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Thermal Analysis of High Performance Lightweight Concrete Sandwich Panels

Dr. Husain M.Husain* , Dr. Zain A. Raouf & Dr. Wasan I. Khalil*****

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Abstract

This work is concerned with experimental and finite element investigation to determine the temperature distribution in hot weather through the section of the high performance lightweight concrete sandwich panels. In the experimental work thermal conductivity of unreinforced mortar, reinforced mortar and polystyrene concrete were investigated, then the thermal conductivity of eight series of 1000mm length and 200mm width concrete sandwich panels with two reinforced mortar faces of 20 mm in thickness and core of 30 and 50mm in thickness from polystyrene concrete were calculated. A nonlinear one – dimensional finite element analysis has been used to conduct an analytical investigation on the temperature distribution through the section of concrete sandwich panels. ANSYS (version 8) computer programme was utilized and 2-node LINK elements were used.

The experimental results show that thermal conductivity of the concrete sandwich panels is low with average value of 0.446 W/m.K and the thermal conductivity of the panels with similar type and volume content of reinforcement decreases by about 17% when the core thickness increases from 30 to 50 mm. The finite element results of temperature distribution show good agreement with the experimental measurements.

Keywords: Sandwich panels, Thermal conductivity, Mortar, Temperature.

التحليل الحراري للبلاطات الخرسانية المركبة عالية الاداء وخفيفة الوزن

الخلاصة

يشمل هذا البحث دراسة عملية وتحليلية بأستخدام طريقة العناصر المحددة لتحديد التوزيع الحراري خلال مقطع البلاطات الخرسانية المركبة عالية الاداء وخفيفة الوزن في الجو الحار.
تضمن البرنامج العملي دراسة معامل التوصيل الحراري للمونة الغير مسلحة, المونة المسلحة وخرسانة البولي ستايرين, بعد ذلك تم حساب معامل التوصيل الحراري لثمان مجاميع من البلاطات الخرسانية المركبة بطول ١٠٠٠مم وعرض ٢٠٠ مم ذات طبقتين من المونة المسلحة بسمك ٢٠مم وطبقة لباب وسطية من خرسانة البولي ستايرين بسمك ٣٠ مم و٥٠مم.
استعملت طريقة العناصر المحددة احادية البعد اللاخطية لأجراء تحليل نظري لتوزيع درجات الحرارة خلال مقطع البلاطات المركبة بالاستفادة من برنامج(ANSYS –V8) (انسيس/ صيغة ٨). استخدمت عناصر رابطة(LINK elements) ثنائية الابعاد وذات عقدتين في التحليل الحراري بطريقة العناصر المحددة. اظهرت النتائج العملية إن معامل التوصيل الحراري للبلاطات الخرسانية المركبة واطئ وبمعدل ٠,٤٤٦ واط/متر. كلفن وإن معامل التوصيل الحراري للبلاطات المتماثلة من حيث نوع ومحتوى التسليح يقل بحدود ١٧ % عند زيادة سمك طبقة اللباب من ٣٠ الى٥٠مم. كما اظهرت نتائج تحليل العناصر المحددة لتوزيع درجات الحرارة توافقا جيدا مع النتائج العملية.

* Engineering College, University of Tikrit/ Tikrit
** Engineering College, University of Baghdad/ Baghdad
*** Building and Construction Engineering Department, University of Technology/ Baghdad

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

Introduction:

Concrete sandwich panels considered in this investigation consist of thin ferrocement – like faces of relatively high performance and high elastic modulus separated by a relatively thick layer of low strength and lower density concrete as a core. The core material was made of expanded polystyrene concrete which is an ultra – lightweight concrete consisting of lightweight expanded polystyrene beads and cement matrix. The density of the polystyrene concrete ranges between 300 to 1600 kg/m^3 [1], this low density and porous structure give polystyrene concrete excellent thermal and sound insulation properties. The use of concrete sandwich panels offers many benefits because of their unique construction advantages. The main benefit of concrete sandwich panels is that the insulation layer provides superior thermal insulating properties.

The thermal insulation properties of a building material can be identified by the coefficient of thermal conductivity (k).

ASTM [2] and British standards [3] define thermal conductivity (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".

The thermal conductivity of polystyrene concrete was studied by a number of workers [4, 5]. They showed that a marked reduction in thermal conductivity occurs with the increase in polystyrene beads content and the thermal conductivity of polystyrene concrete ranges between 0.11 – 0.419 W/m.K within a density range of 354– 1170 kg/m^3 respectively. Other researchers considered the interacted factors which influence the thermal conductivity of concrete, mortar and cement paste. They found that:[6]

1- Aggregate volume fraction and moisture condition of specimen are shown to be mainly affecting factors on the conductivity of concrete.

2- The conductivities of mortar and cement paste are strongly affected by water –cement ratio and types of admixture.

3- Age hardly changes the conductivity except for very early age.

