M1, M13, and M10)

3.6 The Temperature Distribution Test

The measurement of the temperature distribution through the concrete panel is made from the samples mentioned in paragraph 3.5, using 8 thermocouples.These cables were placed in each sample as follow, 3 thermocables at the outer panel, and 5 thermocables through the concrete panel as shown in **Fig. 5**, with code numbers, as (M1, M6, M7, M10, and M13).

4. RESULTS AND DISCUSSION

The results of the water absorption for concrete specimen tests are shown in **Fig. 6**. It can be seen from the figure that the increasing of the mass ratio of sand as in M2 (Cement: sand: coarse, 1:3:3) increases the water absorption of the sample compared with the sample M1 (Cement: sand: coarse, 1:2:3) and this is explained by **Celik and Marar, 1996**, which reported that sand acts as a filler in the concrete and increasing of the sand content more than 15% causes an increase in the absorption of water. While, the percentage of absorption of water decreased for the samples M3 to M5 due to the coarse aggregates have absorbed water more than alabaster aggregates, as **Gencel, et al., 2012,** resulted in his research. Then the water absorption started to increase, reaching the maximum values in M6 and M7. This is because the increase in the wood ash content raises the water absorption due to its high absorption properties, this agrees with

Siddique, 2012. The adding of the plastic net to the concrete mixture for the samples groups (M8 to M10) and (M11 to M13) has an insignificant effect on the water absorption because that the PET fiber is a hydrophobic polymer absorbs little water **Kim, et al., 2008**.

The flexural strength is calculated by **Eq. (4)** and the results are displayed in **Table 2**. The fracture force-tested for the concrete specimen is shown in **Fig. 7**. The results of the flexural strength testing show that the fracture force increased in sample M2 due to the high quantity of sand which increase the interaction between the mixed content. This is also founded by **Balogun and Adepegba, 1982**. The increment of onyx aggregate replacement with coarse alabaster aggregate decreases the flexural strength in samples M3, M4, and M5. This decay of results is obtained from the effect of the irregular shapes with sharp edges of the alabaster aggregate causes voids between the different aggregates and weakens the sample as **Gencel, et al., 2012,** resulted in his work. However, adding of the wood ash decreases the thermal properties but on the other hand it has a negative effect on fracture force, as shown in samples M6 and M7, this is because of the high brittleness property of the wood ash. This is confirmed by **Udoeyo, et al., 2006**. So, adding a plastic net to the mixture to reinforce the samples enhanced the fracture force, as indicated by the samples M10and M13 in comparison with samples M6 and M7. The increase of the number of the net layer increases the fracture force, as found by **de Oliveira and Castro-Gomes, 2011**. This is because the plastic net gives a good strengthening and ductility; also reduces the brittleness of the sample caused by the high quantity of the wood ash.

The densities of the tested samples are shown in **Fig.8**, where results show a very close in the densities of the samples M1 and M2, this means that the varying of sand mass ratio has an insignificant effect on the mixture density. While, the mass ratios of onyx-aggregate increases the sample density increases also, this is in samples M3 to M5, which is due to the high density of the aggregates **Hebhoub, et al., 2011**. However, the light weight of the wood ash replaced with sand in the concrete panel mixture, decreased the densities of the samples M6 and M7. This is because the wood ash has less density compared with sand and gravel **Abdullahi, 2006**. The reinforced samples M8 to M13 have low densities because the lighter weight of the plastic net with big volume occupation takes into the mixture. This is similar to **Saikia and de Brito, 2014**.

The results of the thermal conductivity are shown in **Fig. 9**. The results showed that the thermal conductivity increased in sample M2 as compared with sample M1.This is due to the fact that thermal conductivity of fine aggregate is high and uniformly distributed in the mixture with the addition of fine aggregate **Kim, et al., 2003**. The replacement of the onyx aggregate with the coarse aggregate raise the thermal conductivity for samples M3, M4 and M5 due to the air voids generated between the irregular shapes of the alabaster and the coarse aggregates, as well as, these voids reduced with the adding the alabaster aggregate **Topçu and Uygunoğlu, 2010**. The thermal conductivity reduced in in samples M6 and M7 due to the high content of low thermal conductivity wood ash. **Taoukil, et al., 2013** showed that addition of wood shavings in the concrete reduces the thermal conductivity of the composite. The addition of the of plastic nets causes the thermal conductivity reduced in M8, M9 and M10 for the concrete mixture with 50% wood ash content and reduced in sample M11,M12 and M13 for the mixture with 100% wood ash content, this is due to the low conductivity of the plastic net **Foti, 2013**.

