Effect of thermal insulation on compressive strength of concrete exposed to high temperature by using ansys software.

تأثير العازل الحراري على مقاومة الأنضغاط للكونكريت المعرض لدرجات حرارية عالية بأستخدام برنامج الأنسز

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Abstract:

The concrete construction suffer from the loss of a lot of mechanical properties (compressive strength) when exposed to fire because of the dehydration of cement paste which causes to lose of its adhesive property. The study has been carried out to establish the **mathematical equation** between the compressive strength of concrete and firing temperature at varying times depending on the experimental data of firing concrete obtained from previous studies .Result of mathematical equation gave good agreement

Depending on the thermal properties of concrete got a relationships as **mathematical equations** to explain the temperatures distribution and time on firing specimen of transient heat by using the ansys software 14, also the study included the effect of adding a Calcium Silicate as insulation on those variable. Compressive strength was calculated from ansys results with and without insulator depend on the earlier mathematical equation. Results showed the influence of adding insulation material to reduce the fire effect's on the residual compressive strength of fired specimen's.

Finally, it can refer to the the possibility of the use the research equations to give first prediction of the amount of damage caused by the fire in the concrete constructions after knowing the fire temperature and the type , thickness of the insulators.

Key words: - Firing time, Firing temperature, Compressive strength, Ansys software, calcium silicate insulator

المستخلص

تعاني المنشآت الخرسانية من فقدان خواصها الميكانيكية (مقاومة الانضغاط)عندما تتعرض للحريق بسبب تحلل عجينة الاسمنت والتي تسبب فقدانها لخاصية التلاصق .أجريت الدراسة لبناء معادلة رياضية تربط بين مقاومة الانضغاط للخرسانة ودرجة حرارة الحرق عند ازمان مختلفة بالاعتماد على البيانات العملية للخرسانة المعرضة للحرق لأحد الدراسات السابقة. نتائج المعادلة الرياضية اعطت تطابق جيد مع البيانات العملية.

بالاعتماد على الخواص الحرارية للخرسانة حصلنا على علاقات رياضية توضح توزيع درجات الحرارة مع الزمن للعينة المعرضة للحرق خلال انتقال الحرارة غير المستقر باستخدام برنامج الانسز 14. كما شملت الدراسة دراسة تأثير اضافة سيليكات الكالسيوم كعازل على تلك المتغيرات.

تم حساب مقاومة الانضغاط لنتائج الانسز بعازل وبدون عازل بالاعتماد على المعادلة الرياضية السابقة .

اشارت النتائج الى ان تأثير اضافة العازل يعمل عل تقليل اثر الحريق على المتبقي من مقاومة الانضغاط للعينة المعرضة للحرق .

اخيرا يمكن الاشارة الى امكانية استخدام معادلات البحث لتعطينا توقع اولي لمقدار الضرر المتسبب من قبل الحريق للبنايات للخرسانية بعد معرفة درجة حرارة الحريق ونوع وسمك العازل

الكلمات المرشدة:- زمن الحريق, درجة حرارة الحرق, مقاومة الانضغاط, عازل سيليكات الكالسيوم, برنامج الانسز.

Introduction

Concrete in general composite material possesses high specific heat , low thermal conductivity ,low thermal expansion as well as high density and high compressive strength make it as a good material in the constructed application in natural conduction. concrete is a set of ceramic materials (sand, gravel) often associated with each other with an adhesive is cement, which is a silicate and aluminate calcium (C_2S, C_3S, C_3A , C_2F, C_4AF) ,these materials react with water to form a binder (adhesive) be responsible for connecting the concrete block and increase its resistance to compression. Insulation material Concrete has air gaps in it as a pore, that make it as a thermal insulator more clearly than concrete. When concrete exposed to high temperatures (more than 300°C) the bonds between the hydrated cement components and the crystal water would break down and thus loses its ability to paste, causing the loss of compression resistance of concrete is totally or partially depending on the firing temperature[1-7].

The compressive strength of light weight concrete reduce with the percentage of changes in temperature and the finishing layers depending on the changes of cooling condition as percentage of reducing in compressive strength increased with the incensement of temperature above 300°C for the samples without finishing[2]. The experimental program consists of compressive and bond strength tests on four types of concrete mix at normal and elevated temperatures. The concrete mix containing mineral admixtures showed better performance at high temperatures than concretes without mineral admixture. The reduction in compressive strength ranged between 17.3% and 27% at 400ºC and between 66.6% and 73.68% at 800ºC [3].

