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Fire Behavior of RC Flat Slabs Containing Recycled Ceramic Aggregate

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***Abstract:** This study is to investigate experimentally fire resistance of flat slab manufactured using recycled crushed ceramics as coarse aggregate. From an economic point of view, this experiment is costly; however, if it managed and done correctly it can save raw materials, and conserve natural resources. The test is carried out on six slabs measuring 1.65*1.65*0.15m tested under flexural load exposed to fire under load for about 120 min. Two slabs were control without recycled ceramics aggregate, one slab with recycled ceramics aggregate with ratio of 35%, and three slabs with different ratios of 20%, 35% and 50% cast in layers such that the lower layer which was exposed to fire contains crushed ceramics, and the upper layer from ordinary concrete. This paper examines the feasibility of using ceramics wastes in concrete. The behavior of R.C flat slabs manufactured with recycled crushed ceramics was similar to that the normal concrete.*

***Keywords:** fire resistance, ceramics, flexural, flat slabs.*

I. INTRODUCTION

About 50 million tons of construction demolition waste yearly. The process of producing ceramic goods include natural materials, which contains a high percentage of clay minerals, going through thermal processing to acquire characteristic and properties of fried clay. Tassew S.T. et al [1] developed an innovation structure system for slabs using ceramics concretes, reinforcement steel and glass textile reinforcement. The conclusion of his research was that the tensile reinforcement, the concrete strength, and the cross-section affect the crack type, crack pattern, and flexural crack widths of the R.C ceramic concrete slab Moreover, the depth of concrete, the layers of reinforcement, and the type of construction has an effect on the peak load of the textile of the R.C composite panels. Ceramic concrete has a low thermal conductivity therefore heats up slowly during a fire [2]. The fire resistance of the R.C slabs depends on the flexural reinforcements and the concrete cover [3]. Pervious experiments conclude that spalling of the floor slab was extensive and exposed the bottom steel reinforcement during fire. Even though the flexural strength was reduced, the event of collapse didn't occur. The main conclusion of the results is to prevent the premature collapse from happening by making designers understand the behavior of the R.C structures during the fire.

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II. EXPERIMENTAL PROGRAM

A. Experimental program matrix

The experimental program matrix consists of six RC flat slabs. The six slabs were cast without central column; two as a control slab" SF0" and "SD0" without adding crushed ceramics, the remaining slabs "SF35" with 35% crushed ceramics aggregate, and"SD20", "SD35" and "SD50" with ratios 20%, 35%, and 50% were cast in two layers, the bottom layer with thickness 50mm and the top layer 100mm with normal aggregate concrete, see Fig 1. The slabs with dimension 1650 x 1650 x 150 mm with bottom reinforcement fay 10@100 mm and top reinforcement fay 10 @ 200 mm.

Table- I: Experimental program matrix.

Specimen	Concrete Type	
	Top layer "100mm"	Bottom layer "50mm"
SF0	Normal aggregate concrete	
SD0	Normal aggregate concrete	
SF35	recycled ceramics concrete	
SD20	Normal aggregate concrete	recycled ceramics concrete
SD35	Normal aggregate concrete	recycled ceramics concrete
SD50	Normal aggregate concrete	recycled ceramics concrete

B. Material Properties

The average compressive strength of the normal / recycled concrete based on ASTM C 39 [4] is 25 MPa and the average tensile strength is 2.50 MPa. The average yield strength of steel reinforcement is 400 MPa with a modulus of elasticity of 200 GPa (DIN 50145) [7] and the ultimate strength is 600 MPa. The mix composition of the studied normal and recycled concrete is shown in Table II & III.

Table- II: Normal concrete mix composition.

Sand (kg/m^3)	450
Gravel (kg/m^3)	1100
Cement (kg/m^3)	350
Water (L/m^3)	175
W/C	0.5

Table- III: Recycled concrete mix composition.

Sand (kg/m^3)	450
recycled ceramics (kg/m^3)	1100
Cement (kg/m^3)	350
Water (kg/m^3)	175
W/C	0.5

Porous ceramic coarse aggregates" (PCCA) used in this study were obtained from ceramic industries in Egypt.

C. Test Set-up

Two fire flames were placed at distance of 500 mm each with length of 1500 mm. The free span was 1500 mm x 1500 mm. Load was applied from the load cell. All slabs were loading up to the flexural load. The load was kept constant during firing. The overall view of the test setup is shown in Fig. (1).