Experimental Work

Mortar Mix:

Ordinary Portland cement from Lebanon named Trabet Al-Saba'a was used throughout this investigation. Its chemical composition and physical properties are given in Tables (1) and (2) respectively. The test results show that the cement conforms to the provisions of Iraqi specification No.(5)-1984. Natural sand of maximum size 4.76 mm was used in this investigation. It was brought from Al-Ukhaider region and its gradation lies in zone (4). The grading test results conform to Iraqi specification No.45-1984. Table (3) shows the properties of fine aggregate. Mortar mix used to produce the high performance faces of concrete sandwich panels is 1:1(cement: sand) with 17% feldspar powder replacement of cement by weight, water cement ratio 0.249 and super plasticizer dosage 4% by weight of cement. This mix has 28 days compressive strength of about 80N/mm^2

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Polystyrene Concrete

Polystyrene concrete mix used in this investigation as a core material in the sandwich panels consists of cement and polystyrene in the ratio (c/p) of 1:4 by volume with water-cement ratio of 0.38 by weight. The density of this mix is 470 kg/m^3. A high content of polystyrene was selected to provide good insulation properties for the core as mentioned by other researchers[4, 5]. The sieve analysis of the polystyrene beads is given in Table (4).

Test Variables:

Test specimens were classified to eight series of 1000mm length and 200mm width concrete sandwich panels with two reinforced high performance mortar faces of 20mm in thickness and core of 30 and 50mm in thickness from polystyrene concrete. The variables studied in the test series were the thickness of polystyrene concrete core (30mm and 50mm), type of reinforcement of faces as shown in Fig. (1) (polyimide grid, polypropylene mesh and chicken wire mesh) and volume fraction of reinforcement meshes (2.8% and 5.6%). Details are shown in Table (5).

Preparation of Sandwich Panel Specimens

In order to cast sandwich panels, moulds were prepared with internal dimensions of (200×1000 mm) and depth of 70 and 90mm. The moulds were made from wooden frame for the edges and plywood block were used for the base to obtain smooth surfaces. The edges of the moulds were bolted to the base with sufficient number of bolts to ensure water tightness. Before casting, the mould sides and the base were oiled slightly to prevent mortar sticking to the surfaces. Bottom layer of the mortar mix was first cast and distributed along the entire mould, and a layer of reinforcement mesh was placed. The same procedure was followed for the other remaining amounts of mix and reinforcement meshes were placed consequently. Then polystyrene concrete mix was placed over the bottom layer of mortar. The upper layer of the mortar mix was placed over polystyrene concrete following the same procedure described previously for the bottom layer of mortar. The compaction of each layer was carried out by knocking the sides of mould with many blows. After casting, the moulds were covered with polyethylene sheet for about 24 hours, and then demoulded for curing.

Thermal Conductivity Test Specimens:

Prism specimens of 200×100×50mm were prepared from the same mixes of mortar, polystyrene concrete and reinforcement meshes to measure thermal conductivity of mortar and polystyrene concrete.

Curing

After demoulding, all specimens were cured by the same method which consisted of covering the specimens with burlap and spraying water on them every day, then covering them with polyethylene sheets. The specimens were cured for 60 days after that they were kept in the laboratory for 7 days to be normally dried until the time of testing .Only the polystyrene concrete specimens were cured by covering them with sealed air – tight polyethylene sheets.

Experimental Tests

Thermal Conductivity Test

Thermal conductivity test was carried out according to (B.S.874) by using the thermal conductivity meter model (TC-31)[7] manufactured by (KOYOTO ELECTRONICS COMPANY) as shown in Fig. (2).

The thermal conductivity was measured by calculating the temperature increase of a thin metal heating wire before a thermal equilibrium is reached. The heating wire which was held between two identical prismatic samples (200×100×50mm) each became hot due to heat energy when an electric current was applied to it as shown in Fig. (3).The thermal conductivity was determined based on the fact that the greater the thermal conductivity of the sample being measured, the faster the heat moves and dissipates and the less and slower the temperature rises in the heating wire. The temperature rise of the heating wire was calculated by the apparatus, and then it was displayed digitally. The average of three readings for each specimen was recorded. The measured value of the thermal conductivity is in terms of (W/m.K).

Temperature Measurement Test The temperature through the section of concrete sandwich panels with 3 and 5cm core thickness after exposure to ambient temperature was measured by using (Nickel Chrome – Nickel Alumel) thermocouples and by digital electronic thermometer. Calibration was made to the apparatus before the beginning of the temperature measurement. The thermocouples wires were fixed in the specified position inside the specimens as indicated in Fig. (4). Temperature readings were taken for different periods of time after direct exposure to sun radiation in summer.

Thermal Finite Element Analysis

A thermal analysis gives the temperature distribution and related thermal quantities in a system or component. Typical thermal quantities of interest are the temperature distribution; the amount of heat lost or gained thermal gradients and thermal fluxes.

For the heat problem in this investigation, there are two modes of heat transfer (conduction and convection). When a temperature gradient exists in a medium, conduction heat transfer occurs and the energy is transported from the high temperature region to the low temperature region by molecular activities. The heat transfer rate is given by Fourier's law[8]:

$$q_{y(conduction)} = -kA\frac{dT}{dy} \quad \text{..... (1)}$$

where:

q_y: the y – component of the heat transfer rate.

k: thermal conductivity of the medium in y –direction.

A: area of the medium perpendicular to y – direction.

$\frac{dT}{dy}$: Temperature gradient in y – direction.

The minus sign in Equation (1) is due to the fact that heat flows in the direction of decreasing temperature (negative temperature gradient).