Mortars with and without silica fume were exposed to different temperatures, up to 1200°C. High temperature has caused damages in mechanical properties of mortars with or without silica fume, which showed significant decrease in mechanical strengths at 600 °C. Compressive strength does not change up to 300°C in all groups. The strengths of specimens with and without silica fume decreased above 300°C, respectively. Critical temperature is 300 for the strength loss of mortars. Losses are more rapid after this temperature up to 600°C. The loss in compressive strength for mortar with silica fume is more than normal mortars above 600°C [4]. some research studies the relationship between compressive strength and bond strength with difference temperatures. Also, the effect of inclusion of fly ash with cement mortar is studied. The test results indicate that the compressive and bond strength of cement mortar decreases with the increase of temperature and the bond strength of cement mortar completely vanishes at 800°C. At the same time the compressive strength of mortar reaches its minimum value at 1000 °C [5,6].

The bond strength of cement mortar completely vanishes at 600 °C. At the same temperature the compressive strength of mortar reaches its minimum value[6]. Another paper study the effect of substitution of metakaolin (MK) by silica fume (SF) on thermal stability of Portland cement blended pastes. The results of investigation showed that the compressive strength of pre-heated blended cement increases with temperature up to 400°C and then it decreases as the pre-heated temperatures increase up to 800°C,and the work explain the decrease of percentage of hydrated cementous phases with increase temperature due to broken the bond between oxides and water that lead to the loss of cement to adhesive property [7]. The effect of high temperature was studied during fire on the bond and compressive strength of cement mortar containing different volume percentage of fly ash. The test results indicate that the compressive and bond strengths of mortar containing different percentage of fly ash initially increase with the increase of temperature but after 200 °C they decrease with the further increase of temperature[8].

One of experimental investigations are carried out of cement mortar cubes with the inclusion of different percentage of steel fiber. Compressive strength of fiber reinforced mortar initially increases up to 200 °C temperature and after that it decreases with the further increase of temperature [9]. The effect of high temperature on thermal conductivity of concrete with different types of pozzolans and aggregates is investigated. The results indicate that thermal conductivity of concretes with siliceous aggregates was found to be a bit higher than the concretes made with calcareous aggregates except for the series with granulated blast furnace slag at room temperature.

Thermal conductivity of concrete is a little decreased by the increasing temperature. So that consider the change in thermal conductivity of concrete up to 300 °C will be negligible[10].

A series of experiments was performed to investigate the residual strength of NSC, HSC and HSC-PP subjected to elevated temperatures ranging from (300 - 700)°C for a heating duration between 1 hour and 9 hours. The residual strength of concrete decreases as the exposure temperature increases, and prolonging the heating time decreases also the residual concrete strength. The strength degradation of heated concretes comes mainly from the peak temperature and the increase of exposure heating time [11].

The influence of elevated temperature on the properties of concrete is important for fire resistance studies. The effect of high temperature on the properties of self-compacting concrete (SCC) compared with the normal concrete (NC) was investigated . The properties of SCC and NC were measured after exposed to 200°C, 400°C and 600°C for two hours and the Behavior of thermally treated SCC was studied using X-ray diffraction (XRD). Results from these tests show that the increasing the temperature of furnace up to 400°C and 600°C decreasing the compressive strength [12].

The mathematical model and computer program employed of number of studies is capable of predicting the fire resistance of rectangular reinforced concrete columns with an accuracy that is adequate for practical purposes. It involves the calculation of the temperatures in the column and its deformations and strength during the exposure to fire, The strength decreases with time until it becomes so low that the column can no longer support the load [13,14].

According to literature survey it was seen that

1. The concrete materials commonly used in construction applications in civil engineering for possession of a range of mechanical properties , but it loses a large portion of those properties when exposed to high temperatures , especially during the fire .
2. Mechanical properties of concrete exposed to high temperatures begin to drop at 300 ° C approx.
3. The relationship between the time of exposure to the temperature is proportional with the amount of decrease in temperature.
4. the reason for the decrease in the mechanical properties of concrete exposed to high temperatures resulting from the decomposition of chemical bonds between the water molecule compounds and concrete and thus losing strength adhesive components of the concrete, leading to the loss of the mechanical properties of concrete.

