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EVALUATION OF FIRE ENDURANCE OF SELF COMPACTED CONCRETE SLAB REINFORCED WITH STEEL FIBER REINFORCEMENT AND STEEL BARS

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ABSTRACT:- The effect of steel fiber on the deflection of self- compacted slabs under fire (600^0c) was investigated in this study. Three specimens were tested experimentally and numerically (by using sophisticated finite element programme ANSYS 7.0) to determine the deflection of these specimens under two point load after burned under (600^0c) in a tested furnace for four hours. Numerical study by using ANSYS programme is performed to calculate the critical temperature and the temperature through the slabs with steel fiber content of (0%,0.2%, and 0.5%). Another six model slabs with steel fiber content of (0.5%) were studied numerically by using ANSYS 7.0 to investigate the effect of arrange of parameters on the fire performance of self- compacted steel fiber reinforced concrete slabs.
The main factors that influence the fire resistance of self- compacted steel fiber reinforced concrete slabs are: slab thickness, concrete cover thickness , moisture content.
The experimental results showed that the deflection of burned slab with steel fiber of (0.2%) decreased to 30% than the deflection of burned slab without steel fiber under the same failure load. While the deflection of burned slab with steel fiber of (0.5%) decreased to 50% than the deflection of burned slab without steel fiber under the same failure load. On the other hand , the deflection results were checked with finite elements method by using sophisticated finite element programme (ANSYS 7.0) and it was found that the results were acceptable and the difference was not more than 9%. The results from thermal analysis showed that the temperature decrease with the increase in the concrete depth of the self compacted steel fiber reinforced concrete slabs, while the critical temperature for the slabs with steel fiber of (0%,0.2%,0.5%) were (250^0c, 350^0c, 580^0c) respectively.
Parametric study results showed that the slab thickness dose not have significant effect on the fire resistance of the self compacted steel fiber reinforced concrete slabs, while concrete cover thickness has a significant effect on the fire resistance of the self compacted steel fiber reinforced concrete slabs. Fire resistance increases with an increase in the moisture content of the concrete in the slabs.
Keywords: Steel fiber, ANSYS 7.0, Concrete, Fire resistance.

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1. INTRODUCTION

Steel fibers are used instead of ordinary steel reinforcement or in addition to reinforcing bars. Both under service and ultimate loading conditions, the fiber reinforcement is subjected to resist tensile forces(1).

Steel fiber reinforced concrete is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and

randomly oriented. The addition of steel fibers to concrete changes its mechanical properties. Depending on the type and amount of fibers an increase in ductility and better cracking behavior can be achieved[2]. Fibers are usually used in concrete to control plastic shrinkage cracking and drying shrinkage cracking. They also lower the permeability of concrete and thus reduce bleeding of water. The amount of fibers added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibers) termed volume fraction (Vf). Vf typically ranges from (0.1-3%)[3]. Aspect ratio (L/d) is calculated by dividing fiber length (L) by its diameter (d). Increase in the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers which are too long tend to ball in the mix and create workability problems.
Steel fibers are manufactured in different types: hooked, undulated or flat, according to the construction project[3]

2-SELF-COMPACTED CONCRETE

Self- compacted concrete was developed around 1988 in Japan, to improve the durability of concrete structures. The early stage deteriorations of concrete structures are a results of the manual placing
and the inadequate consolidation. Therefore, the need for development of concrete with high fluidity and no segregation was felt. For several years, the problem of the durability of concrete structures has been a major problem posed to engineers. To make durable concrete structures, sufficient compaction is required. Compaction for conventional concrete is done by vibrating. Over vibration can easily cause segregation. If steel is not properly surrounded by concrete it leads to durability problems. The answer to the problem may be a type of concrete which can get compacted in to every corner of formwork and gap between steel, purely by means of its own weight and without the need for compaction. The SSC concept can be stated as the concrete that meets special performance and uniformity requirements that cannot always be obtained by using conventional ingredients, normal mixing procedure and curing practices[4]. Its important to test whether the concrete is self-compactable or not and also to evaluate deformability or viscosity for estimating proper mix proportioning if the concrete dose not have sufficient self- compact actability. The existing procedures for self-compacting characteristics are those, which measure height different points under free flow and also resistance against blocking. There is some test to show whether the concrete is self-compacted or not these test are [5]:
1- Slump flow Test for measuring flow ability.
2- V- Fannel Test.
3- U-Type Test.
4- L- Box Test.
5- Fill Box Test.
6- Ring Combination Test.
7- GTM segregation test.
8- Orimet\J-ring combination Test.
In our study,the V-Fannel, U-Type and L-box tests were used to found the content of our mixtures.

2-1- MIX DESIGN

Self- compatibility can be largely effected by the characteristics of materials and the mix proportion. A rational mix design method for SCC using a variety of materials is necessary. The mixed design as proposed is[6]:
A- Coarse aggregate content is fixed at 50% of the solid volume,
B- Fine aggregate content is fixed at 40% of the mortar volume,

C- Water powder ratio in volume is assumed as 0.9 to 1.0 depending on the properties of the powder,
D- Super plasticizer dosage and the final water- powder ratio are determined so as to ensure compatibility.
The mix design is shown in Table (1).