Convection heat transfer occurs when air in motion comes into contact with a surface whose temperature is higher from the moving air temperature. The overall heat transfer rate between the air and the surface is governed by Newton's law of cooling, according to the following equation[8]:

$$q_{(covection)} = hA\,(T_s - T_a) \quad \ldots (2)$$

where:

h: heat transfer coefficient from (25 – 50 W/m^2.k).

T_s: surface temperature.

T_a: temperature of the moving air.

By applying the energy balance to a differential element in the panel cross section shown in Fig.(5)[8]

$$q_y = q_{y+dy} + dq_{convection} \quad \ldots\ldots (3)$$

or,

$$q_y = q_y + \frac{dq_y}{dy}dy + dq_{convection} \quad \ldots\ldots\ldots(4)$$

By substituting Fourier's law (Eq. (1)) and Newton's law of cooling (Eq. (2)) in Equation (4), the one – dimensional heat transfer through the section of the panel in this investigation is governed by the following heat equation[8]:

$$-kA\frac{d^2T}{dy^2} + hA(T_s - T_a) = 0 \quad \ldots .. (5)$$

For the heat transfer problem in this investigation, there is no heat convection through the layers of the panel cross section, so Equation (5) can be written as follows:

$$-kA\frac{d^2T}{dy^2} = 0 \quad \ldots\ldots (6)$$

Equation (6) is subjected to a set of boundary conditions. First, the temperature of the upper surface T_1 is generally known, that is:

$$T_1 = T_t \quad \ldots\ldots (7)$$

and

$$-kA\frac{dT}{dy}\Big|_{y=L} = hA(T_L - T_a) \ldots\ldots (8)$$

Equation (8) simply states that the heat energy conducted to the lower surface of the panel section must be equal to the heat energy transfer by convection due to surrounding moving air.

Finite Element Programme and Type of Element

The finite element solution obtained by using ANSYS in this investigation is one – dimensional heat transfer problem. The programme handles all three primary modes of heat transfer, conduction, convection and radiation[9].

Two types of uniaxial link elements, LINK 32 and LINK 34, were used to solve the one – dimensional heat – conduction problem in this work. LINK 32 elements is a uniaxial heat conduction element, it allows for the transfer of heat between its two nodes via conduction mode. The nodal degree of freedom associated with this element is temperature. The element is defined by its two nodes, cross – sectional area and material properties such as thermal conductivity. LINK 34 elements is a uniaxial convection link that allows for heat transfer between its nodes by convection. This element is defined by its two nodes, a convective surface area and a convective heat transfer (film) coefficient. The geometry, node locations and coordinate system for conducting bar element LINK 32 and convection element LINK 34 are shown in Figures (6) and (7) respectively[9].

Results and Discussions

Thermal Conductivity Results of the Faces and Core Materials

The thermal conductivity of mortar varies with its density and moisture content, the lower water – cement ratio and the denser cement matrix in high strength high performance mortar result in higher thermal conductivity (lower thermal resistance) than that measured in lower strength mortar[10].

Before calculating the thermal conductivity of concrete sandwich panels, it was necessary to evaluate the thermal conductivity of the materials which were used to prepare the panel specimens. The results of thermal conductivity of unreinforced mortar, polystyrene concrete and mortar reinforced with different types and volume fractions of reinforcement used to produce the concrete sandwich panels are shown in Table (6). It can be seen that the thermal conductivity for mortar reinforced with either polyimide grids or polypropylene meshes with volume content 2.8% is slightly higher than that of unreinforced mortar, while the increase in volume fraction to 5.6% leads to a decrease in thermal conductivity by about 11% and 5.6% for mortar reinforced with polyimide grids or polypropylene meshes respectively. This may be due to the fact that the incorporation of fibre causes a decrease in the effective water content of the matrix[11], so the lower the water content of the mix, the higher the conductivity of the hardened mortar[12]. On the other hand, the increase in volume fraction of fibre to 5.6% leads to a reduction in the compactability of the mix thus increasing the entrapped air and this is followed by a decrease in density[13]. This rarefaction will affect the thermal conductivity of the composite since the thermal conductivity decreases as the density decreases.

The results also indicate that the value of thermal conductivity increases by about 7% and 8% when the mortar is reinforced with chicken wire meshes with volume fraction of 0.32% and 0.64% respectively. This is because the thermal conductivity of steel (chicken wire meshes) is higher than the thermal conductivity of the mortar.

Obviously it can be seen that the thermal conductivity of polystyrene concrete is much lower than that of the unreinforced mortar and mortar reinforced with different types of reinforcement. This is because of the fact that lightweight concretes have high porosity which leads to very low thermal conductivity because of the large volume of air voids[12]. These results agree with the results obtained by Cheng and Lee[14].

Thermal Conductivity of Concrete Sandwich Panels

The computational method to determine the equivalent thermal conductivity (k_{eq}) of multi – layer panels (sandwich panels) is based on the thermal conductivity and thickness of each layer according to the following equation[1,15]:

$$k_{eq} = \frac{t_1 + t_2 + t_3}{\frac{t_1}{k_1} + \frac{t_2}{k_2} + \frac{t_3}{k_3}} \quad \text{..... (9)}$$

Where t_1, t_2, t_3 and k_1, k_2 , k_3 are the thickness and thermal conductivity of upper face, polystyrene concrete core and lower face respectively.