THERMAL ANALYSIS

Summary results of the study of previous research built the idea of research .Ansys(14) software is used to solve the thermal- transient analysis case to study the effect of thermal insulation on the mechanical properties of Concrete exhibition to high temperatures.

1- Depending on the experimental results of research[11]we obtained mathematical relationship describes the effect of each of the firing temperature and firing time on the residual compressive strength of normal strength concrete (NSC) As shown in equation (1).

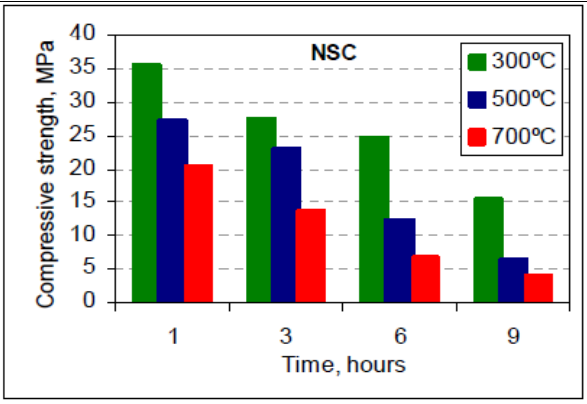


Fig.(1) experimental graph of residual comp. strength of (NSC) heated concrete[11]

Table(1) experimental data of residual comp. strength of (NSC) heated concrete from fig.(1)

firing temp.(°C)	Firing time(hr.)			
	1	3	6	9
	Compressive strength (MPa)			
300	36	28	25	15.5
500	27	23	12	6.5
700	21	14	7	4

$$\text{Comp. St.} = 45.01502268 - 0.03125 * T - 2.3628 * t \qquad (1)$$

R^2 = standard mean deviation = 0.96

T= firing temp. ($^{\circ}$C)

t = firing time (hr.)

Theoretical results of residual compressive strength of non-insulated of equation (1) explain in table (6).

Assume exposing a piece of Normal Strength Concrete (NSC) as a cubic shape with dimensions of (5*5*5 cm) to fire at different temperatures and for different periods of burning in two cases insulator and without insulator as shown in fig.(2), where it was placed inside the insulator of 5 cm thickness from all directions. Adoption of the physical and thermal properties of concrete for use in ansys(14) software to study the thermal behavior through exposure to fire directly or insulated, although we selected the calcium silicate as a thermal insulator to see their effect on the thermal behavior of concrete in the ansys software, table (2) explain the properties of used material [15,16,17].

Table (2) physical and thermal properties of Concrete and insulator

Properties of Concrete	Bulk density (Kg/m^3)	Specific heat Capacity (Cp) (J/kg.k)	Thermal conductivity K(w/m.°C)
Normal Strength Concrete(NSC)	2300	750	1.6
Calcium Silicate insulator (CSI)	260	960	0.08

2 Above data were used in ansys (14) software and many assumptions are made:

a- Heat transfer through the specimen in one dimension.

b- Thermal properties of used materials not varying with respect to temperature.

c- Transient heat transfer through the specimen.

d- Surface temperature of specimen has the same value of firing temperature .

e- Initial temperature of the specimen is 30°C.

f- Minimum time step 0.01second.

g- Maximum time step 200 second.

h- Firing temperature (300,500,700) °C.

i- Firing time (1,3,6,9)hours.

