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Experimental Investigation of the Behavior of Reactive Powder Concrete Beams with and without Shear Reinforcement

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ABSTRACT

Reactive powder concrete (The RPC) is a promising building material for the foreseeable future because of its benefits over other forms of concrete. However, neither the blending specifications neither the flexural members made from this material's mechanical strength is specified in any code. The goal of the current effort is to investigate the flexural, and shear strengths of RPC beams. Five groups of beams made with RPC are intended to investigate the maximum and service flexural and shear strengths. Three groups are designed to fail in flexure and two to fail in shear. According to experimental testing, it was found that experimental loads applied on beams were always higher than the theoretical load calculated using the equations of Japanese codes (20 – 30 %). It was also noted that the shear failure load was 5% to 22% higher than the theoretical load.

KEYWORDS: Concrete with reactive powder, concrete with ultra-high performance, steel fiber reinforced concrete, shear strength and flexural strength of reinforced concrete beams, silica fume, and shear fractures.

1 INTRODUCTION

The last few decades, the development of super plasticizer additives has resulted in concrete that is durable and robust. For this purpose, one possible use is silica fume. Silica. To create packing volume concrete, fume material and an agent with a high range reduced water content are combined. The volume of solids in a particular volume is referred to in this process as packing density, as shown in Fig. (1).

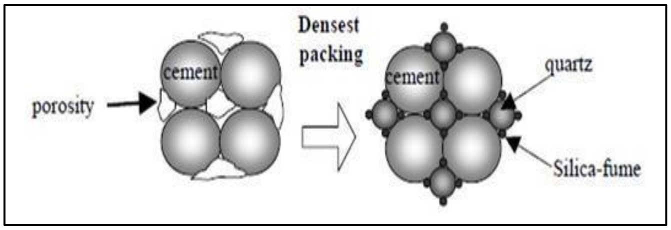


Fig. 1 Packing volume design [1]

With the help of the aforementioned tools, it is possible to achieve higher durability and a compression strength of more than 200 MPa [2]. Ultra-High-Performance Concrete is a generation of reactive particle concrete [2], [3], [4], [5]. Researchers at the French research center Bouygues invented it in the first decade of the 1990s, and Richard and Cheyrezy revealed it for the first time in 2008 [6].

The suitable proportion of aspect ratio, high tensile steel fibers, cement, silica fume, fine sand with a maximum particle size of 600 m, This innovative concrete composition consists of low water-to-cement or water-to-binder ratios and hyper plasticizer. As a result of the absence of coarse aggregate, RPC cannot be considered regular concrete. Currently, several research projects use coarse aggregate in an effort to achieve the same qualities [7]. Today, research uses coarse aggregate in an effort to achieve the same properties.

A 120 m span, a 15 m arch height, and a thickness that can range from 30 mm to 100 mm are all features of Seoul, South Korea's Footbridge of Peace. The long-term reliability of UHPC was put to the test in 1997 when it was utilized in place of steel beams that were supposed to be replaced in the cooling towers of the Cattenom power station in France. Due to its longevity and potential for maintenance elimination, UHPC was chosen because of the environment's high corrosion attack. An AFGC-SETRA working group visited the site three years later and found no signs of UHPC degeneration [9]. UHPC was cast in place to join the twin T-pre stress girders. As well as that, the Shepard's Creek Bridge in New South Wales, Australia. Steel fibers in RPC are what give it its ductility. Then, this particular type of concrete was able to take the lead because of three crucial characteristics: high strength, high durability, and ductility. The optimum uses for this kind of concrete are thought to be in long-span bridges, maritime constructions, and tall skyscrapers. The following components were presented by Richard and Cheyrezy in 1995 (as cited in Ref [2]) to create RPC:

1. Using fine sand instead of gravel to achieve the ideal concrete density.
2. To enhance the pozzolanic interaction, silica fume is used.
3. Obtaining the ideal granular mixture to accomplish the greatest volume packing. By applying pre-set pressure, the compacting state is increased.
4. Using pre-set pressure to increase the compaction condition.
5. The substructure is enhanced through heat treatment.

2 EXPERIMENTAL WORKS

Creating reactive powder concrete that satisfies the criteria of ease of use, resilience, and enhanced strength imposes stricter prerequisites on gathering materials compared to lower-strength concrete. Reactive powder concrete has been created utilizing a wide array of distinctive components, determined through the outcomes of test combinations. Generally, reactive powder concrete comprises a higher proportion of Portland cement and decrease in the water-to-cement ratio (W/C). The experimental phase of the current research seeks to investigate the attributes of RPC and anticipate its advantageous effects when applied in conjunction with steel rebars within beam components. The timeline for the experimental work can be categorized into two primary tasks:

1. Using 150 mm-dia. cubes, cylinders, and prisms, the characteristics of RPC were measured. 300 mm high cylinders, 100 * 100 * 100 mm cubes, and 150 * 150 * 540 mm prisms to determine the RPC's strength in compression, tension, and flexure. Investigations are also conducted into how age, curing state (hot vs. normal), workability of the fresh mixture, and curing temperature affect these strengths. Utilizing three trial RPC mixtures, this exercise is completed. This task was conducted by the authors in a previous work [11], forming the first part of the research. It is worth noting that both parts of the study were conducted simultaneously.

