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Increasing ultimate strength of reinforced concrete slab by using Reactive Powder Concrete and study the effect of high temperature on them

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ABSTRACT

The main purpose of this search is to study the punching shear behavior of fourteen specimens of Reactive Powder Concrete (RPC) two-way flat plate slabs, half of these slabs have been exposed to a high temperature up to 400 C° by using an electric oven. All slabs have dimensions of (400x400x60) mm, with steel reinforcement mesh of (Ø6mm) diameter. Laboratory tests show that there is an increase in the value of First Crack Loading (FCL) and Ultimate Load (UL) by (208, and 216.67) % and a decrease in deflection by (56.85) % due using slab with complete reactive powder relative to a slap made of normal concrete. The use of the (RPC)mixture in layers in slabs gave results close to the slab which consists of full (RPC) this gives the benefit of more than the use of a slab that contains full reactive powder concrete in terms of cost, the increase was in FCL and UL by (130.8, 169.23, 102.7 and 135.135) % and a decrease in the value of deflection by (37.17, 47.64) %. The use of a partial reactive powder mixture also showed good results, and by increasing the dimensions of the RPC area, the results were better. the increase in FCL and UL by (54, 116, and 185) % and (53, 116.67, and 166.67) % and a decrease in value of deflection by (36.12, 42.4, and 50.26) % from reference slab.

When slabs are subjected to high temperatures, there may be a decrease in the value of the FCL and UL and an increase in the value of deflection when compared to models not exposed to high temperature. But when compared to the reference slab with the same circumstance showed an increase in the value of the FCL and the rate ranged between (50- 200) % and the UL was the ratio ranged between (51.35-208.1) % and a decrease in the value of the deflection where the ratio ranged (21-46) %.

1. Introduction

A flat plate is a slab resting directly on columns. The slab is reinforced in such a manner to be capable of transmitting the loads directly and safely to the supporting columns without the need of using column capitals or drop panels. A flat plate construction does not necessarily mean complete beamless construction since such beams often used at some location such as around staircases and around large openings in the slab [1]. Each structural member has different levels of load sensitivity, Concrete slabs are the most sensitive structural elements during construction phases. Most failure type occurring in the flat slabs is the punching shear. This type of failure occurs around the columns as a result of a concentrated load

Figure 1. flat plate concrete construction [2].

Figure 2. Typical punching shear failure [3].

RPC is defined as the generic name of cementitious composite materials that consists of more than one material mixed with each other so that it becomes one material working as unity with good physical properties for strength and ductility [4].

Vainiunas et al [5] analyzed the punching shear behavior of slab-to-column connection. The main conclusion reached was that the value of punching force depends on the ratio of shear forces and bending moments acting within the critical section. Mohammed [6] tested twenty-four specimens of RPC and Normal Concrete "NC", The main variables adopted by the researcher were RPC ratio, volumetric steel fiber, and longitudinal steel ratio. experimental results give that RPC gives higher capacity in loading and decreases in deflection. Yousef [7] studied the effect of steel fiber and silica fume on properties of (RPC). Simply supported beams were adopted to investigate the behavior of RPC under four-point loading. From the experimental tests result, the increase in steel fiber causes increases in ultimate load, also, the maximum deflection decrease.

Graybeal et al. 2002 [8] made an experimental investigation on RPC by adding Portland cement, silica fume, fine sand, steel fibers, and superplasticizer, with a w/c ratio of 0.19. They showed that the RPC has compressive strength ranging between 193 and 207 MPa obtained by using 100×200mm cylinders. They have stated that eliminating coarse aggregate and substituting finely ground powders were the main causes to achieve the mentioned strength.

Jungwirth,**2002 [9]** stated that the addition of steel fibers as 2% by volume of the RPC, has a significant effect on the reinforcement system. These fibers improve the tensile behavior, increase the ductility of the material and lead to an even distribution of the microcracks. This eliminates significantly the need for passive reinforcement of the structures. A modulus of rupture up to 35 MPa was obtained.

Masami et al.2005 [10] studied the effect of air curing at 20 °C and steam curing at 90°C on the strength and fresh properties of RPC. The results showed that RPC has high fluidity reaching flow of about 270mm in the state of fresh mortar, and when it is hardened it has high levels of strength and toughness, with a compressive strength of about 146 MPa after 28 days of curing at 20 °C and 230 MPa after 48 hours of steam curing at 90 °C, and bending strength of about 46.1 MPa cured at 90 °C for 48 hours by steam curing.

al-ne'aime,2006 [11] studied the static properties and impact resistance of RPC incorporating reactive silica sand powder as a pozzolanic material and compared it with original RPC incorporating silica fume. The influence of the superplasticizer type, fine sand type, the particle size of fine sand and time of vibration on the performance of RPC in terms of w/c and compressive strength was studied. The mechanical properties and impact resistance of RPC were studied and at various ages of curing and various curing temperatures.