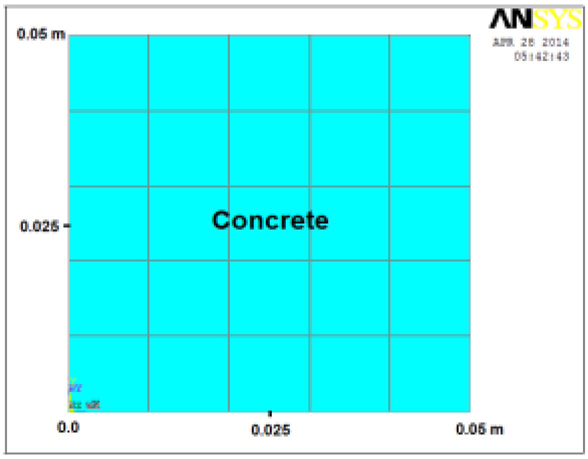


Fig (2-a)specimen of concrete without insulator

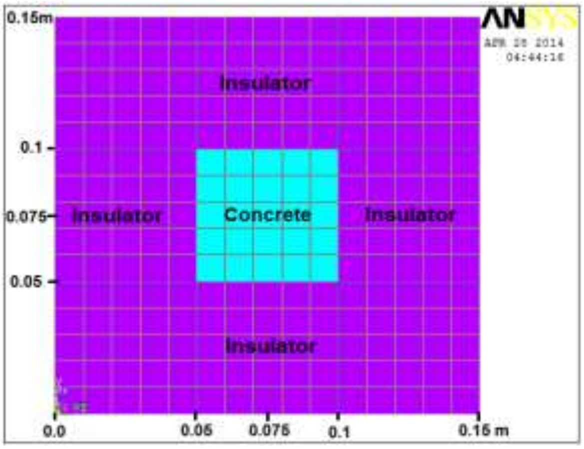


Fig (2-b)specimen of concrete with insulator

From ansys software we got a set of results as a data, graphs and shapes showing the thermal behavior of concrete at different temperatures and different burning times with and without insulator.

Table(3-a) temp. distribution on Concrete without insulator

TIME	477 TEMP TEMP_2	TIME	477 TEMP TEMP_2	TIME	477 TEMP TEMP_2
1.0000	30.0000	1.0000	30.0000	1.0000	30.0000
2.0000	30.0000	2.0000	30.0000	2.0000	30.0000
3.2905	30.0000	3.2905	30.0000	3.2905	30.0001
5.0868	30.0004	5.0868	30.0007	5.0868	30.0010
7.7247	30.0058	7.7247	30.0101	7.7247	30.0144
.	.	.	.	.	.
971.22	299.173	1035.1	499.010	1099.1	699.088
2482.6	300.000	2546.5	500.000	2610.4	700.000
2682.6	300.000	2746.5	500.000	2810.4	700.000
.	.	.	.	.	.
32283.	300.000	32273.	500.000	32210.	700.000
32400.	300.000	32400.	500.000	32400.	700.000

Table(3-b) temp. distribution at face (x=0.05) and center (x=.075) on Concrete with insulator

TIME	81 TEMP x=0.075	TIME	81 TEMP x=.075	TIME	81 TEMP x=.075
1.0000	30.0000	1.0000	30.0000	1.0000	30.0000
2.0000	30.0000	2.0000	30.0000	2.0000	30.0000
5.0000	30.0000	5.0000	30.0000	5.0000	30.0000
14.000	30.0000	14.000	30.0000	14.000	30.0000
37.633	30.0000	37.633	30.0000	37.633	30.0000
.	.	.	.	.	.
32254.	286.997	32254.	477.365	32254.	667.733
32354.	287.124	32354.	477.587	32354.	668.050
32400.	287.183	32400.	477.689	32400.	668.194

TIME	36 TEMP x=0.05	TIME	36 TEMP x=.05	TIME	36 TEMP x=.05
1.0000	30.000	1.0000	30.000	1.0000	30.000
2.0000	30.000	2.0000	30.000	2.0000	30.000
5.0000	30.000	5.0000	30.000	5.0000	30.000
14.000	30.000	14.000	30.000	14.000	30.000
37.633	30.000	37.633	30.000	37.633	30.000
.	.	.	.	.	.
32254.	287.17	32354.	477.89	32354.	668.48
32354.	287.30	32400.	477.99	32400.	668.62

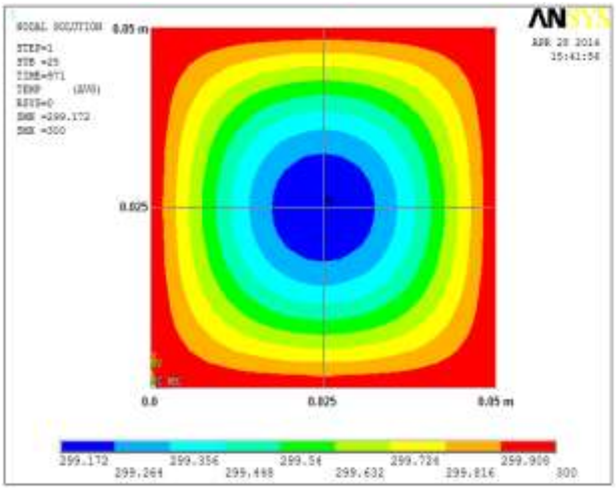


Fig (3-a) Nodal solution of temperature map and contours at firing temperature at 300°C & 971 Sec. Without insulator