3- EXPERIMENTTAL WORK

In this study, the effect of steel fiber on the deflection of self- compacted concrete slabs exposed to fire (600^0c) were studied using three slabs specimens with dimensions of (600x250 mm)(i.e. h/L=16%) with thickness of (100mm).
The slabs were reinforced with steel bars in two directions (in short direction ø4@145mm c/c) and (in long direction ø4@115mm c/c)as shown in Figure (1). three slabs were tested :
1/ Self- compacted concrete slab without steel fiber (SL1).
2/ Self- compacted concrete slab with {0.2% Vf} steel fiber added to concrete mix (SL2).
3/ Self- compacted concrete slab with {0.5%Vf} steel fiber added to concrete mix (SL3).
Nine concrete cubes were tested to found the compressive strength for three slabs and the average values for these cubes for slabs (SL1 to SL3) for twenty eight days curing , these compressive strength were reduced after exposed to fire of 600^0c[7] as shown in table (2).
In all mixes, the cement was Ordinary Portland cement, Type I, which
was manufactured by United Company Cement factory/Iraq. Al-Ekhaider natural sand of (4.75mm) maximum size was used as fine aggregate. while the coarse aggregate was crushed gravel with max size of (19mm). The steel fiber used was flat steel fiber. The properties of the steel fibers added to concrete are listed in table(3) while the properties of steel reinforcement (at $20c^0$ and at $600c^0$) are listed in table (4)[8] . Twenty four hours after pouring, the slabs were stripped out from moulds and cured in water containers for twenty eight days. Then the slabs were removed from the water containers and then burn in a tested furnace until the temperature reaches 600^0c after four hours .The burn slabs tested in a flexural machine under two point loads as shown in Figure (2). The two point loads were applied gradually until the cracks were appeared and then the slabs was failure. The deflection of the slab with every applied load was readied by the gage of the flexural machine.

4-THEIORITICAL WORK:

4-1- Finite Element Software:

A successful analysis of an engineering problem needs the existence of an efficient code translation of the existing solution algorithm to be used by a digital computer. Finite element method are good examples of the fact due to the required target memories and tedious computations. For the present work purposes , it is sufficient to use a general pre-made programme, since neither special circumstances are met nor special aims are to be accomplished. In this work, the commercial program ANSYS 7.0 [9] is used to accomplish the finite element method. ANSYS 7.0 is an interactive finite element programme for the analysis of linear and nonlinear structural systems. Static and dynamic analyses are achieved by a combination of one, two and three- dimensional elements.

4-2 Adopted elements [9] :

The present study adopts several elements to simulate the reinforced slab as follows:

A- Solid 65 (Three- Dimensional Reinforced Concrete Element) :

This is used for the three- dimensional modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression in concrete applications, the solid capability of the element may be used to model the concrete while the
rebar capability is available for modelling reinforcement behaviour as shown in Fig (3).(This element will be use for concrete and reinforced concrete parts).

B- Steel Fiber :

The orientation of the fiber reinforced with in an element is depicted in Fig(4) the element coordinate system is (x,y,z)and (xi,yi, zi)are shown in the figure.

4-3-Thermal analysis:

The numerical model uses an explicit finite difference approach to calculate temperatures in the slabs, for the purposes of calculation, the slab is divided in to a number of elementary layers, as shown in Fig (5). The thickness of all layers is Δx, with the exception of boundary layers which are 1/2 Δx thick, and each layer is represented by a unique point, Pm. Only a thermal analysis is carried out during the modeling. The temperature in each layer is assumed to be uniform and equal to that of the representative point, Pm. Initially , at time t=0 , the slab is assumed to be at room temperature ($20c^0$) . the temperature in the various layers of the slab is then calculated for time t= Δt using finite difference heat transfer equations derived on the basis of an elemental energy balance[9]. The temperature determined for t= Δt are used as the initial temperature for calculation of the temperature at time t=2Δt, and the process is repeated until one of the failure criteria is reached. For the purposes of modeling, the first cracks of the slab is assumed to occur when the temperature in the reinforcement reaches the critical temperature[9].
For the calculation of temperatures, only the properties of concrete are considered, and the reinforcement is assumed to have no influence on the temperature propagation. This assumption can be justified on the basis that the volume of reinforcement is small in comparison with the volume of concrete[10]. The moisture is taken in to account by assuming that moisture beings to evaporate from an element when its temperature reaches $100c^0$ until all of the moisture has evaporated. In thermal analysis the three slabs (SL1,SL2,SL3) were taken as a model , these slabs were subjected to temperature of $600c^0$ for four hours without applying load to determine the critical temperature when the first cracks were appeared.
Only the thermal properties of concrete (thermal conductivity, specific heat, and density) are required as a function for temperature for the analysis. These properties are built into the program for the three slabs(SL1,SL2,SL3). Table (5) shows the thermal properties of self compacted steel fiber reinforced concrete used in the analysis[8].

4-4-Parametric study:

A set of numerical studies was carried out using the model to investigate the effect of three parameters on the fire resistance of self- compacted steel fiber reinforced concrete slabs. The slabs were exposed to standard fire conditions for 600^0c only with out applying load. Data from the numerical studies were analyzed to predict the failure of the slabs based on the thermal failure criteria. In all of the slabs studied, failure was began when the internal tensile reinforcement reached its critical temperature. The goal of the parametric studies was to identify the governing factors in the development of the fire resistance guidelines for self compacted steel fiber reinforced concrete.

4-4-1- Effect of Slab Thickness:

The effect of the slab thickness on the fire resistance of self-compacted steel fiber reinforced concrete slabs is shown in Fig(10).Three slabs with three thicknesses were used, these slabs have the same fiber content (Vf=0.5%).

1- Slab (AS1) have the same dimensions of slab (SL1) with thickness of 100mm.
2- Slab (AS2) have the same dimensions of slab (SL1) with thickness of 150mm.
3- Slab (AS3) have the same dimensions of slab (SL1) with thickness of 200mm.