Mohammed, 2013 [12] tested RPC and normal concrete "NC" with twenty-four specimens tested and failed as flexural. The main variables adopted by the researcher were RPC ratio, volumetric steel fiber, and longitudinal steel ratio. By experimental results, RPC gives higher capacity in loading and decreases in deflection.

Wille et al,2011 [13] Prove that it is relatively simple and possible to enhance UHPC without relying on heat treatment or pressure and using a traditional concrete mixer. The initial process of increasing packing density was through the proper selection of particulate matter and improved flow. The following mix procedure was obtained for UHPC production with a pressure strength exceeding 150MPa

1- Mix silica smoke and soft sand for 5 minutes.
2- Add other dry ingredients (cement and glass powder) and mix for another 5 minutes.
3- 3-Add each water within 1 minute add all high-water water distillers and mix for an additional 5 minutes.
4- Add fiber, if any, and mix for 2 more minutes.

The initial compressive force targeted in this study was 150MPa. Strengths of up to 190MPa were obtained without fiber addition and exceeded 200MPa when adding short steel fibers in quantities of 2.5% by volume.

Voo et al,2003 [14] examined many specimens of RPC for the two-point flexural tensile strength. They used two types of steel fiber, Type I were straight fibers 13 mm long by 0.2 mm diameter, type II ended hooked fibers 30 mm long by 0.5 mm diameter. They concluded that end hooked fibers perform better than straight fibers. The flexural strength of 23.2MPa was obtained for straight fibers and 25.2MPa for end hooked fibers. Their results indicated an increase in flexural strength by more than (8%) for end hooked fibers compared to straight fibers.

2.The aim of this study

1- The main purpose behind the experimental program is to study the punching shear behavior of fourteen specimens of two-way flat plate slabs.

2- Study the effect of high temperature on concrete strength in the presence of reactive powder concrete mixture.

3. Methodology

Each test slab of the present investigation was square with dimensions of (400x400x60) mm, the slab was simply supported along its four edges and loaded by a central steel column of dimension (40x40) mm. Slabs designation were as following:

1st symbol (R) for reference slab.

2nd symbol (O) for no addition.

3^{ed} symbol (RP,) for a concrete type (RPC)

4th symbol (L) for layers.

5th symbol (100, 160, 220) mm dimensions of the partial reactive powder mixture (RPC). **See Fig.3 to more details.**

6th symbol (15, 30) mm dimensions for layers of (RPC). **Fig.4 to more details.**

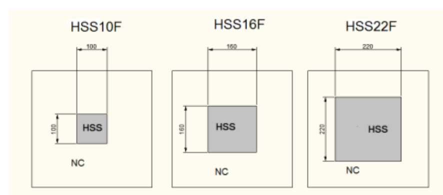


Figure 3. Use (HSC) in Suqear shap with different dimensions

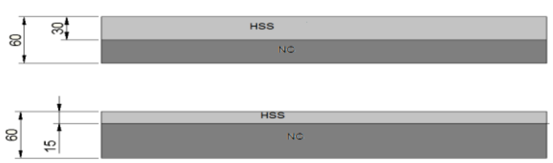


Figure 4. Use (HSC) in layer with different dimensions

All the samples were designed according to (ACI-318-14) [15]., Two types of concrete were used

Table (1). The table shows the symbols used in the search

Group	specimens	Dimension L	B	T	Description
	R^{1ST}O^{2nd}O	40	40	6	This model is reference consists of normal concrete without any additions.
	RP^{3th}OO	40	40	6	Consists of a fully mixture of reactivepowder concrete.
	RPL^{4th}15^{6th}	40	40	6	In this model the reactive powder concrete was placed in a layer with dimension 1.5 cm the remaining layer consists of ordinary concrete with dimension 4.5cm.see fig.3
	RPL30^{6th}	40	40	6	In this model the reactive powder concrete was placed in a layer with dimension 3 cm the remaining layer consists of ordinary concrete with dimension 3cm.see fig.3
R.P.C	RPS^{7th}10^{5th}	40	40	6	In this model, reactive powder concrete was placed in a partial area with a square shape in the middle of the model with dimensions (10*10) cm The rest of the model space consists of normal concrete. see fig.4
	RPS16^{5th}	40	40	6	In this model, reactive powder concrete was placed in a partial area with a square shape in the middle of the model with dimensions (16*16) cm the rest of the model space consists of normal concrete. see fig.4
	RPS22^{5th}	40	40	6	In this model, reactive powder concrete was placed in a partial area with a square shape in the middle of the model with dimensions (22*22) cm the rest of the model space consists of normal concrete. see fig.4

normal concrete and reactive powder concrete. Table (2) and (3) gives mix proportions of (NSC) and (R.P.C) used in this research.