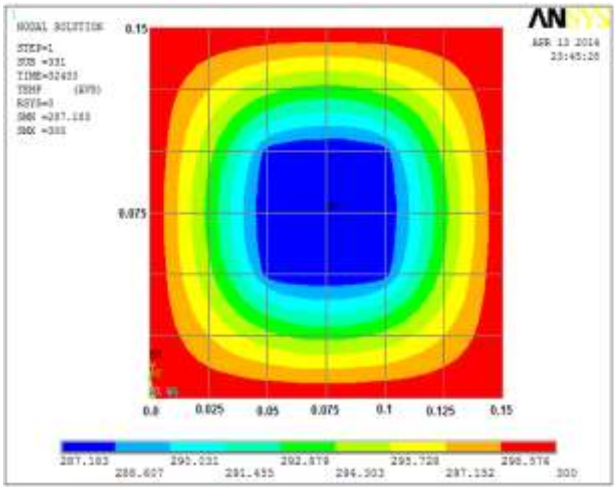


Fig (3-b) Nodal solution of temperature map and contours at firing temperature at 300°C&32400 Sec. With insulator

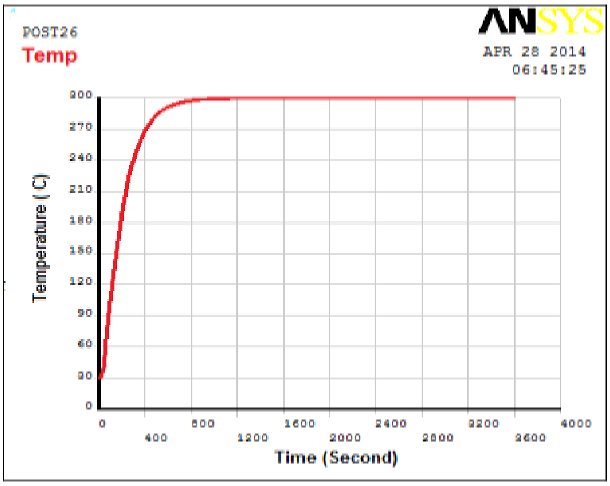


Fig (3-c) Specimen temp. close to 300°C Through 971 sec.Without insulator

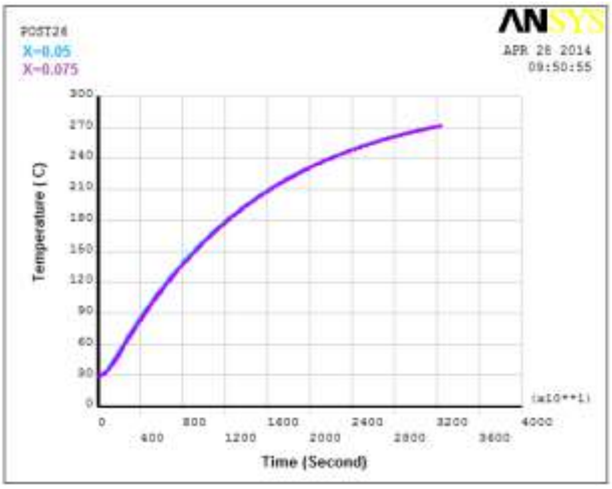


Fig (3-d) Specimen temp.at face & center don’t reach 300°C through 32400 sec. With insulator

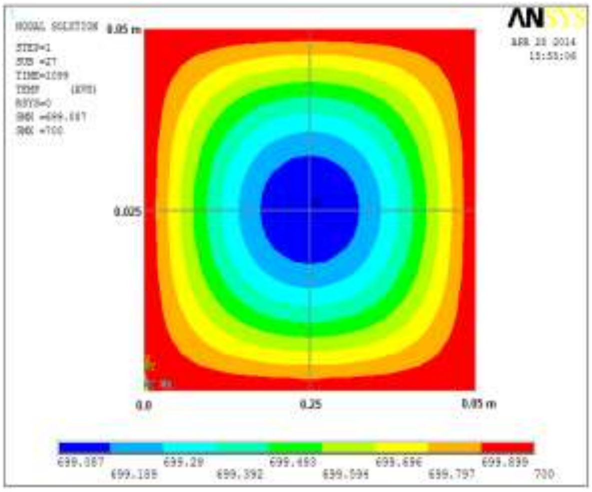


Fig (4-a) Nodal solution of temperature map and contours at firing temperature 700°C & 1099 Sec. Without insulator