The values of the thermal conductivity of the concrete sandwich panels (k_{eq}) are shown in Table (7) and plotted in Fig. (8). In general it can be seen from the table and Fig. (8) that the panels with similar type and volume content of reinforcement, the value of thermal conductivity decreases by an average value of 17% when the core thickness increases from 3cm to 5cm. This is because of the very low thermal conductivity of the core material (polystyrene concrete). Also it is clear that there is a very slight increase in thermal conductivity of specimens reinforced with either polyimide grids or polypropylene meshes with volume fraction of 2.8% for both core thicknesses (3 and 5cm) as compared with unreinforced panel specimen. On the other hand there is an average decrease of 1.4% in thermal conductivity of panels reinforced with either polyimide grids or polypropylene meshes with volume fraction 5.6% for both core thicknesses (3 and 5cm). This is attributed to the values of thermal conductivity and thickness of each layer of concrete sandwich panel as shown in Table (6).

The results also indicate that the thermal conductivity of concrete sandwich panels in series 6, 7 and 8 with tension face reinforced with chicken wire meshes is slightly higher than that of specimens with the same core thickness, type and volume content of reinforcement in the compression face, but with tension face reinforced with either polyimide grids or polypropylene meshes (series 2, 3 and 4 respectively). This is attributed to the slightly higher thermal conductivity of the mortar reinforced with chicken wire meshes as compared with the thermal conductivity of the mortar reinforced with either polyimide grids or polypropylene meshes. This is ascribed to the results given in Table (6). It can be noticed from Table (7) that the mean coefficient of thermal conductivity of concrete sandwich panels of core thickness 3cm is found to be 0.487 W/m.K, while for concrete sandwich panels of 5cm core thickness the mean value was 0.404 W/m.K. Such values may be considered as relatively low and this means that the sandwich section is a good insulator with respect to the investigated dimensions.

Experimental Results of Temperature Distribution

Figure (9) shows the experimental results of the temperature distribution with time at the surface of the upper face, surface of lower face and positions 1, 2, 3 inside the section of the concrete sandwich panels with core thickness 3 and 5cm in hot weather under the actual conditions in July 2006, each temperature value represents the average of three measurements. It can be seen that there is a significant rise in the temperature for all positions with time. This may be due to the increase in ambient air temperature with time, which is absorbed by the upper surface of the specimen. This increase in temperature continued for about 3 hours after exposure to sun, thereafter the temperature decreased at all positions. This is probably due to the decrease in the ambient air temperature and the beginning of the dissipation of heat from the specimen which depends on the temperature outside[16].

Tables (8), (9) and Figure (9) indicate that the core material (polystyrene concrete) of the concrete sandwich panels has a significant effect on the reduction of temperature through the section of the specimen. The reduction of temperature after 3 hours of exposure to sun in position 2 was about 7 and 9°C, on the other hand the reduction of temperature in position 3 was about 12 and 13°C for specimens with core thickness 3 and 5cm respectively in comparison with the temperature of the upper surface. This is due to the low thermal conductivity of the polystyrene concrete.

Temperature Distribution Results Obtained from Computer Analysis

As mentioned previously a computer programme (ANSYS) was used to determine the temperature transfer through the section of the concrete sandwich panel, the programme is based on the finite element method. The analysis was carried out by using the following method:

1. The positions 1, 2, 3, 4, 5, 6 and 7 located at the centre and the interface of each layer of the section of the specimen represent as nodes at the ends of link elements. Fig. (10) shows the nodes and link elements at the centre of the cross sectional area of the concrete sandwich panel.
2. The information about the upper surface temperature of the specimen (T_t), heat transfer coefficient (h) and the thermal conductivity of each layer (k_1, k_2, k_3) as tested experimentally was fed to the programme. The temperature in each node inside the section was calculated and these results were compared with those obtained from the experimental work.

Tables (8), (9) and Figures (11), (12) show the results of the experimental and the finite element temperature distribution through the section of the concrete sandwich panel in hot weather under actual conditions at different times. The tables and figures show that the temperature at the core region (position 2) and at the middle depth of the lower surface of the specimen (position 3) significantly decreases relative to the temperature at the upper surface and position 1. This is due to the low thermal conductivity of the core material (polystyrene concrete). Also the tables and figures indicate that the finite element analysis results have good agreement with the experimental results.

Conclusions

From the analysis of the results presented in this work and within the limitation of the investigation programme, the following conclusions can be drawn:

1. Thermal conductivity of the concrete sandwich panels is low. The average value is 0.446 W/m.K.
2. Thermal conductivity of the panels with similar type and volume content of reinforcement decreases by about 17% when the core thickness increases from 30 to 50mm.
3. The experimental temperature transfer with time through the cross – section of the concrete sandwich panels in hot weather indicates that there is a considerable difference in temperature between the upper surface and each of the core layer and the lower surface at all exposure time periods.
4. The core material (polystyrene concrete) causes a significant decrease in temperature through the depth of the cross – section of the specimens in comparison with the temperature of the upper surface.

5. The finite element results of temperature distribution through each node in the centre of cross – section of the concrete sandwich panel have in general shown good agreement with the experimental results. This confirms the validity of the finite element method using ANSYS programme to predict the thermal distribution through the cross – section of the concrete sandwich panels.
6. The experimental and the finite element results indicate that the use of polystyrene concrete as a core produces good thermal insulation properties for the sandwich panels.