4-4-2- Effect of concrete cover thickness:

The effect of concrete cover thickness on the fire resistance of a slab have the same dimensions of slab (SL1) with slab thickness of (100mm)
and with steel fiber content of (Vf= 0.5%) is shown in Fig(11).
Three slabs were used to study the effect of concrete cover thickness on the fire resistance, these slabs were:

1- Slab (BS1) with concrete cover of (20mm).
2- Slab (BS2) with concrete cover of (40mm).
3- Slab (BS3) with concrete cover of (60mm).

4-4-3- Effect of moisture content:

The effect of moisture content on the fire resistance of a slab have the same dimensions of slab (SL1) and have a thickness of (100mm) and with steel fiber content of (Vf= 0.5%) is shown in Fig(12).
Three slabs were used to study the effect of concrete moisture on the fire resistance, these slabs were:

1- Slab (CS1) with moisture content of 10%.
2- Slab (CS2) with moisture content of 15%.
3- Slab (CS3) with moisture content of 20%.

5-RESULTS

The result shown in figures [(6-A),(6B),(6C),(7),(8),(9),(10),(11),(12)].

6- DISCUSSION AND CONCLUSIONS

Figures (6A,6B,6C) show the relation ship between load and deflection for slabs (SL1,SL2,SL3) these slabs were burned under 600^0c for four hours then the two point load were applied, it can be seen that the curves were nearly linear up to {12kN}. The strengthening mechanism in this portion of the behavior involves a transfer of stress from the matrix to the fibers by interfacial shear. The imposed stress is sheared between the matrix and the fibers until the matrix cracks at which was termed as " first cracking strength". The deflection increased with the increase of load this because with increasing loads, the fibers tends to gradually pull out from the matrix leading to a nonlinear load- deflection response until the ultimate flexural load capacity for slabs(SL2, SL3) were reached. This point is termed as "peak strength". After the peak point the deflection was increase until the failure was complete. From Fig.(6A,6B,6C) it can be seen that the deflection decrease with the increase in the percentage of steel fiber in concrete used, this behavior was due to the ability of the fiber composite to absorb large amount of energy before failure and is a characteristic that distinguishes fiber- reinforced concrete from plain concrete.

This characteristic is referred to as "toughness" .
From Fig(7), Fig (8) and Fig (9), it can be seen that the temperature decrease with the increase of concrete depth under the same time of temperature exposure , i.e. for the slab

(SL1) at depth 15mm the temperature is 600^0c after 120min of temperature exposure ,while at depth of 50mm the temperature was 310 ^{0}c under the same time of temperature exposure .The critical temperature when the first cracks.

appeared for slabs (SL1,SL2, SL3) were (2500c^0 ,350c^0 and 580c^0) respectively.

In the Fig (10), for slab thickness above 100mm , the predicted fire resistance remains essentially constant. This is due to the fact that the reinforcement is close to the fire exposed face of the slab, and so the over all thickness dose not significantly affect the heat transfer in the critical cover region between the reinforcement and the fire. For thinner slabs (less than 80mm thick) the fire resistance decreases with decreasing slab thickness.This can be attributed to the larger thermal mass of thicker slabs, which allows them to absorb more thermal energy for an equivalent overall rise in temperature. Hence, for the case of fire resistance defined in terms of exceeding the critical temperature of the reinforcement, for slab thicknesses that would be used in practice, the overall slab thickness dose not appear to be a significant parameter.

From Fig (11) it is evident that the thickness of the concrete cover to the reinforcement has a pronounced effect on the fire resistance of the slabs. This can be attributed to the fact that the failure of the slabs is assumed to be governed by the critical temperature of the reinforcement. larger concrete cover thickness delays the transmission of heat to the reinforcement, there by enhancing fire resistance.

From Fig (12) fire resistance increases with an increase in the moisture content of the concrete in the slabs. The beneficial effect of increased moisture content on the fire resistance of slabs can be explained by considering the fact that moist concrete required more thermal energy to rise its temperature than an equivalent slab with lower moisture content subsequently increasing the fire resistance of the slab. The reason for this is two fold. First, moist concrete has a slightly higher heat capacity than dry concrete virtue of the pore space that is occupied by water. Second, moisture in the concrete evaporates at temperature close to 100^0c , which consumes thermal energy due to the latent heat of vaporization of water. The results is that the temperature in the concrete remains close to 100^0c until all of the moisture has evaporated, increasing the fire resistance of slabs with higher moisture content. Thus , for typical slabs, with concrete moisture content in the range of 5 to 10%, the effect of moisture content on fire resistance is marginal.

So from figures (6,7,8,9,10,11and 12) the following points can be obtained:

1-The load –deflection curves in Fig (6) shows that when used (0.2% of steel fiber content) in slab (SL2), the deflection decreased to (30%) than slab (SL1) for the same load failure, while for (0.5% of steel fiber content) used in slab (SL3) , the deflection decreased to (50%) than slab (SL1) for the same load failure.

2- The exposure temperature decreases with the increase the depth of the slaps under the same time of exposure. The critical temperature for slabs (SL1,SL2,SL3) were (250 350, 580^0c respectively).

3-Slab thickness dose not have significant effect on the fire resistance of the self compacted steel fiber reinforced concrete slabs.

4-Concrete cover thickness has a significant effect on the fire resistance of the self compacted steel fiber reinforced concrete slabs. Slabs with greater cover thickness provide higher fire resistance.