Table (2) Properties of Concrete Mix (NC)

Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	w/c
400	600	1200	0.45

Table (3) Properties of Concrete Mix (RPC)

Description	Results
Cement (Kg/m^3)	1000
Sand (Kg/m^3)	1000
Gravel (Kg/m^3)	----
Silica Fume %	20
W/C	0.2
Superplasticizer (L/m^3)	5
Steel Fiber Content %	1
Steel Fiber Content (Kg/m^3)	78

The molds used in casting the samples of research made of ply-wood lubricated with a special oil to resist moisture as shown in fig.5

Figure5. Some molds are used

After the casting process and curing the models put them in water for 28 days as shown in the fig.6

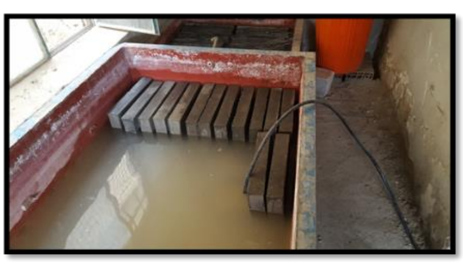


Figure6. Slabs during curing

Before the testing day, the slabs were taken out from the container of curing and dried for one day in fresh air. During the drying time, the slab specimens were cleaned and painted with white paint on both surfaces, to achieve clear visibility of cracks during testing. Before testing the specimens, positions of supports, centrally applied load, and dial gauge were marked. The central deflection of the slab specimen was measured at the center of the slab by using a dial gauge of 0.01mm (ELE type) and (30mm) sensitivity. The load is applied at an increment of 5 kN. This load was applied which gave a good picture of the structural behavior of the slab. A special supporting frame was manufactured and used inside the testing machine with a clear distance of supporting of (400x400) mm, to provide the required space for the board. This supporting frame is manufactured using four welded steel beams to form a square shape. These four steel beams contain a 25 mm welded steel tape on the upper face to provide simple support for the edge of the board Solid square steel cube of dimensions (40X40) mm placed over the center of the slab to provide a concentrated load as shown in Fig. 7 shows the details of slab testing.

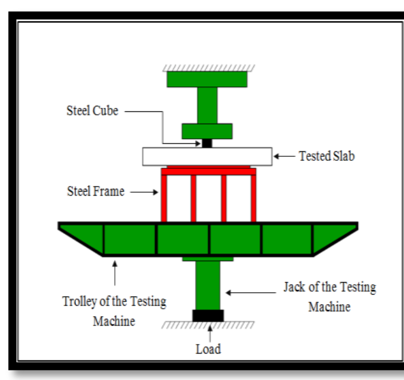


Figure7. The hydraulic Universal testing machine

4. Result and discussion

The Table 4 below shows the standard of the material properties has been used for (N.C), for (R.P.C) use three cylinders (100*200) mm ASTM C 39/C39M-01 and standard cubes (100) mm (B.S: 1881: part 116)

Table (4) stander used in the test

Specimen (mm)	No. of specimen	Test	Standards of test
Cube 100*100*100	3	Cube compression strength	B:S: 1881: part 116 [16]
Cylindrieal R:100 mm H:200mm	3	Cylindrieal Compression Strength	ASTM C39/C39M-05 [17]
Cylindrieal R:100mm H:200mm	3	Splitting Tensile Strength	ASTM C496-04 [18]
Prism B:100mm L:500mm	3	Modulus of Rupture	ASTM C78-02 [19]

This tables 5 and 6 shows the results of the properties of the materials used at the age of 28 days. All results obtained are the average of three models.