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Table (1) Chemical composition and main compounds of the cement used throughout this work

Oxide	% by weight	Limit of Iraq specification No.5/1984
CaO	62.8	-
SiO_2	21.2	-
Al_2O_3	5.2	-
Fe_2O_3	3.5	-
MgO	0.95	$\leq$ 5.0
SO_3	2.6	$\leq$ 2.8
Na_2O	0.3	-
K_2O	0.4	-
Loss on ignition	2.2	$\leq$ 4.0
Insoluble residue	1.0	$\leq$ 1.5
Lime saturation factor	0.89	< 1.02 > 0.66
Main compounds		
C_3S	47.16	-
C_2S	25.29	-
C_3A	7.86	
C_4A_F	10.64	-

Table (2) Physical properties of cement

Physical properties	Test results	Limit of Iraq specification No.5/1984
Specific surface area, Blain method, m^2/kg	346	$\geq$ 230
Soundness, Le-Chatelier method (mm)	1	< 10
Setting time, Vicat's method Initial setting, hr : min Final setting, hr : min	 1:55 3:15	 $\geq$ 45 minutes $\leq$ 10 hours
Compressive strength 3-days N/mm^2 7-days N/mm^2	 22.5 38.5	 $\geq$ 15 $\geq$ 23

Table (3) Fine aggregate properties

Sieve size (mm)	% Passing	Limit of Iraqi specification No.45/1984, zone (4)
4.75 mm	100	95-100
2.36 mm	99	95-100
1.18 mm	93.5	90-100
0.60 mm	82.3	80-100
0.30 mm	47.5	15-50
0.15 mm	10.2	0-15
SO_3 content = 0.4 % (specification requirements 0.5%) Clay content = 0.1 % (specification requirements 5%) Specific gravity = 2.61 Absorption = 1%		

Table (4) Polystyrene beads sieve analysis

Sieve size mm	% Passing
6.7	100
4.75	60.64
2.36	2.38
2.0	1.91
1.7	1.09
1.18	0.54
1.0	0.09
0.85	0

Table (5) Details of test sandwich panel specimens

Series No.	Designation	Core thickness mm	Upper face			Lower face		
			Type of Reinforcement	Volume fraction of Reinforcement Vf %	No. of layer of reinforcement	Type of reinforcement	Volume fraction of reinforcement Vf %	No. of layer of reinforcement
1	P3	30	Non	—	—	Non	—	—
	P5	50	Non	—	—	Non	—	—
2	1GP3	30	Polyimide grids	2.8	1	Polyimide grids	2.8	1
	2GP3	30	Polyimide grids	5.6	2	Polyimide grids	5.6	2
3	1GP5	50	Polyimide grids	2.8	1	Polyimide grids	2.8	1
	2GP5	50	Polyimide grids	5.6	2	Polyimide grids	5.6	2
4	1PL3	30	Polypropylene meshes	2.8	1	Polypropylene meshes	2.8	1
	2PL3	30	Polypropylene meshes	5.6	2	Polypropylene meshes	5.6	2
5	1PL5	50	Polypropylene meshes	2.8	1	Polypropylene meshes	2.8	1
	2PL5	50	Polypropylene meshes	5.6	2	Polypropylene meshes	5.6	2
6	1HGP3	30	Polyimide grids	2.8	1	Chicken wire	0.32	1
	2HGP3	30	Polyimide grids	5.6	2	Chicken wire	0.64	2
7	1HGP5	50	Polyimide grids	2.8	1	Chicken wire	0.32	1
	2HGP5	50	Polyimide grids	5.6	2	Chicken wire	0.64	2
8	1HPL3	30	Polypropylene meshes	2.8	1	Chicken wire	0.32	1
	2HPL3	30	Polypropylene meshes	5.6	2	Chicken wire	0.64	2

Table (6) Thermal conductivity of reinforced mortar and polystyrene concrete

Type of specimen	Volume fraction of reinforcement Vf %	Thermal conductivity (k) W/m.K
Mortar without reinforcement	0	1.571
Mortar reinforced with polyimide grids	2.8	1.623
	5.6	1.395
Mortar reinforced with polypropylene meshes	2.8	1.603
	5.6	1.48
Mortar reinforced with chicken wire meshes	0.32	1.681
	0.64	1.695
Polystyrene concrete	—	0.254

Table (7) Equivalent thermal conductivity of the concrete sandwich panels

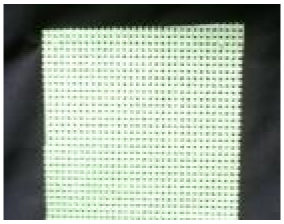
Serial No.	Specimen mark	Thermal conductivity (k_{eq}) W/m.K
1	P3	0.488
	P5	0.405
2	1GP3	0.49
	2GP3	0.477
3	1GP5	0.406
	2GP5	0.399
4	1PL3	0.489
	2PL3	0.482
5	1PL5	0.406
	2PL5	0.402
6	1HGP3	0.492
	2HGP3	0.485
7	1HGP5	0.407
	2HGP5	0.404
8	1HPL3	0.491
	2HPL3	0.488

Table (8) Experimental and finite element results of temperature distribution through the section of concrete sandwich panel with core thickness 3cm in July 2006