Fig. 10 shows the specific heat results, the results showed that the minimum specific heat is for sample M2, which equals to 0.7 kJ/ kg K. As the mass ratio of sand increases in sample M1 the specific heat reduces, the specific heat increases also. This fact is shown by **Xu and Chung, 2000**. The addition of the alabaster aggregate to the concrete mixture, as in sample M3, increases the specific heat of the sample and more addition to alabaster aggregate tends to reduce the specific heat, as in samples M4 and M5. However, the addition of the wood ash raises the specific as in sample M6, the continuous adding wood ash tends to increase the specific heat as in sample M7. This is because the lightening of concrete by wood aggregates engenders a significant increase of the thermal insulation capacity as concluded by **Taoukil, et al., 2011**. The reinforcement of the samples by PET nets increases the specific heat of the samples as concluded by **Saikia and de Brito, 2012**.The emissivity is 0.901,0.909 and 0.889 for M1,M10 and M13 respectively. The measured temperature distribution through the outer layer of the roofs 1 to 5 is shown in **Fig. 11.**Where roof 1, roof 2, roof3, roof4 and roof5repersentes M1, M6, M7, M10 and M13 respectively. It can be seen from the figure the outer surface temperature reaches its minimum temperature at 4 hrs and maximum temperature at 16 hrs. Also, It can be seen from the figure that the outer surface temperatures along the day are about the same, while the inside surface temperature affected by the type of the roof. The traditional roof (roof 1) gives minimum temperature distribution at 0 hrs, while the maximum temperature distribution is at 12 hrs for the same roof. This means that traditionally has low thermal mass as compared with another roof. Roof 4 shows a high thermal mass and time delay with the outdoor conditions.

5. CONCLUSIONS

The analysis and discussion of the research results for the improved high thermal mass and high thermal resistance concrete panel made of different additive materials, could be significantly reduce the variation and heat flux effects on the indoor temperature with an agreement with the Iraqi standard for the mechanical property of the concrete panels used for flattening the building. Also, from this research, it can be recommended that the optimum concrete mixing ratio can be used as a new panel to flatten the Iraqi building in the future. Also, the following conclusions can be derived from the work:

1- The enhancements of replacing the Onyx aggregate with the coarse aggregate increased the specific heat by 12.5% for M3 as compared with M1, but at the same time, thermal conductivity and density are decreased by 8.22% and 8.89% for M3 as compared to M1.

2- The enhancements by adding wood ash to the concrete panel mixture reduce thermal conductivity and density by 35% and 16% for M7 as compared to M1 but at the same time the specific heat increases by 59% for M7 as compared to M1. While increasing the content of the wood ash in the concrete mixture decreases the flexure strength by 67% and in other side increase the water absorption to33% for M7 as compared to M1.

3- The enhancements of adding PET to the concrete panel mixture increase the flexure strength by 7% and 15% for M10, M13 as compared to M1, but it has an insignificant effect on water absorption. Also, PET will reduce the thermal conductivity by 42% and 53% for M10, M13 as compared with M1and density by 37%, 28% for M10, M13 as compared with M1, while the specific heat increase by 41%, 79% for M10, M13 as compared with M1.

4- The best concrete panel mixing ratio chosen in this research is indicated by M10 due to its good thermal insulation than M1. In which the reduction in heat flow through roof M10 is about 5%, as compared to the M1. As well as M 10 is acceptable according to the Iraqi standards No. 1107 on 2002.

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NOMENCLATURE

c= Half of the specimen thickness mm
F= Fracture load kN
I= Current A
K and H= Probe constant
L= Length of the support (outer) span mm
m= Mass of concrete panel kg
$Q_1$and Q_2 = Heat flow at time t_1 and t_2 respectively. kJ
R= The electric resistance of Probe heater Ω/m
t_1 and t_2= Time after heater turn On s
$T_1$and T_2= The temperature at t_1. t_2 ^{o}f

V = Voltage drop V
w= The width of the specimen mm
λ= The thermal conductivity of sample W/m.K
σ_f = Flexural strength kN/mm^2

Table 1. The mixing ratio of the quantities for all the stages.