Table 5. Mechanical properties for (NC) Mixes

f'_c (MPa)	f_{cu} (MPa)	E_c (GPa)	f_{sp} (MPa)	f_r (MPa)
32	39	27.132	4.81	4

Table 6. Mechanical properties for (RPC) Mixes

f'_c (MPa)	f_{cu} (MPa)	E_c (GPa)	f_{sp} (MPa)	f_r (MPa)
128.85	140.05	49	14.2	23.77

Figure8. the cubes, prisms, and cylinders

5. The first crack and ultimate load

The table (7) shows the values of first crack and ultimate load for all models

Table (7) shows the first crack and ultimate

Slab	F.C.L*	U.L**	F.C.L/U.L	R1***	R2****
R000	6.5	30	21.6	-	-
RP00	20	95	21	308	316.67
RPL15	15	60	25	230.8	200
RPL30	17.5	70	25	269.23	233.33
RPS10	10	46	22	154	153.33
RPS16	14	65	22	216	216.67
RPS22	18.5	80	23.1	285	266.67
R000F	5	18.5	27	-	-
RP00F	15	57	26.3	300	308.1
RPL15F	10	37.5	26.7	200	202.7
RPL30F	12.5	43.5	29	250	235.135
RPS10F	7.5	28	26.8	150	151.35
RPS16F	10	39	25.64	200	210.8
RPS22F	12.5	48	26	250	259.46

*** $\frac{F.C.L}{(F.C.L)R}$ *F.C.L: First Crack

**** $\frac{U.L}{(U.LR)}$ **U.L: Ultimate Load

From table (7):

1- In the reference slab (ROOO) the first crack occurs at 6.5 kN and this value increased by (208, 130.8, 169.23,54,116 and 185) % in slabs (RPOO, RPL15, RPL30, RPS10, RPS16, and RPS22) respectively.

2- In the reference slab (ROOOF) the first crack occurs at 5 kN and this value increased by (200, 100, 150,50,100 and 150) % in slabs (RPOOF, RPL15F, RPL30F, RPS10F, RPS16F, and RPS22F) respectively.

3- It can be noted that with the increase in the compressive strength The pattern of failure has changed from one model to another. For slab (RPOO) the first crack occurred under the loaded area in the tension surface of the slabs. By increasing the load, these cracks widen and increased in number to form a quadrate shape. For slabs (RPL15, RPL30, RPS10, RPS16, and RPS22) with the increase in the load, the cracks increased in number with less rate of expansion, at ultimate load, punching shear failure occurred. For the last slab (RPS22) as the load was increased, can noted the appearance of two punch shear Because it contains a mixture R.P.C with a square dimension 22 * 22 and the rest N.C, which increased the strength of the slab.

4- In slab (RPOOF) the cracks appear at tension zone at mid-span, As the load increased, the concrete began to fall at a higher rate than (RPOO) Due to exposure to high temperature.in slabs (RPL15, RPL30) The cracks began to form a square shape, and the number of cracks was more in the slab (RPL30F) than the slab (RPL15F) because the slab (RPL30F) bears more than the slab (RPL15F). In the latter slabs (RPS10F, RPS16F, RPS22F) noted that the number of cracks increases to increase the resistance of the model, in the slab (RPS22F) the percentage of cracks in it high because it contains the mixture of (RPC) More than slabs (RPL15F, RPS10F, RPS16) and closer to the slabs (RP00F, RPL30F).

5- The reference slabs ROOO had the ultimate load capacity of 30kN. For the slabs (RPOO, RPL15, RPL30, RPS10, RPS16, and RPS22) the ultimate load increase by (216.67, 100, 133.33, 53.33, 116.67 and 166.67) % respectively from the reference slab. Because of the use of reactive powder concrete.

6- The reference slabs ROOOF had the ultimate load capacity of 18.5kN. For the slabs (RPOOF, RPL15F, RPL30F, RPS10F, RPS16F and RPS22F) the ultimate load increase by (108.1, 102.7, 135.135, 51.35, 110.08 and 159.46) % respectively from the reference slab. although the models were exposed to a high temperature of up to 400 c°.

6. Load Deflection

Explain the following Figures the central load-deflection curve for all tested slabs of each group to illustrate the general behavior of these specimens, and shows the relation between central deflection with the all tested slab specimens. These figures were illustrated the different in the stiffness value among the tested specimens through the observed values of the deflection.