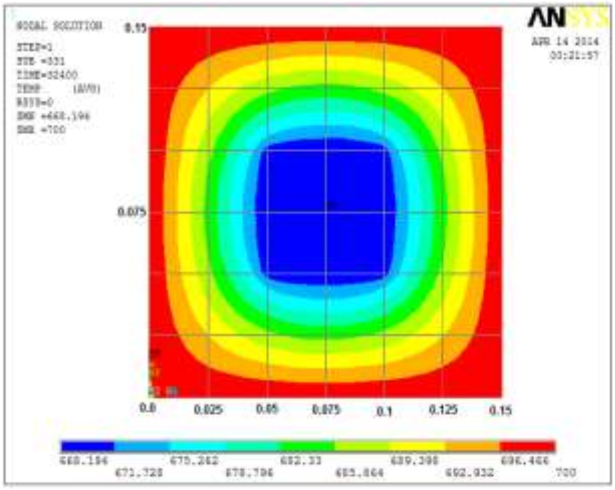


Fig (4-b)Nodal solution of temperature map and contours at firing temperature 700°C& 32400 Sec. With insulator

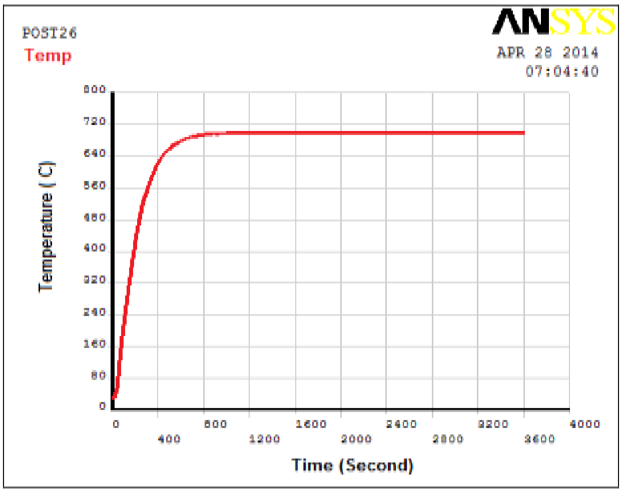


Fig (4-c) Specimen temp. close to 700°C Through 1099 sec. Without insulator

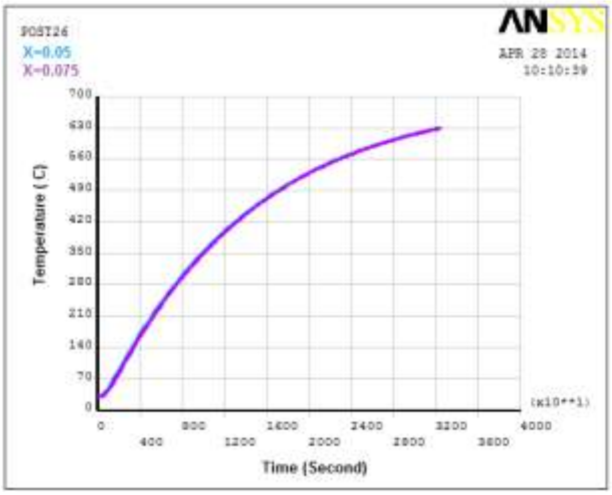


Fig (4-d) Specimen temp. at face & center don't reach 700°C through 32400 sec. With insulator