5- fire resistance increases with an increase in the moisture content of the concrete in the slabs. for typical slabs, with concrete moisture content in the range of 5 to 10%, the effect of moisture content on fire resistance is marginal.

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Table(1): Mix design used for self- compacted fiber reinforced concrete slab**.**

Used materials	**Amount content**
cement	550 Kg/m^3
Coarse aggregate	832 Kg/m^3
Fine aggregate	825 Kg/m^3
Water/ cement ratio	0.21
Super plasticizer %from weight of cement content	9.5%

Table(2): Compression strength of SC steel fiber tested slabs.

No. of slab	**%Vf steel fiber content**	**Compression Strength MPa at 20c^0**	**Compression Strength MPa at 600c^0**
SL1	0%	34	32
SL2	0.2%	35	32
SL3	0.5%	37	35

Table(3): Properties of steel fiber.

Property	Specifications
Density	7860kg/m^3 (remains constant at 600^{0}c)
Modulus of elasticity	200x10^{3}Mpa (at 600^{0}c become 40x10^3)
Average length	250mm
Normal diameter	0.4mm
Aspect ratio(L\d)	625

Table (4): Properties of steel reinforcement**.**

Name	Dimensions (mm)	Yield strength (MPa) at 20c^0	Modulus of elasticity MPa at 20c^0	Poisson's ratio	Yield strength (MPa) at 600c^0	Modulus of elasticity MPa at 600c^0
Steel Bar Reinforcement	diam ø4	420	200x10^3	0.3	91.014	40x10^3

Table (5): thermal properties of self compacted steel fiber reinforced concrete used in the analysis.

property	Temperature c^0	value
Conductivity J/m.hr.c^0	20 200 850 1600	203 203 101.7 101.7
Specific heat J/kg.c^0	constant	36.72
Density kg/m^3	constant	2400

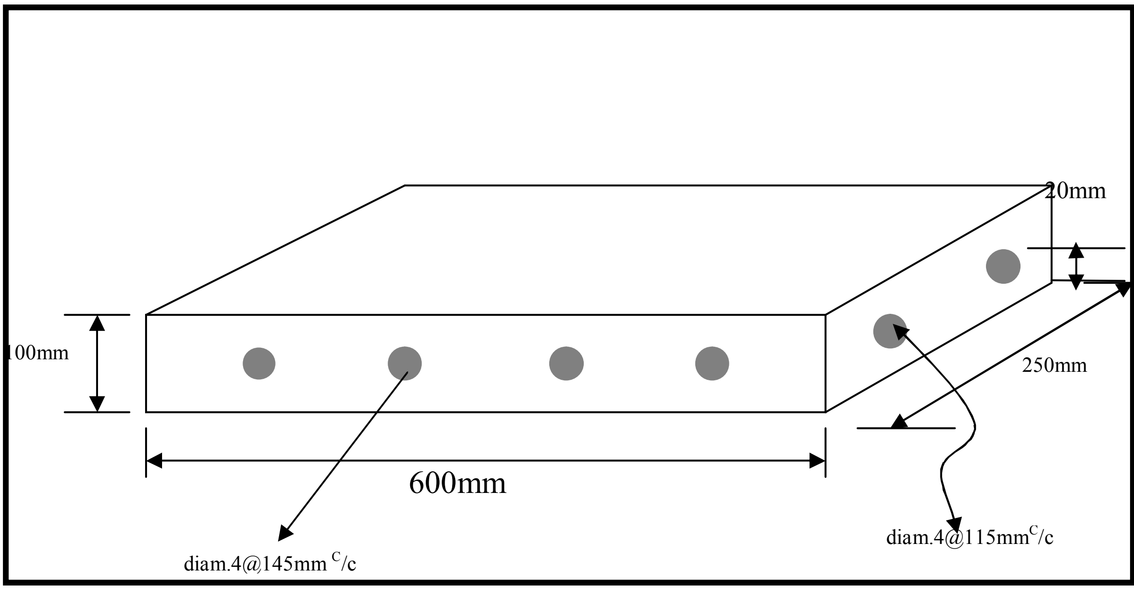

Fig.(1): Test slab dimensions and reinforcement.