Table (8) Central Deflection of R.P.C

Slab	U.L (kN)	Deflection at U.L (mm)
R000	30	9.55
RP00	95	4.12
RPL15	60	6
RPL30	70	5
RPS10	46	6.1
RPS16	65	5.5
RPS22	80	4.75
R000F	18.5	11
RP00F	57	5.95
RPL15F	37.5	8.7
RPL30F	43.5	7
RPS10F	28	7.15
RPS16F	39	6.9
RPS22F	48	6.35

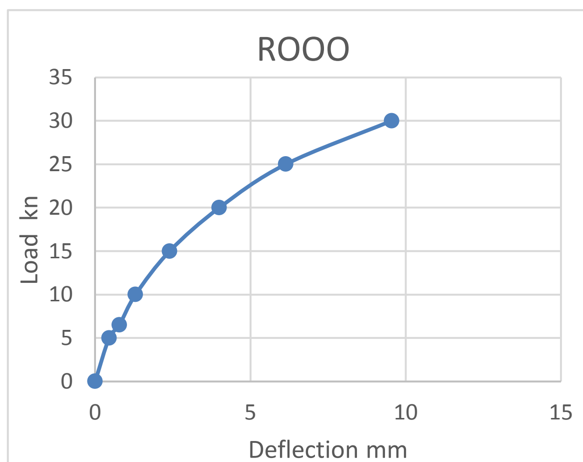


Figure9. Center Load – Deflection Curve of Specimen (ROOO)

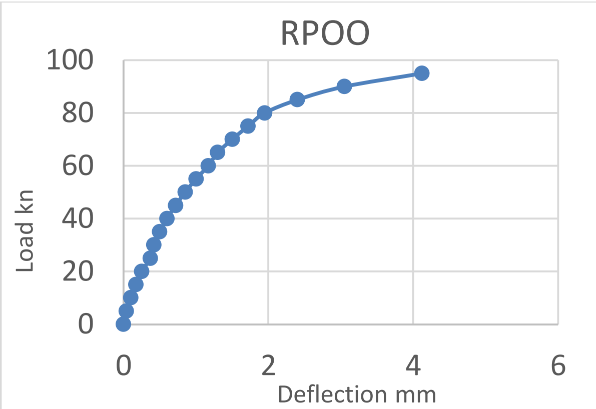


Figure10. Load Deflection Curve of Specimen (RPOO)

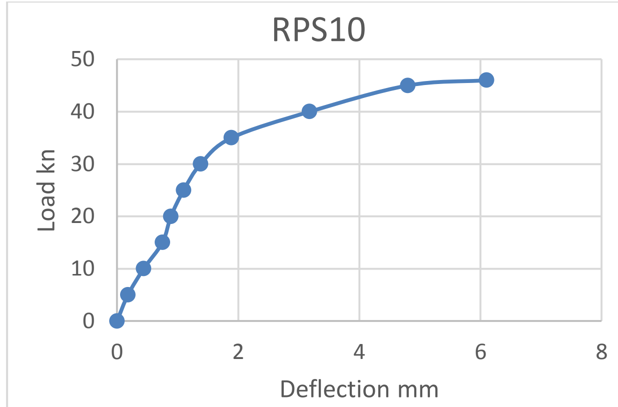


Figure13. Load Deflection Curve of Specimen (RPS10)

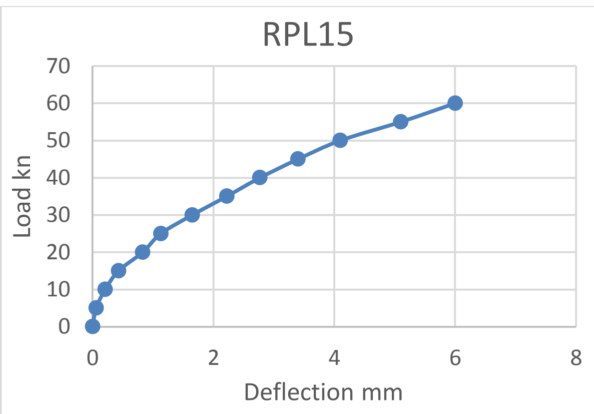


Figure11. Load Deflection Curve of Specimen (RPL15)

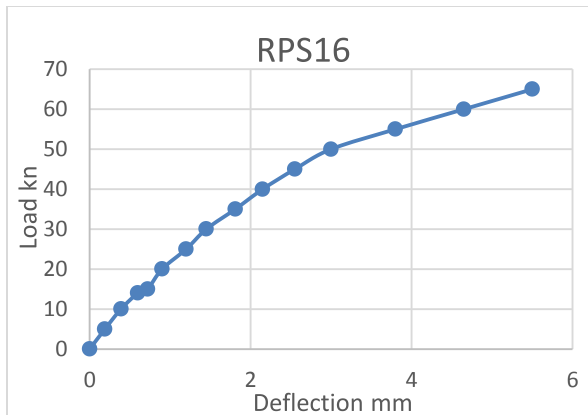


Figure14. Load Deflection Curve of Specimen (RPS16)