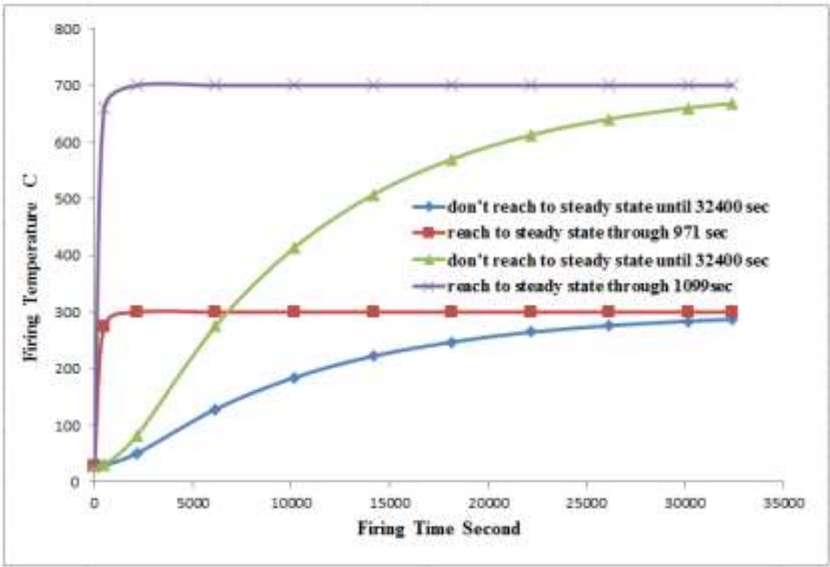


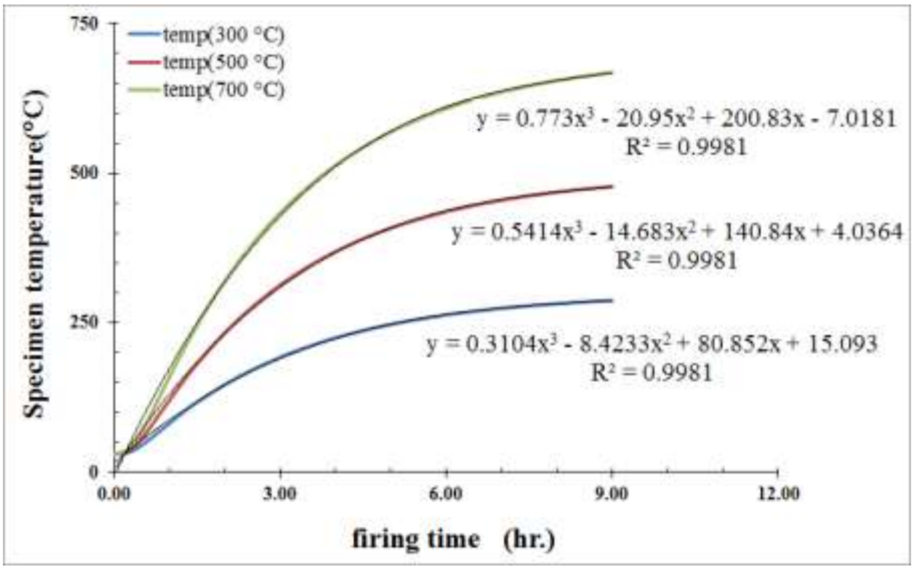
Fig (5) temperature &time which illustrate what happen through the figures (3),(4) at (300&700)°C with and without insulator.

Results and Discussion

Results of ansys explain the following :-

1- The temperature of non-insulated fired concrete specimen's reach to the firing temperature during a very short time at any firing temperature, i.e. reached to steady state case of heat transfer, while the temperature for the insulated concrete specimen's did not reach to the firing temperature during the total firing time, and the heat transfer remains at transient case through these specimen's. These facts shown in the table (3) and figures (3,4&5). These results illustrate the effect of the insulator to reduce the fire effects on the insulated specimen's compared with non-insulated specimen's.
2- Through the above analysis, we can considered the temperature for the non-insulated concrete specimens have same value of firing temperature as well as the firing time, then we can be applied these data in equation (1) to find the residual of the compressive strength of the firing of non-insulated concrete specimen's as illustrated in table (6).
3- From the results of the temperature distribution through the fired insulated concrete specimen's which taken from the ansys software as shown in table (3 - b). we plotted curves showing the

distribution of specimen temperatures with firing time as shown in fig.(6), and also found mathematical equations for these curves to describe the average temperature for these specimens at any firing time as shown in equation(2).