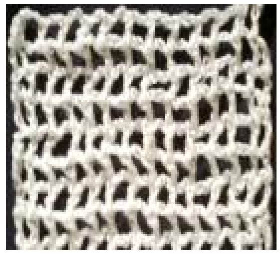
Time of exposure to sun radiation hr	Ambient air temperature °C	Upper surface temperature °C	Lower surface temperature °C		Temperature in position - °C		
					1	2	3
0	35.4	32.2	32.1	F.E.A.	32.1	31.8	31.6
				Experimental	31.7	31.3	31.3
1	36.8	44.6	33.3	F.E.A.	44.1	38.93	33.75
				Experimental	42.85	38.4	33.4
2	37.4	46.7	34.8	F.E.A.	46.1	40.74	35.33
				Experimental	45.9	41.4	35.23
3	40	49.7	35.5	F.E.A.	49	42.59	36.1
				Experimental	47.73	42.67	37.6
4	39.7	49.6	34.9	F.E.A.	48.9	42.28	35.8
				Experimental	48.1	43.7	37
5	39.3	47.5	34.9	F.E.A	46.93	41.21	35.49
				Experimental	45.3	41.8	36.78
6	39	44.9	33.1	F.E.A.	44.46	39.1	34.66
				Experimental	43.23	40.3	35
7	39	42.7	32.6	F.E.A.	42.34	38.64	33.94
				Experimental	40.5	38.6	34.5
8	38.7	39.2	31.2	F.E.A.	38.84	36.8	32.51
				Experimental	39.3	38	34
9	35.6	35.4	30.5	F.E.A.	35.16	32.95	31.75
				Experimental	35.2	34.8	33.58
10	34.2	33.6	29.6	F.E.A.	33.4	31.89	30.9
				Experimental	33.1	33.1	32.1

Table (9) Experimental and finite element results of temperature distribution through the section of concrete sandwich panel with core thickness 5cm in July 2006

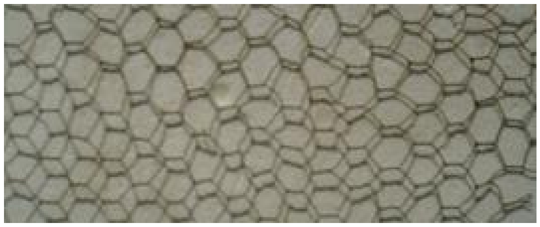
Time of exposure to sun radiation hr	Ambient air temperature °C	Upper surface temperature °C	Lower surface temperature °C		Temperature in position - °C		
					1	2	3
0	36.2	32.2	31.7	F.E.A.	31.9	31.76	31.7
				Experimental	31.7	31.7	31.7
1	38	43.8	33.6	F.E.A.	43.5	38.7	33.89
				Experimental	43.1	36.8	33.8
2	38.6	48	35.3	F.E.A.	47.64	41.65	35.66
				Experimental	47.2	40.2	36.3
3	40.5	49.5	35.9	F.E.A.	48.85	42.7	36.29
				Experimental	48	40.4	36.7
4	40.1	49.1	35.6	F.E.A.	48.52	42.35	35.99
				Experimental	47.5	40.2	36.3
5	40	47.6	33.7	F.E.A.	47.2	40.67	34.13
				Experimental	46.9	39.3	34.8
6	39.1	45.7	33.6	F.E.A.	45.34	39.67	33.99
				Experimental	44.9	38.2	34.2
7	38.6	44.2	33.3	F.E.A.	43.8	38.73	33.56
				Experimental	41.6	36.9	33.7
8	37.2	38.9	32	F.E.A.	38.78	35.49	32.2
				Experimental	37.9	35.2	32.9
9	36	35.6	31.2	F.E.A.	35.47	33.38	31.29
				Experimental	35.6	34.1	32.4
10	33.4	33.4	31.1	F.E.A.	33.29	32.22	31.15
				Experimental	32.9	32.3	31.2



a- polyimide grid



b- polypropylene mesh



c-chicken wire mesh

Figure (1) Types of reinforcement used in this work

Figure (2) Assembly of the thermal conductivity apparatus

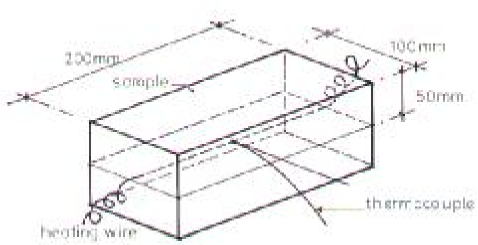


Figure (3) Arrangement of the samples for thermal conductivity test

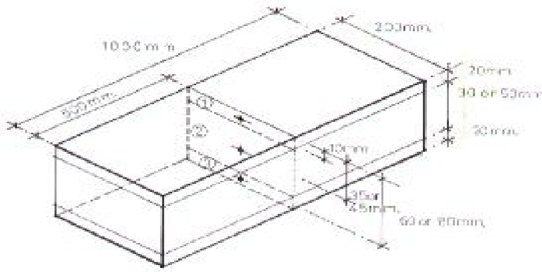


Figure (4) Thermocouples positions through the mid – span section of the concrete sandwich panel