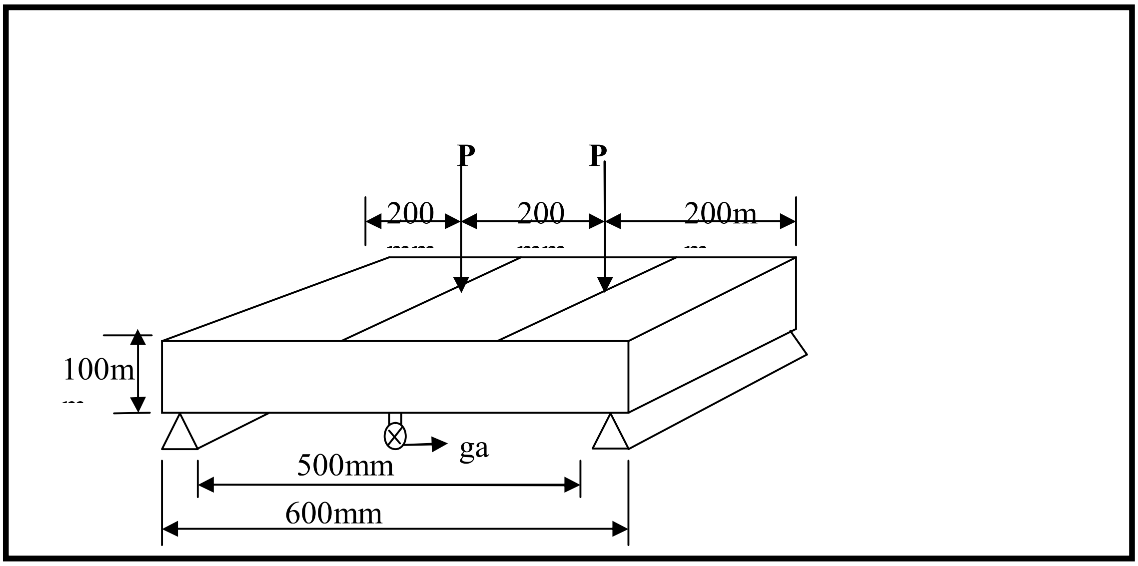

Fig.(2): Two point loads applied on the tested slabs after burned under fire of 600^{0}c.

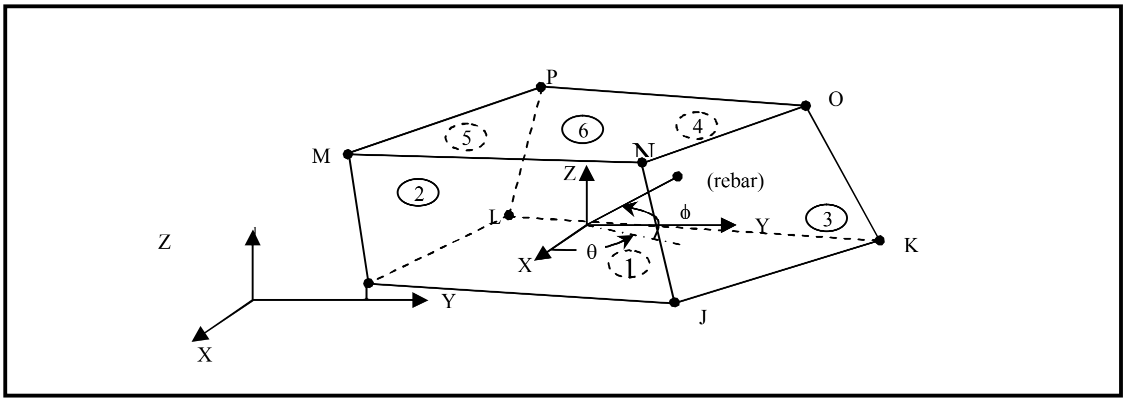

Fig.(3): Solid65 three-dimensional reinforced concrete element.

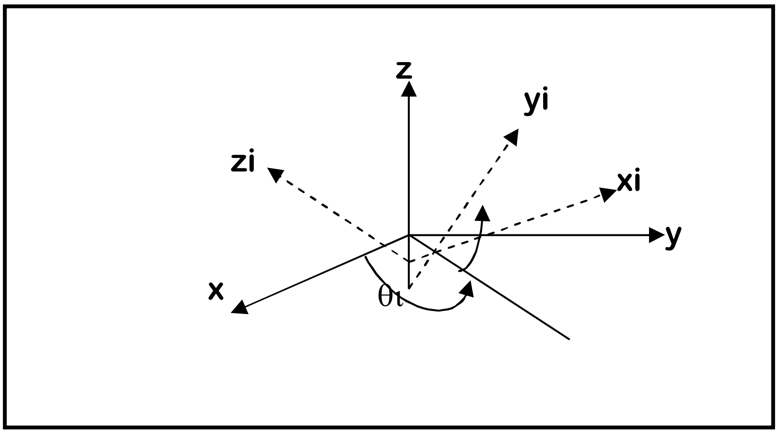

Fig.(4): The coordinate system of fiber reinforced.

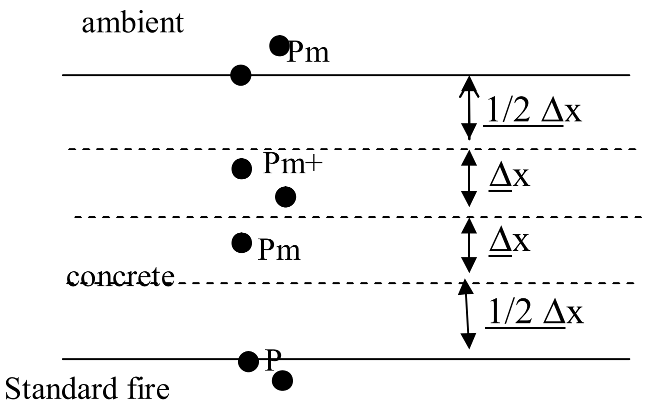

Fig.(5): Discretization of a concrete slab for the heat transfer analysis.

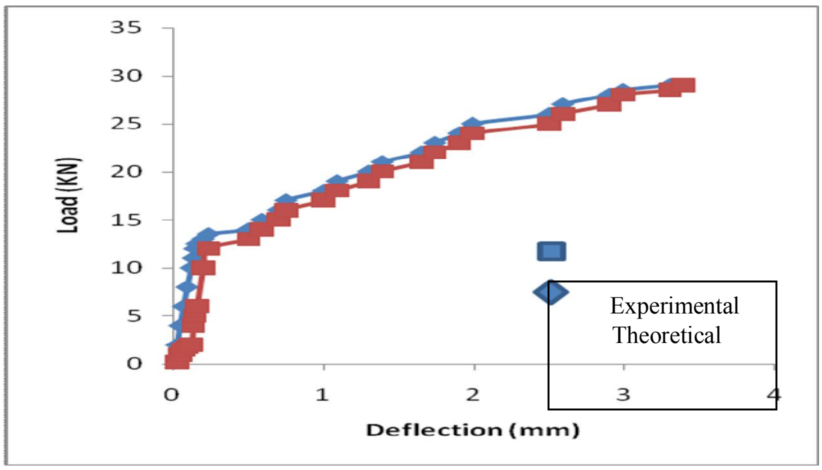

Fig.(6-A): Load – deflection curves for self- compacted concrete slabs without steel fiber content after exposure to 600^{0}c.