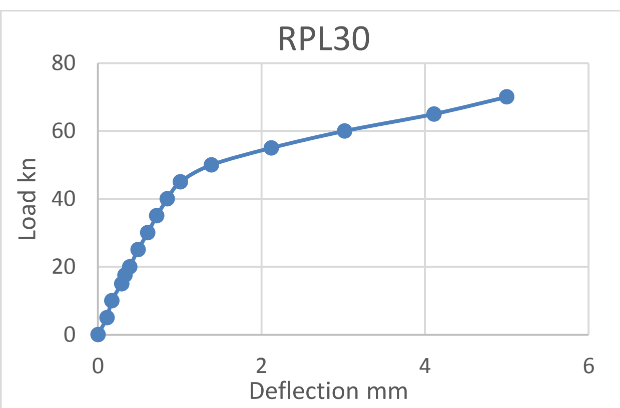


Figure12. Load Deflection Curve of Specimen (RPL30)

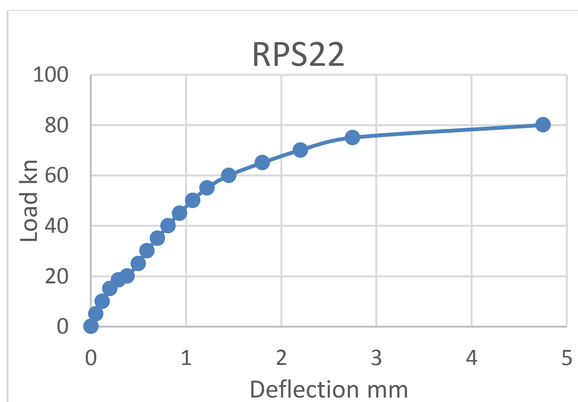


Figure15. Load Deflection Curve of Specimen (RPS22)

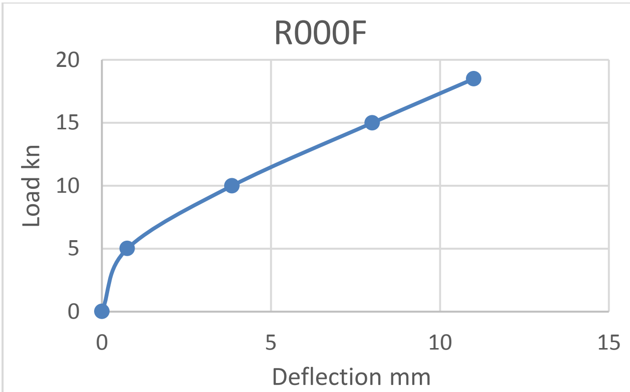


Figure16. Load Deflection Curve of Specimen (ROOOF)

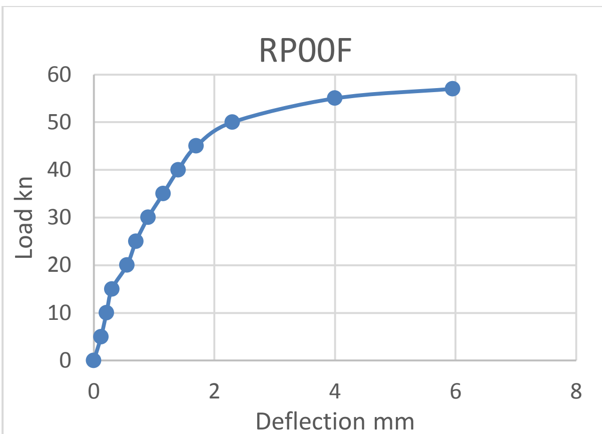


Figure17. Load Deflection Curve of Specimen (RPOOF)

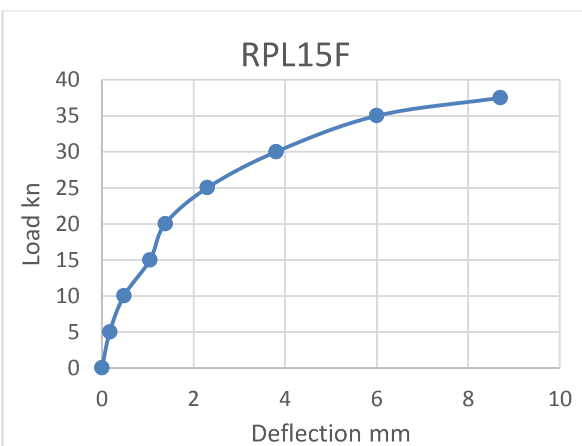


Figure18. Load Deflection Curve of Specimen (RPL15F)