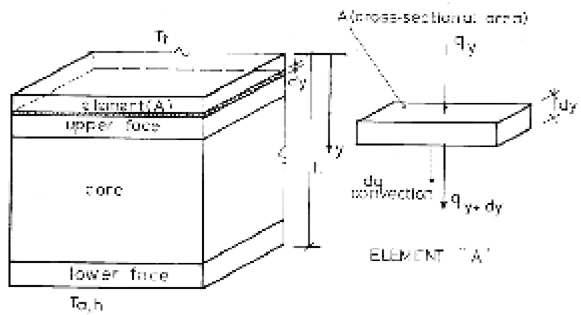


Figure (5) Heat transfer through finite element[8]

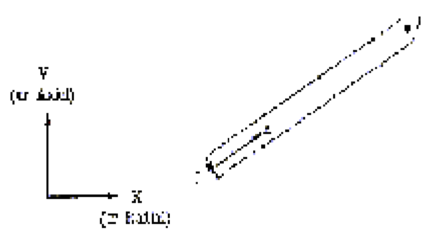


Figure (6) LINK 32 two – dimensional conduction bar[9]

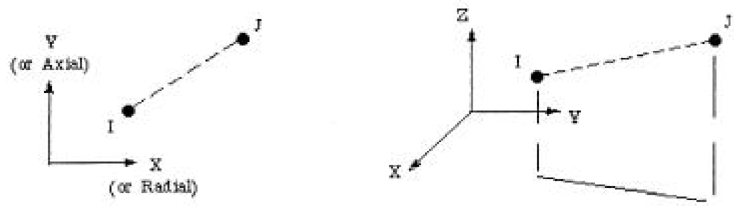


Figure (7) LINK 34 convection link [9]

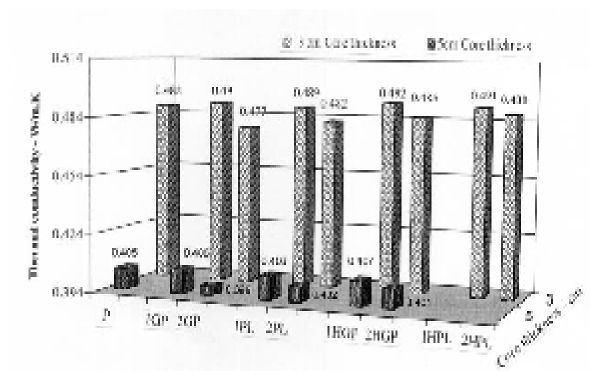
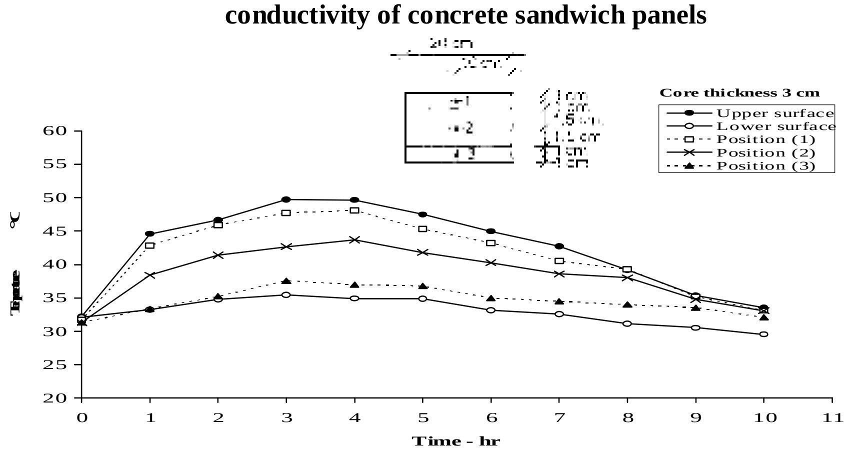


Figure (8) Effect of core thickness and type of reinforcement on thermal conductivity of concrete sandwich panels



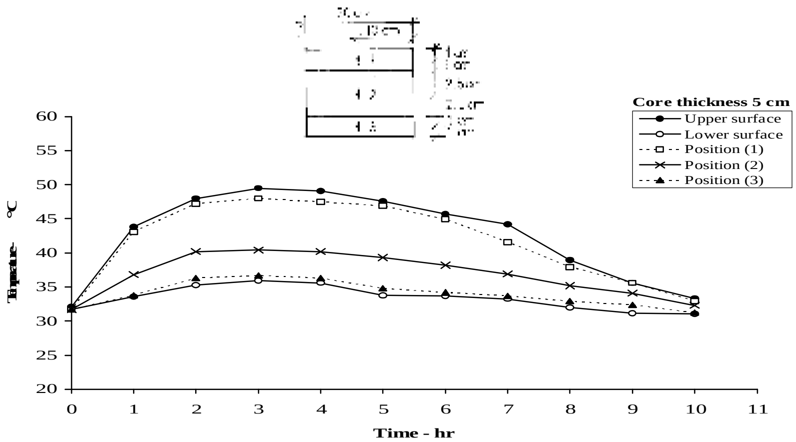
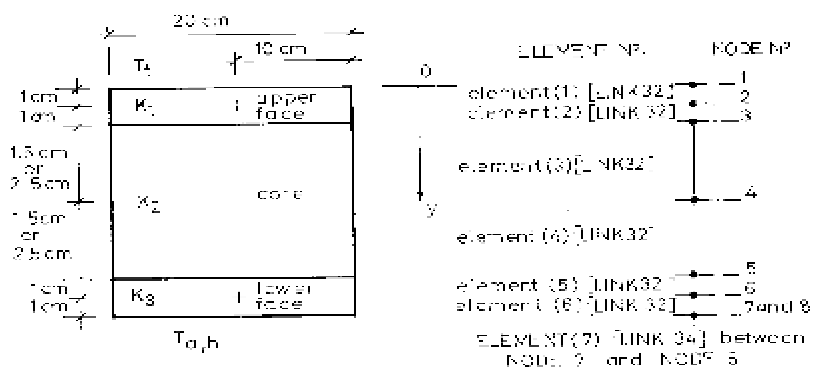
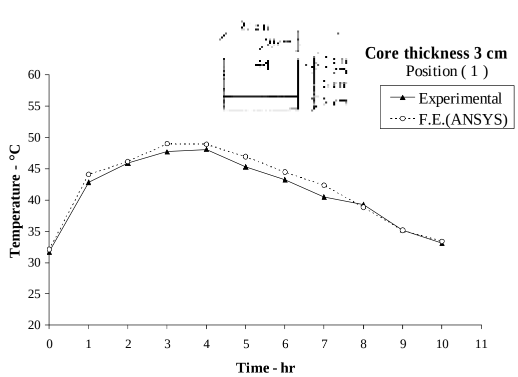