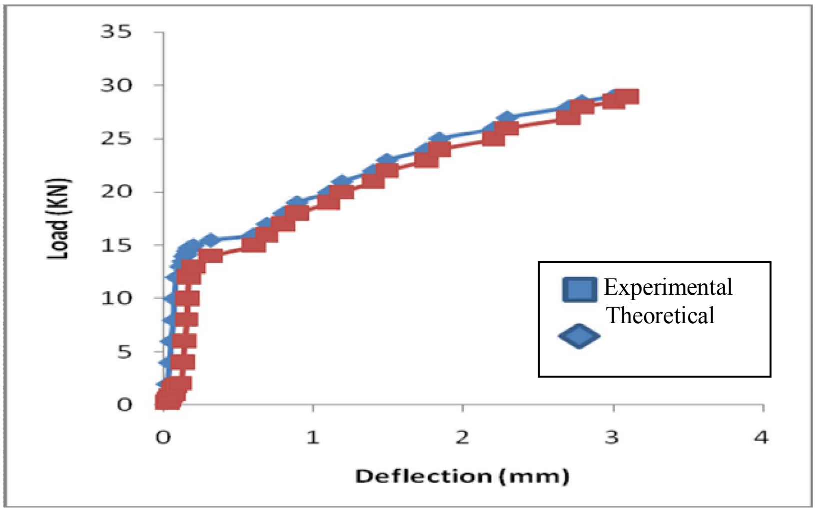

Fig.(6B): Load – deflection curves for self- compacted concrete slabs with steel fiber content of (0.2%) after exposure to 600^0.

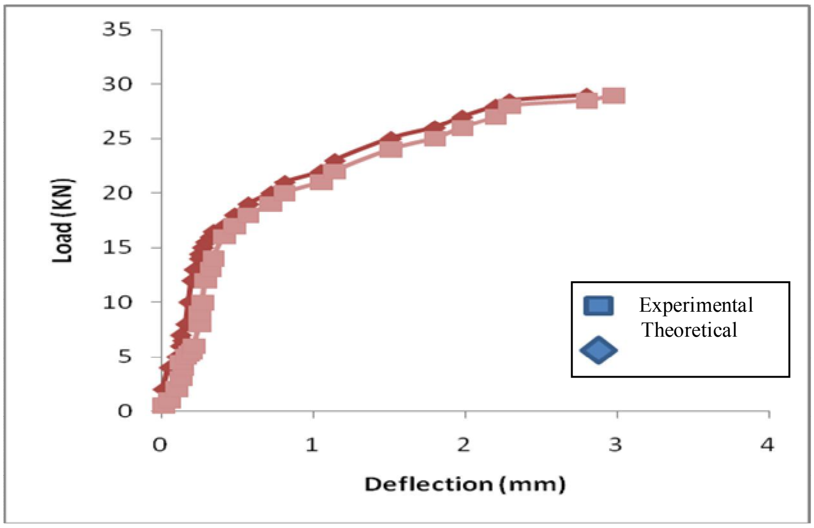

Fig.(6C): Load – deflection curves for self- compacted concrete slabs with steel fiber content of (0.5%) after exposure to 600^0.

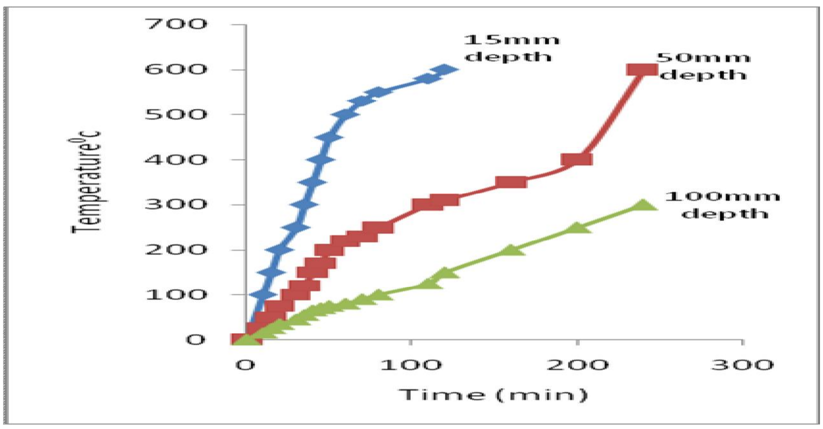

Fig.(7): Temperature through the slab (SL1) during exposure to 600^0c.