Group	S.NO	Mixing Ratio*	Number of PET layer	w/c	Group	S.NO	Mixing Ratio	Number of PET layer	w/c
A	M1	1:2:3:0:0	-	0.5	D	M8	1:1:2:1:1	1	0.65
	M2	1:3:3:0:0	-	0.5		M9	1:1:2:1:1	2	0.65
B	M3	1:2:2:1:0	-	0.5		M10	1:1:2:1:1	3	0.65
	M4	1:2:1:2:0	-	0.5	E	M11	1:0:2:1:2	1	0.75
	M5	1:2:0:3:0	-	0.5		M12	1:0:2:1:2	2	0.75
C	M6	1:1:2:1:1	-	0.65		M13	1:0:2:1:2	3	0.75
	M7	1:0:2:1:2	-	0.75					

* Mixing Ratio: Cement: sand: coarse aggregate: Onyx aggregate: Wood Ash

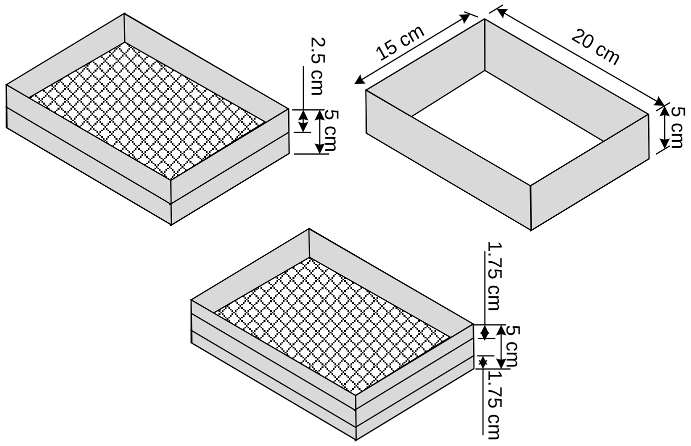

Figure 1. The mold types used in the work.

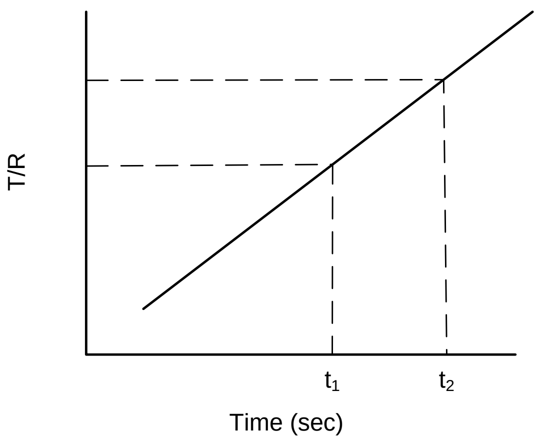

Figure 2. The temperature rising curve.

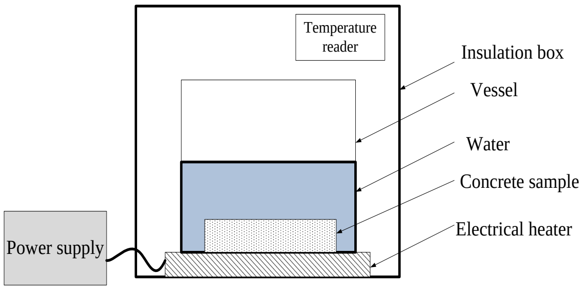

Figure 3. Specific heat demonstration.

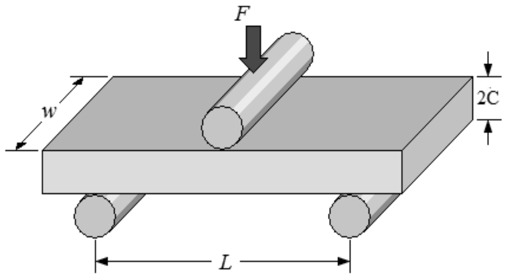

Figure 4 Bend testing of a rectangular bar under the three-point bend.