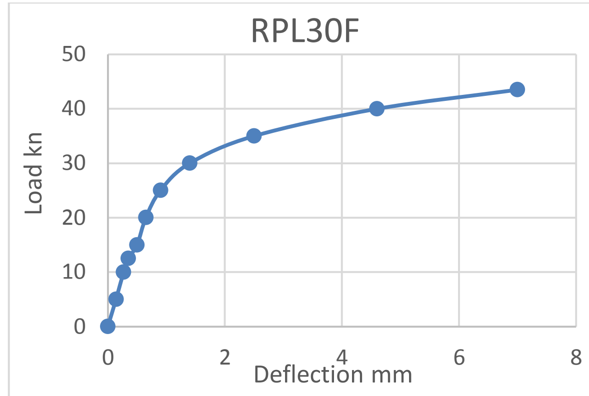


Figure19. Load Deflection Curve of Specimen (RPL30F)

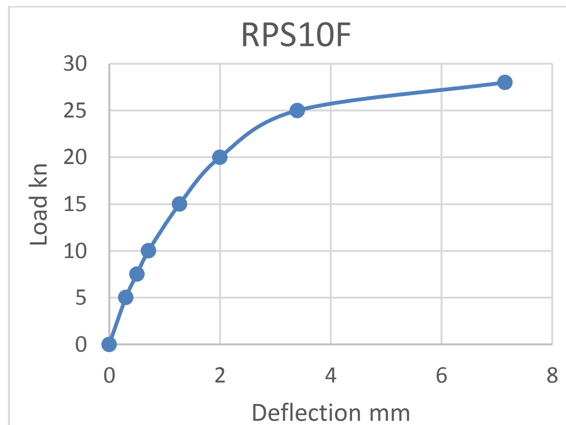


Figure20. Load Deflection Curve of Specimen (RPS10F)

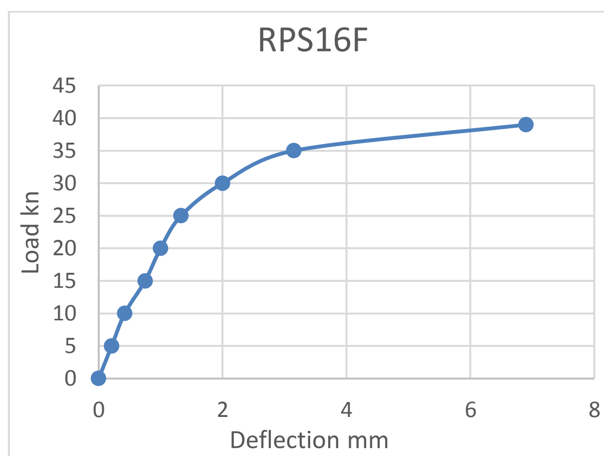


Figure21. Load Deflection Curve of Specimen (RPS16F)

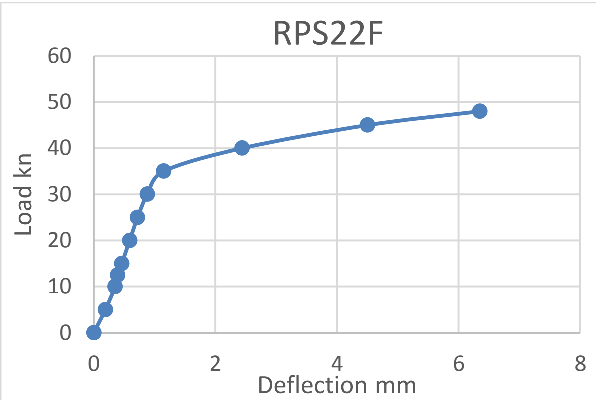
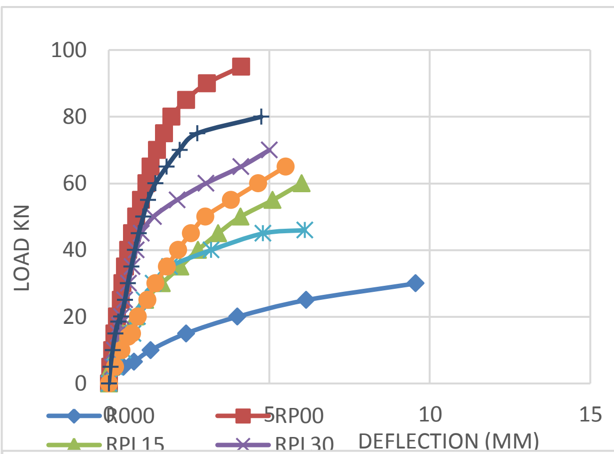