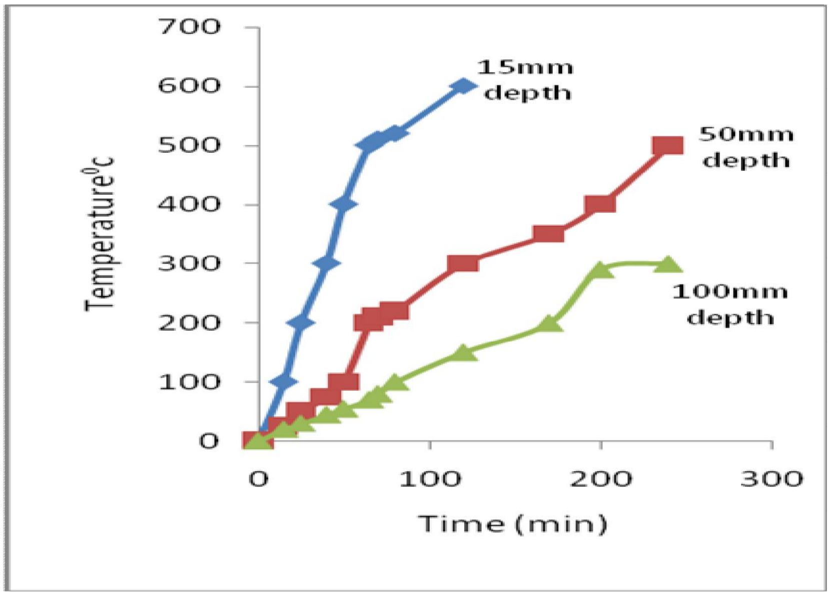

Fig.(8): Temperature through the slab (SL2) during exposure to 600^0c.

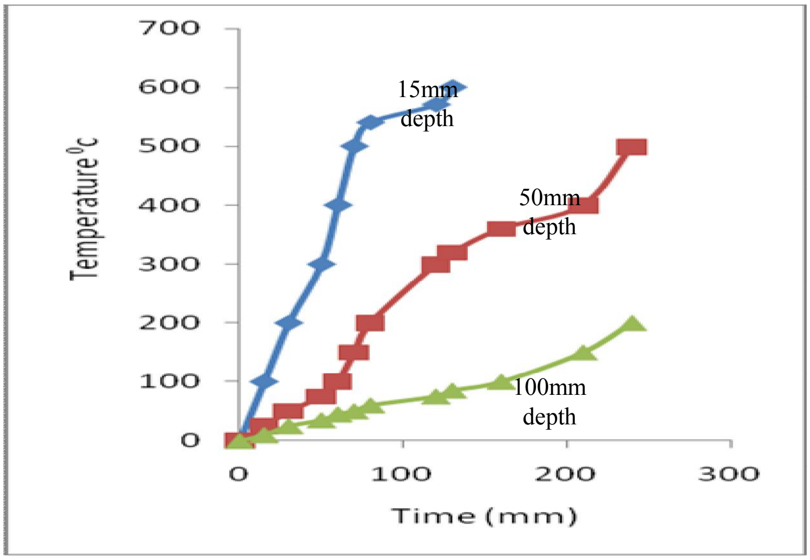

Fig.(9): Temperature through the slab (SL3) during exposure to 600^0c.

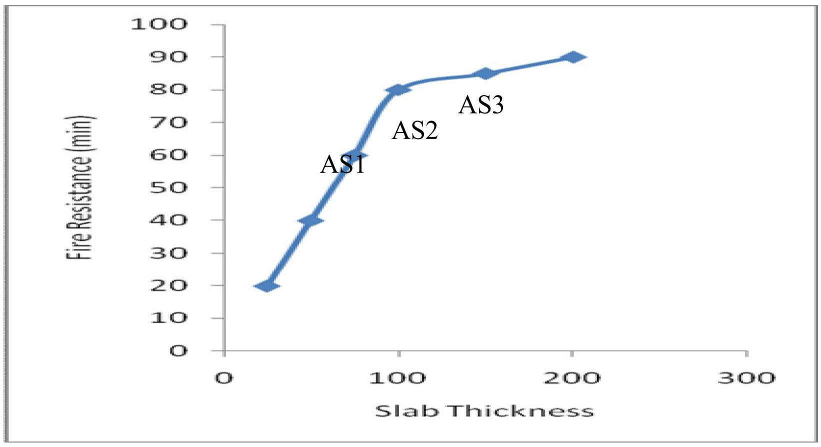

Fig.(10): Relation ship between slab thickness and fire resistance for slabs (AS1,AS2,AS3).

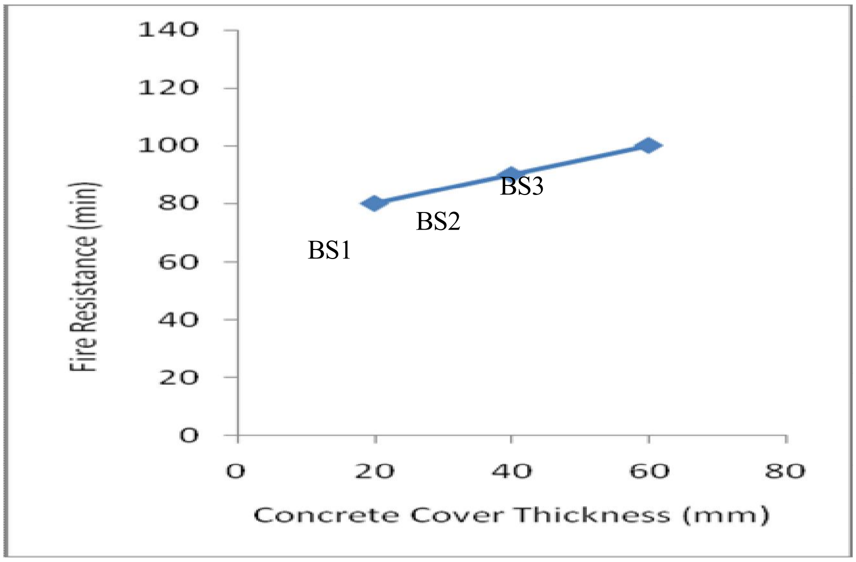

Fig.(11): Relation ship between concrete cover thickness and fire resistance for slabs (BS1,BS2,BS3).