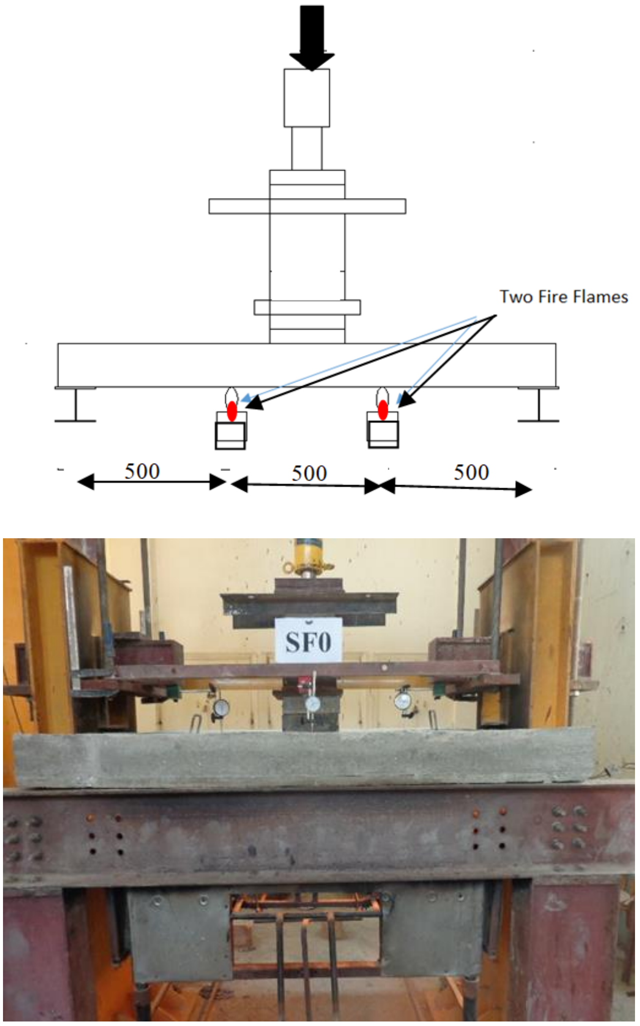

Fig. 1.Test Set-up.

D. Temperature measurement

Two thermocouple gages were placed about 200 mm from the corner in the heated side, the temperature appears in the digital screen as seen in Fig.2. The temperature was reached up to 384°c at this point. The slabs were exposed to fire for 120 minutes, the temperature was recorded with time see Fig.3 also during cooling see Fig.4.

Fig. 2.Temperature digital screen .

III. RESULT AND DISCUSSION

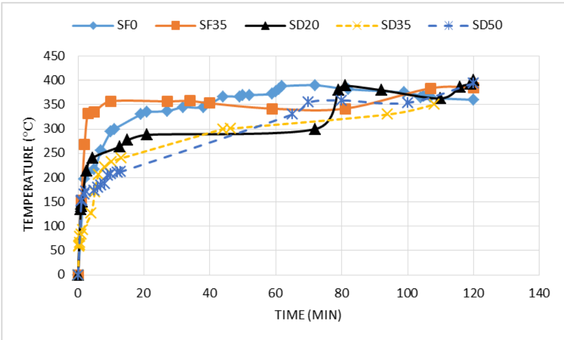

Fig. 3.Temperature degree versus time.

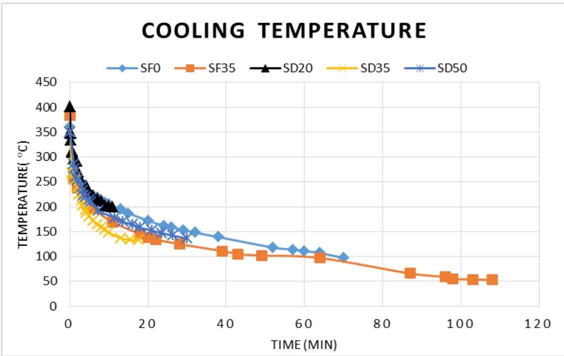

Fig. 4.Temperature versus time during cooling.

As seen from Fig.3 "SF0" and "SF35" simultaneously reach the same temperature and faster than other specimens. Also, "SD35" and "SD50" simultaneously reach the same temperature, but it's slowest of all the other specimen. After 40 minutes, all specimen start getting closer to each until they become one.

From Fig.6 “SD35” get cooler than the other specimens then SF35, SD50, SD20, and SF0. It can be noticed that specimens that contain crushed ceramics get cooler that the control specimen which didn’t contain crushed ceramics. Also, the only specimen that fall during cooling is “SF0”, it falls at 71 minutes from closing the fire at temperature 97°c at load 251kN, all the other specimens that contain crushed ceramics didn’t fell during cooling after reaching the room temperature it was loaded again till failure.

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A. Deflection

In order to record the slabs vertical deflection, five vertical dial gages with 0.01 mm accuracy was used for vertical measurements were used as shown in Fig. (5).