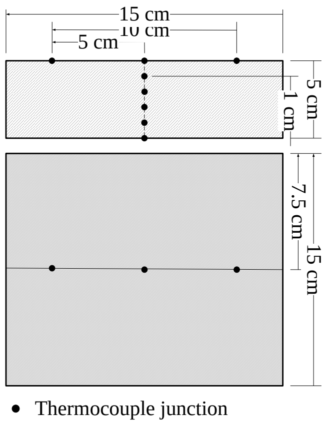

Figure 5. Thermocouples distribution through a concrete panel.

Table 2. Flexural strength.

No.	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13
σ_f kN/mm^2	19	19.76	17.05	15.52	12.25	11.83	6.26	13.64	16.77	20.18	9.32	13.15	16

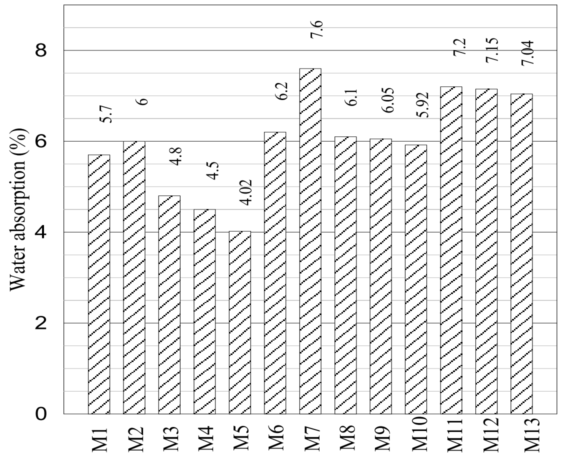

Figure 6.The water absorption test.

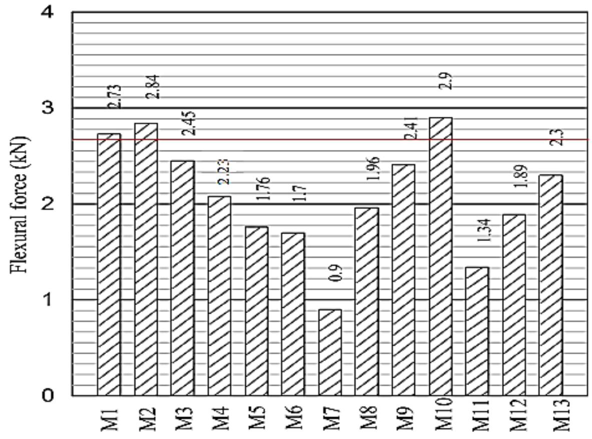

Figure 7. The flexural force testing.

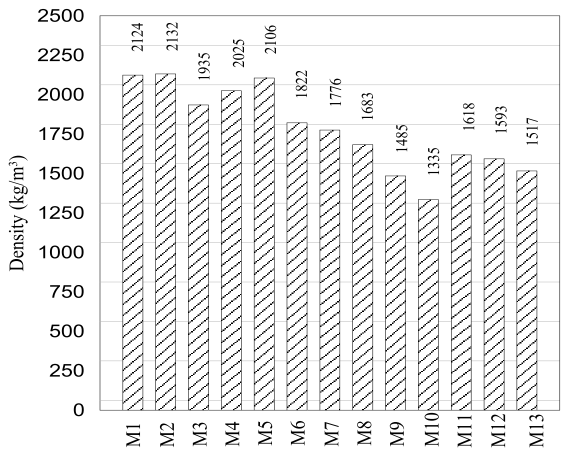

Figure 8. The density test.

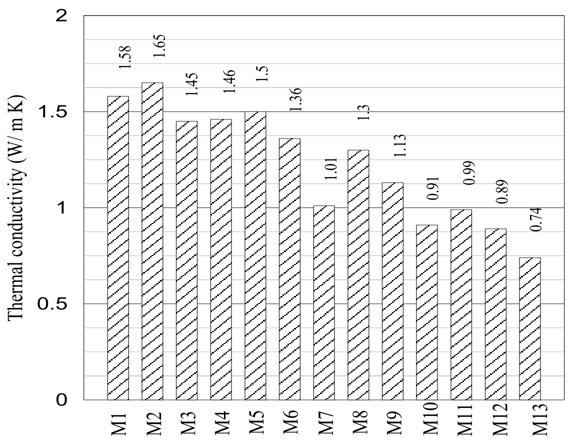

Figure 9. Thermal conductivity coefficient testing.