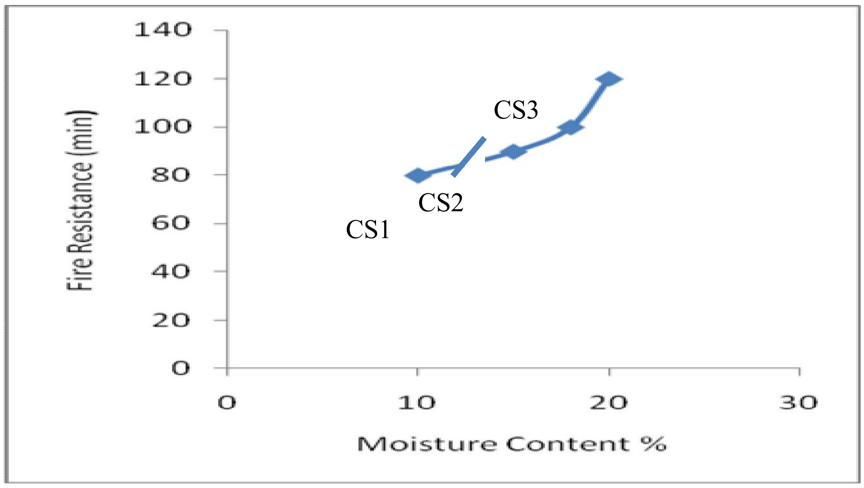

Fig.(12): Relation ship between moisture content and fire resistance for slabs (CS1,CS2,CS3).

Photos of The Experimental Work

Fig.(13): the machine applied load on the slab after burned to 600^0c (Structural libratory in college of engineering in Al- Mustansirya university.

Fig.(14): Cracks in The Slab.

التقيم الحراري للبلاطات الكونكريتية ذاتية الرص مع الالياف المصنوعة من الحديد

م.م.زينة وليد عباس
قسم الهندسة المدنية – كلية الهندسة – الجامعة المستنصرية

الخلاصة

يدرس عمليا تأثير(الألياف) المصنوعة من الحديد على فشل البلاطات الكونكريتية بعد تعرضها إلى حرق تحت درجة ٦٠٠ °م. تم اخذ ثلاثة نماذج من البلاطات ، هذه النماذج تم حرقها أولا في فرن مختبري تحت درجة حرارة ٦٠٠ °م لمدة أربعة ساعات، ثم بعد إخراج هذه النماذج من الفرن يتم تسليط حملين متساويين لإيجاد نسبة الفشل. من جهة أخرى تم اختبار هذه النماذج نظريا بواسطة طريقة العناصر المحددة باستعمال برنامج خاص (ANSYS 7.0) ، وقد وجد إن النتائج مقبولة ونسبة الاختلاف لا تتجاوز ٩% و هي نسبة مقبولة للأغراض العملية مع مراعاة ظروف التجارب. أيضا تم دراسة تدرج الحرارة خلال البلاطات و إيجاد الحرارة الحرجة التي تظهر عندها أول التشققات نظريا بواسطة استعمال نفس البرنامج الخاص و طريقة العناصر المحددة، و قد تم اختبار ثلاثة موديلات من البلاطات مع نسبة فايبر (٠%، ٠,٢%، ٠,٥%) تحت تأثير ٦٠٠ °م و بدون تسليط أحمال. تم اخذ ستة موديلات من البلاطات مع نسبة فايبر (٠,٥%) لدراسة بعض المتغيرات في البلاطات و تأثيرها على مقاومة الحريق . هذه المتغيرات هي: سمك البلاطة، سمك الغلاف الكونكريتي للبلاطة و محتوى الرطوبة للبلاطة. جميع هذه الموديلات تم دراستها نظريا تحت تأثير ٦٠٠ °م فقط و بدون تسليط أحمال بواسطة البرنامج (ANSYS 7.0).

أظهرت النتائج انه بإضافة نسبة حجميه من الفايبر (٠,٢%–٠,٥%) إلى الكونكريت ذاتي الرص فان الفشل يقل بنسبة (٣٠%–٥٠%) على التوالي مقارنة بالبلاطة بدون فايبر تحت تأثير نفس الظروف من الحرارة و الأحمال المسلطة ، ذلك لان الفايبر يزيد من مقاومة الشد للكونكريت. تظهر النتائج النظرية لتدرج الحرارة للبلاطات مع نسبة فايبر (٠%، ٠,٢%، ٠,٥%) إن الحرارة تقل كلما ازداد العمق العمودي للبلاطة بعيدا عن سطح التعرض للحرارة و إن الحرارة الحرجة التي يحدث عندها التشقق للبلاطات مع نسبة فايبر (٠%، ٠,٢%، ٠,٥%) هي (٢٥٠ °م، ٣٥٠ °م، ٥٨٠ °م،) على التوالي. أما بالنسبة للنتائج التي أخذت من الدراسة النظرية لمعرفة تأثير بعض أهم المتغيرات على مقاومة الحريق ، فقد وجد انه سمك البلاطة ليس له تأثير فعال على مقاومة الحريق اي ان التاثير يكون قليل ، بينما تزداد مقاومة الحريق بصورة ملحوظة بزيادة سمك الغطاء الكونكريتي للبلاطة وايضا بزيادة نسبة الرطوبة للكونكريت المستعمل في البلاطات.