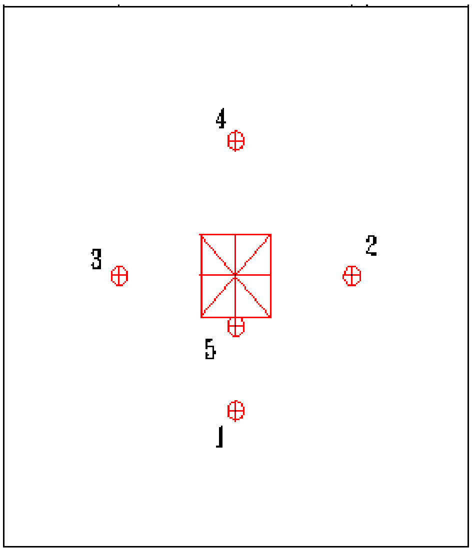

Fig. 5.Dial gauges positions.

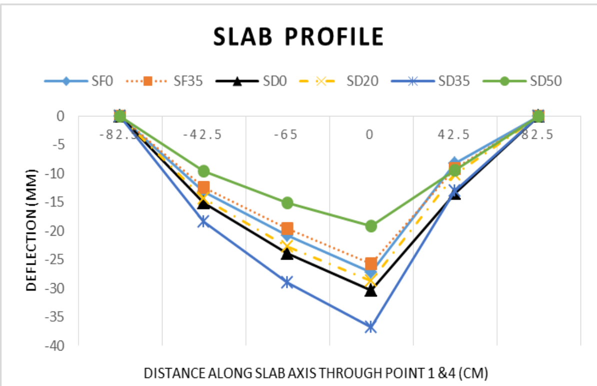

Fig. 6.Load-deflection profile.

As seen from Fig.6 the maximum deflection at mid-point of slabs was 37 mm at slab SD35 and was more 20.7% than the control slab SD0.

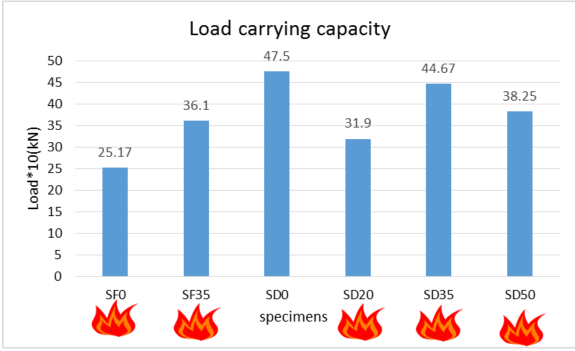

Fig. 7.Load carrying capacity for slabs specimens.

Fig.7 shows that the load carrying capacity of all specimens exposed to fire and the control slab SD0 that did not exposed to fire. The maximum load capacity 475 kN was the control specimen and the minimum load capacity 251 kN was slab specimen SF0 that was exposed to fire and did not contain ceramics. It can be concluded that by replacement 35% from natural aggregate by using ceramics, it can carry load by 44% more than the normal concrete exposing to fire. Generally recycled ceramics concrete slabs exposed to fire have load carrying capacity more than control slab.

B. Crack pattern and mode of failure

The most slabs were not failed during loading under fire exposed except, the control specimen without recycled ceramics SF0 that was failed at load 252 kN. The failure of all tested slabs was started with flexural cracks located around the edge of the loaded plate in the tension side, these cracks were distributed in orthogonal and diagonal direction some slabs were recovered because of being exposed to fire for two hours the flexural cracks increased in their width and moved toward the support see Fig.8.

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Fig. 8.Cracks patteren for tested slabs.

It's clear that from Fig.8, the SF0 control specimen was spalling occur during exposed to fire while specimen SF35 didn't exposed to fire the spalling didn't occur. Generally, spalling happened in all specimens exposed to fire with different ranges. It's clear that slab with recycled crushed ceramics had less spalling than the control slab.

C. Steel tensile strain

Steel tensile strain was measured by strain gauges placed in specimens SD0, SD20, SD35 and SD50. The strain gauges number 1 & 2 were placed in the middle of the bottom mesh in the two orthogonal directions. While Strain number 3 & 4 were placed in the middle of the top mesh in the two orthogonal directions. Steel strain was measured and recorded using a strain indicator connector which was connected to the strain gauges by wires and the readings were taken at each increment of loading. It's clear from Fig.9 that specimen SD50 gets the minimum steel tensile strain before starting firing. So that it gets the minimum deflection in Fig.6.