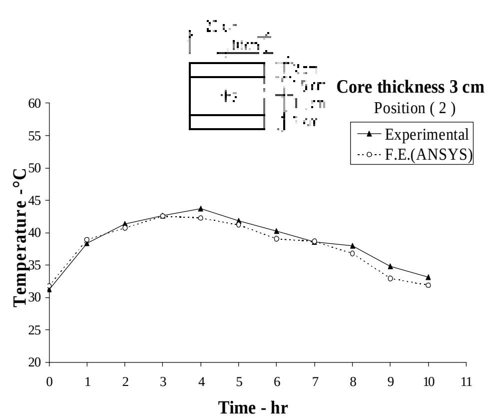
Figure (9) Experimental temperature distribution through the cross section of the concrete sandwich panels in hot weather



(h) is assumed to have a value (40 W/m^2. k)

Figure (10) Finite element model used for the temperature distribution Through the cross section of the concrete sandwich panels





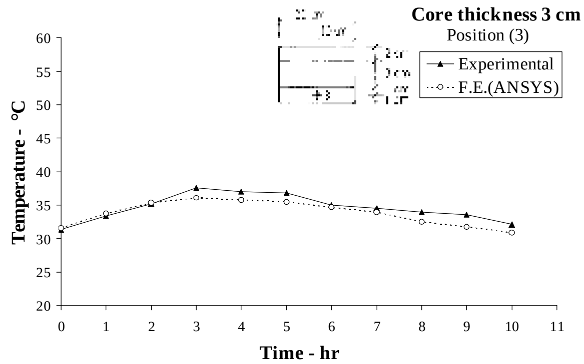


Figure (11) Experimental and finite element results of temperature distribution in concrete sandwich panels with core thickness 3cm at hot weather

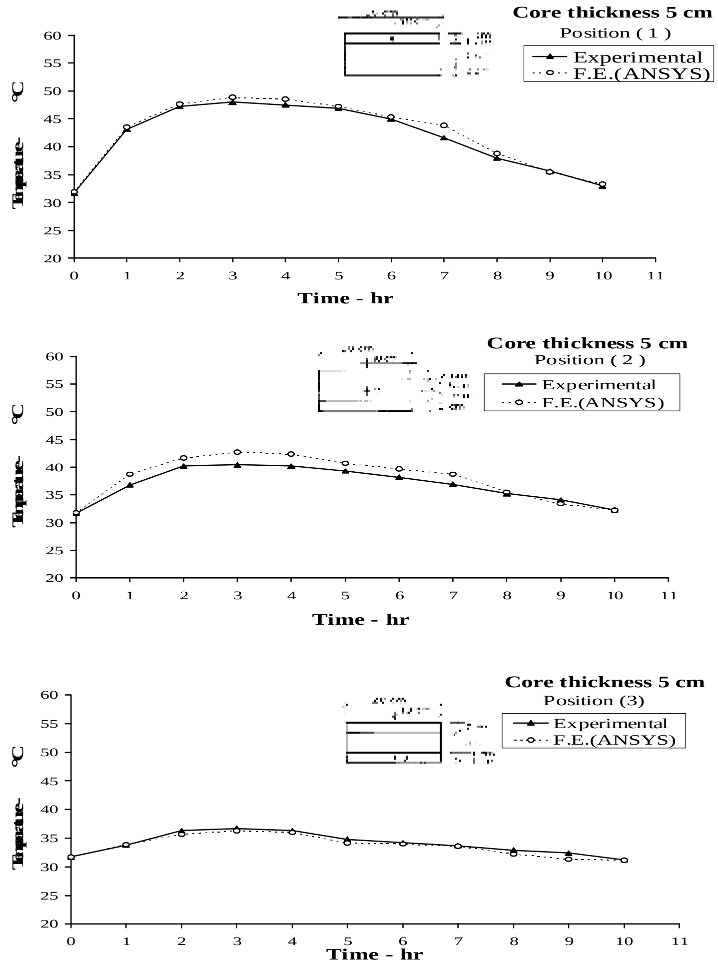


Figure (12) Experimental and finite element results of temperature distribution in concrete sandwich panels with core thickness 5cm at hot weather