Figure22. Load Deflection Curve of Specimen (RPS22F)



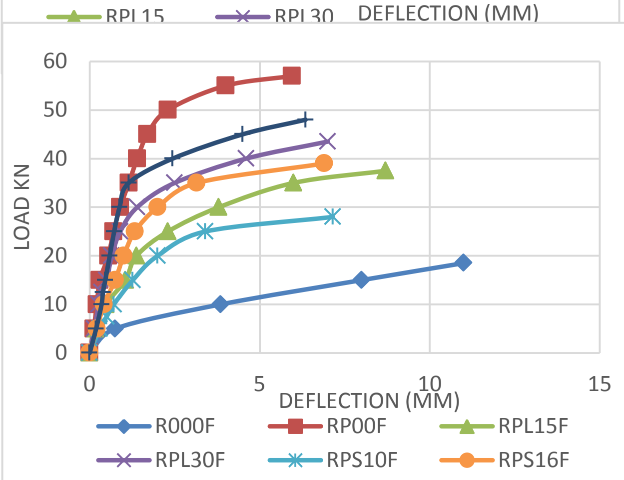


Figure 23. central Load – Deflection Curve of R.P.C group (not exposed to high temperature)

Figure24. Load Deflection Curve of R.P.C group (exposed to high temperature)

- Through previous forms it has been shown that all slabs that have not been subjected to high temperature possess less deflection than the reference slab and due to the use of a reactive powder concrete mixture that resistance up to 120 Mpa.

- In slab(RPOO) shows that it has less deflection than other slabs and less than the main model reference slab (ROOO) by (56.85) % because of the back is the use of a high-resistance mixture is a reactive powder concrete which reach their resistance to 120 MPa, this mixture contains very soft materials, which blocked the gaps in the concrete, which increased the resistance of concrete and reduce deflection.

- In slabs exposed to a high temperature of 400 ° C, there was an increase in the value of deflection from the slabs not exposed to high temperature and because it is a mixture of reactive powder concrete contains soft materials and these materials lead to increase the temperature of the mixture, which led to the weakening slabs.

- In slab(RPOOF) shows that it has less deflection than other slabs and less than the main model reference slab (ROOOf) by (46) %.

7. Compared between slabs exposed to high temperature and slabs not exposed to high temperature

It will be the comparison between the models that have been exposed to high temperature and models that are not exposed to a high degree. Table.8 show the detals.

Table.9 Compart between slabs

Slab	U.L	Del.	R1*	R2**
RP00	95	4.12	-60	-
RPL15	60	6	-62.5	-
RPL30	70	5	-62.14	-
RPS10	46	6.1	-61	-
RPS16	65	5.5	-60	-
RPS22	80	4.75	-60	-
RP00F	57	5.95	-	144.41
RPL15F	37.5	8.7	-	145
RPL30F	43.5	7	-	140
RPS10F	28	7.15	-	117.21
RPS16F	39	6.9	-	125.45
RPS22F	48	6.35	-	133.68

$$R1^{*}=\frac{U.L}{(U.L)R}\ \%$$

$$R2^{**}=\frac{Def.}{Def.}\ \%$$

When the slabs are subjected to a high temperature resulting in a decrease in the resistance of concrete and increase the value of the deflection and because of the back is also that the materials that make up the concrete active heat.

8. Conclusions

1- Through the results obtained show that the use of a mixture of fully reactive powder concrete gave better results than other models, where the increase in U.L in the rate of (216.67%) and a decrease in a deflection in the rate of (56.85%) from the reference model.

2- Use R.P.C with different layer was showed good results, where the specimen was optimum (U.L and P.L) with increase thickness layer of R.P.C.

3- Use R.P.C as a partial area (square shape) in the center of the specimen was showed good results compare with the specimens that consist of two types of concrete as a layer (R.P.C and N.C), where increase the partial area was showed good results.

4- The specimens that exposed to high temperature were showed weakness in the load capacity compare with the specimens are not exposed to high temperature. This weakness because of fine matierial (silica fume and sand) in the R.P.C mixture.

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