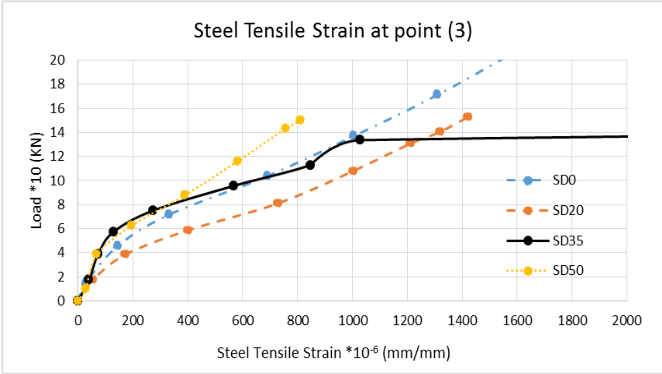

Fig. 9.Steel tensile strain versus load.

IV. FINITE ELEMENT

The computer program ANSYS [8], was used to carry out the analyses. The fire temperature was calculated assuming that the slab was exposed to not uniform fire from below (tension side). The distribution of temperature on slab tension side exposed to fire was plot by ANSYS program. The thermal model 3D, 4.0 nodes shell 131 with conductivity factor K_{XX}=400, specific heat C=385°c was used to model the slabs after 10, 30, 60, 90 and120 minutes from starting the fire.

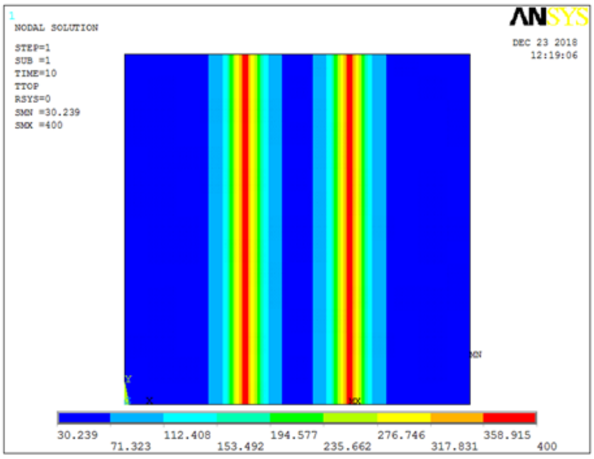

Fig. 10.   Slab surface temperature after 10 Min.

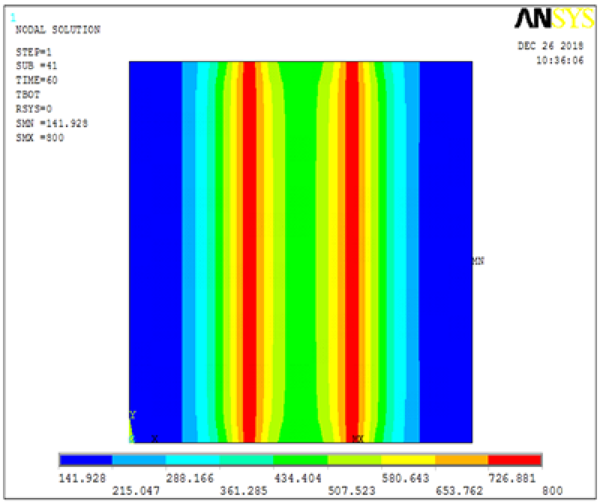

Fig. 11.   Slab surface temperature after 60 Min.

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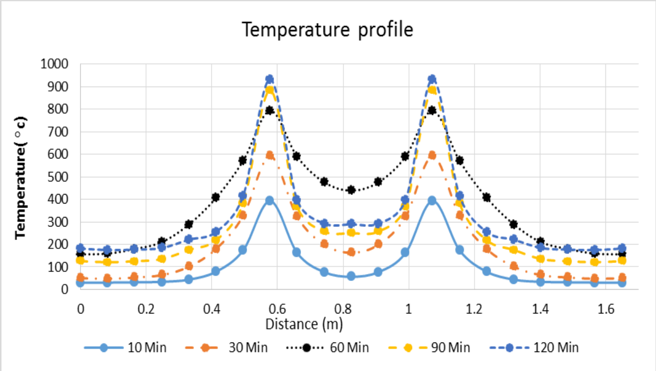

Fig. 12. Temperature profile along the slab.

It's clear from Fig.10 and Fig.11 that the heat distribution isn't uniform distribution.

V. CONCLUSION

According to the experiments, the following conclusions can be drawn:

1. Even though the bottom bars were completely exposed to the fire, which reduced the flexural capacity of the slab drastically, the slab remained stable.
2. Recycled ceramics concrete aggregate prevented large cracks and enabled the slabs to maintain their flexural capacity.
3. It was conclude that performance of recycled ceramics concrete was identical to that of the normal concrete.
4. The finite element model predicted the ultimate load carrying capacity with stander deviation of 0.98.
5. The finite element model predicted the mode of failure and crack pattern observed in the experiments accurately.

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