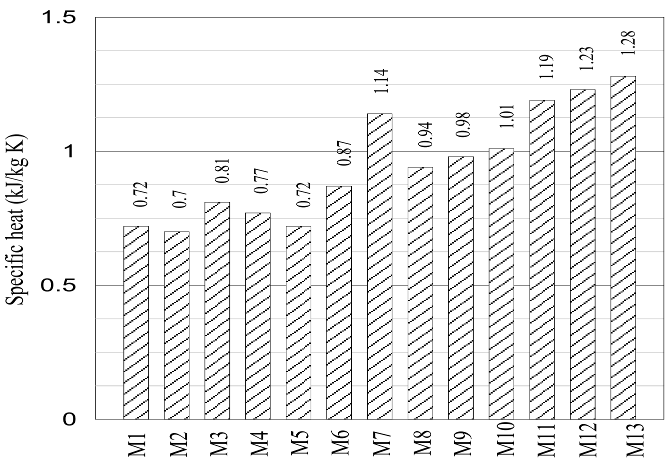

Figure 10. Specific heat test.

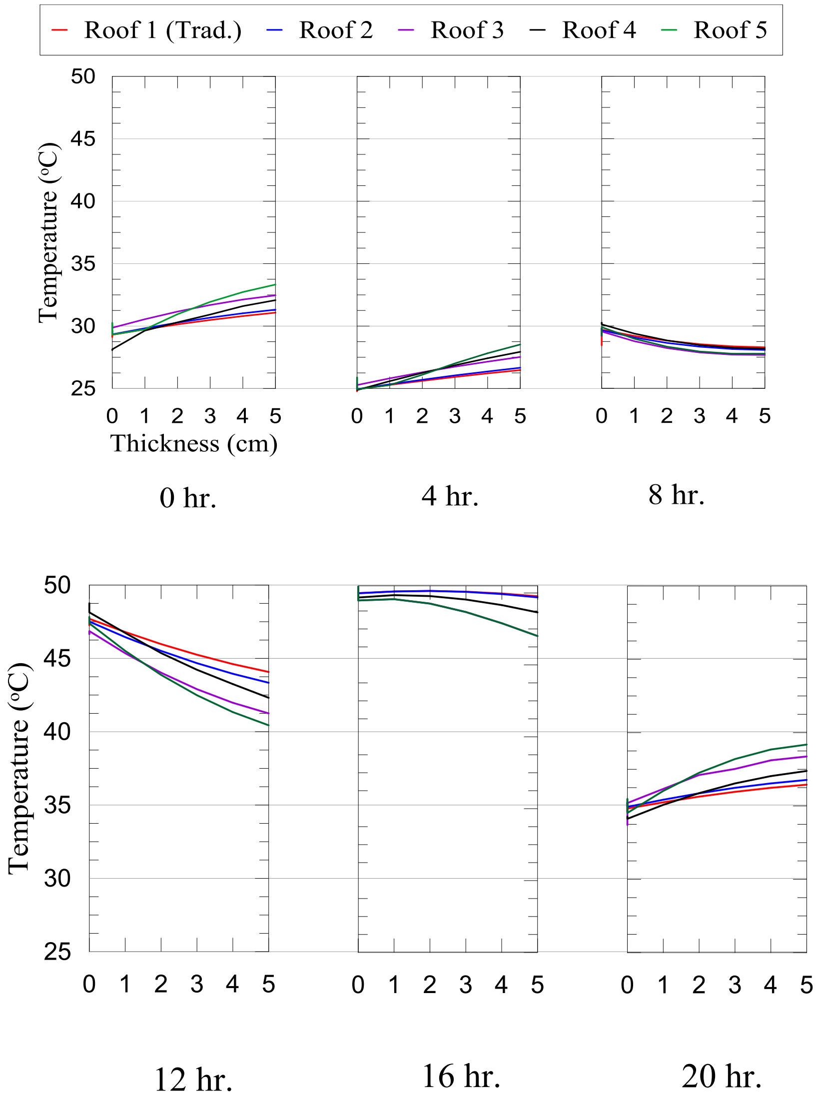

Figure 11. The Measured temperature distribution through the roof.