Fig(6) Average specimen temperatures distribution with firing time

$$T_{avg} = a * t^3 + b * t^2 + c * t + d \quad (2)$$

Where $T_{avg.}$:average (face &center) of concrete specimen temperature (°C) at any firing time.
t : firing time (second)
a,b,c & d : Coefficients

table(4) Coefficients of equation(2)

firing Temperature (°C)	Coefficients				R^2
	a	b	c	d	
300	0.3104	-8.4233	80.852	15.093	0.9981
500	0.5414	-14.683	140.84	4.0364	0.9981
700	0.773	-20.95	200.83	-7.0181	0.9981

The values for the fired insulated concrete specimen temperatures and the firing times which obtained from equation(2) does not represent to the actual values, because of the heat transfer through the specimen remained at un-steady state case. Thus, we need actual values for each of the specimen temperature and the firing time.

a. The actual specimen temperature which represents to the mean temperature between the starting concrete degradation temperature and the highest temperature that sample reach as shown in eq.(3).

$$T_{(actual)} = \left[(T_{avg.} + 250)/2\right] \qquad (3)$$

$T_{(actual)}$= actual firing temperature (°C)

b. To find an actual firing time (which represents the specimen remain at this temperature) for the insulated specimens must deletion the time required to reach the temperature (250°C) from the total firing time, because of the starting concrete degradation temperature at (250°C).
From figure (6) extract a required time to get to the temperature (250°C) for each firing temperature as shown in table(5) . Among those data we can get a mathematical relationship between each of the firing temperature and the time required to get to the temperature (250°C), considering that the decomposition of concrete begins at a temperature equal (250°C) as shown in equation(4).

Table(5)

firing temperature °C	$t_{(250°C)}$ (hr.)
300	5.1542
500	2.1797
700	1.5214

$$t_{(250°C)} = 3 * 10^{-5} * T^2 - 0.038 * T + 13.96 \qquad (4)$$

where $t_{(250°C)}$: time required to reach to 250°C
R^2:standerd mean deviation=1
Then we can get the actual firing time from equation(5)

$$t_{(actual)} = t_{(total)} - t_{(250°C)} \qquad (5)$$

$t_{(actual)}$ = actual firing time
$t_{(total)}$ = total firing time

Substitute the actual temperature and actual time for the above equations in equation(1) to get the residual compressive strength for the fired insulated specimens which illustrate in table(6).

Table(6)results of experimental and theoretical compressive strength

firing temp. (°C)	Firing time (hr.)	Average Specimen temp. (°C)	$t_{(250 C)}$ hr.	$T_{(actual)}$	$t_{(actual)}$		Comp.strangth (MPa.)		
							Theoretical		experimental from research
							With insulator	Without insulator	
300	1	87.8	5.15	*	**	**	34.35	33.3	36
	3	190.2	5.15	*	**	**	34.35	28.6	28
	6	264	5.15	257	0.85		35	21.5	25
	9	286.8	5.15	268.4	3.85		27.6	14.4	16
500	1	130.7	2.18	*	**	**	34.35	27.0	27
	3	309	2.18	279.5	0.82		34.34	22.3	23
	6	437.4	2.18	343.7	3.82		25.25	15.2	12
	9	477	2.18	363.5	6.82		17.54	8.1	6
700	1	173.6	1.52	*	**	**	34.35	20.8	21
	3	427.8	1.52	338.9	1.48		30.93	16.1	14
	6	610.7	1.52	430.4	4.48		20.98	9.0	7
	9	667	1.52	458.5	7.48		13.02	1.9	4

* = Don't reach to 250°C , ** = Neglected

From table(6) we can observe:
1- Result of theoretical residual compressive strength for non-insulated specimens of equation(1) gave good agreement with the experimental data.
2- Because of the temperature of some insulated specimens don't reach to the starting concert destroying temperature, then we consider this specimens don't effected by the fire and it possible to have the same value of non-fired specimens.
3- It can be seen that the influence of add insulator to reduce the fire effect's on the residual compressive strength of fired specimen's, when compared with the theoretical residual compressive strength of non-insulated specimens.

Conclusions

Through the results obtained from the program software and comparing with the results of experimental research can reach a preliminary conclusion included the following points:-

1. Use of thermal insulation leads to a reduction in the fired specimen's temperature and keep the heat transfer through fired specimen's at transient stage and need long time to reach to steady state heat transfer, then leads to minimize the fire effect's to destroy the mechanical properties for concrete construction.
2. Because the standard mean deviation (R^2) of research equation approach to one .It's possible to use these equations to get first prediction of concrete building damage that insulated or no which exposed to fire after know the firing temperature ,type and thickness of insulator.

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