2. The second task constitutes of the evaluating the structural behaviors of reinforced beams made of RPC. This is done by producing and load testing of five groups of beams, three groups for flexural behavior and two groups for shear behavior. Each group consists of three beams specimens differs by selected factors which are f_c' & $\frac{a}{d}$ & ρ_w , and member size. Where: f_c' : Specified compressive strength of concrete, $\frac{a}{d}$: Ratio of shear span to depth, ρ_w : The longitudinal tensile reinforcement ratio.

3 CONTENTS

The principal properties of the materials used in the RPC's construction are found. They can be found by technical document consultation or experimental testing by the manufacturer. 110 MPa was the desired concrete strength. A quality control plan was created to guarantee good concrete manufacturing.

3.1 Cement

Ordinary Portland cement was used, which is commonly available in the local market which is commonly available in the local market satisfying IQS No.5-1984 requirements [12].

3.2 Silica Fume

One of the components needed to make ultra-high-performance concrete is silica fume is significantly more reactive than fly ash or any other naturally occurring pozzolan. To obtain the required strength, the production method in Norway employed widely available micro-silica in a 20-kilogram type sack (MEYCO). The mean particle size of the micro silica is less than 0.1 m, and the SiO2 content is greater than 85%. Due to a type of additive known as high-range water-reducing, silica fume is used as a component of cement material. The typical range of silica fume content in Portland cement is (5 to 15%).

3.3 Fine Sand

We bought the fine sand from a source in Amara City. The sand can only be as big as 600 m. The grading of the used fine sand and the requirements of (IQS No.45: 1984, zone 4). [12]

3.4 Water

In the southern part of Iraq, the water used to create concrete was frequently utilized for drinking. Reverse osmosis is a method of water filtration used to create this water.

3.5 Hyper plasticizer

As an additive, high performance Flo-Crete PC600 was employed [13]. The characteristics of a hyper plasticizer at 25 °C are as follows: Light yellow liquid color 1.07 +/- 0.03 specific gravity, freezing point -1 C. This innovation is part of the third generation of high-range water reduction agents for concrete and grout. It complies with ASTM - C - 494 type G specifications. [14].

3.6 Steel fiber

High tensile steel hooks measuring 0.85 mm in diameter and 50 mm in length, or a 60 aspect ratio, were the fibers used in the concrete mixtures. China's Yutian Zhitai Steel Fiber Manufacturing Co., Ltd. created the fibers. It has a 1000 MPa tensile strength. This kind of steel fiber is categorized as (Type II) by ASTM-A820. [15].

4 MIXING

As previously mentioned, the present work used the mixes explored in a previous work of the authors [11]. In that work, the authors adopted the mix proportions suggested by Naser Hakeem Tu'ma [10] as a starting reference. Two other trial mixes were suggested, tested, and compared with the aforementioned reference mix. Sets of six 100x100x100 mm^3 cubes for compression strength, three 540x150x150 mm^3 prisms for flexural strength, and three 150x300 mm^3 cylinders for tensile strength are created for each combination. For your convenience, we've included the table from Reference [11] that listed the components of each trial mix.

Table 1: Quantities of components used in mixes [12]

Contents	Trails Mix No.1	Trails Mix No. 2	Trails Mix No. 3
Cement (kg/m^3)	768	780	800
Silica fume (kg/m^3)	192	210	225
Fine sand (kg/m^3)	1140	952	1000
Hyper plasticizer (kg/m^3)	40	40	40
Water (kg/m^3)	160	170	170
Steel fiber (kg/m^3)	157	172	190

The combining process can be summed up as follows:

1. Combining all dry ingredients.
2. The addition of roughly 75% of the entire amount of water and 50% of the hyper plasticizer.
3. Stirring the mixture for about five minutes.
4. Add the leftover liquid component (25 percent of the total water plus 50 percent of the hyper plasticizer).
5. Including steel strands.
6. Continue blending for another five minutes.

The precast industries were a good fit for the aforementioned process [16]. The ACI Committee report 544 suggested a similar course of action. [17].

5 CASTING AND CURING

Each of the three mixes is prepared, combined, and poured into molds shaped like beams, cylinders, cubes, and prisms in order to evaluate the mechanical properties of the concrete. All samples were demolded and given a curing period up until the time of the test after the concrete had been placed for 48 hours.

6 COMPRESSIVE, TENSILE AND FLEXURE STRENGTHS OF RPC

Using 100 mm x 100 mm cubes heated to 60 o C for 28 days to cure, the compressive strength was evaluated. The tensile strength of the concrete ranged widely in value. Splitting tensile tests on cylindrical specimens with dimensions of 150 mm in diameter and 300 mm in height were used in this study to evaluate it. Tests on prismatic specimens measuring 150 mm by 150 mm by 540 mm for bending and tensile. Flexural rigidity was provided by the three-point load. For each experiment mix, Table 2 lists the average values of compression strength, splitting tensile strength, and flexural strength as determined from three cubes, three cylinders, and three prisms, respectively.

Table 2: Typical values following a 28-day heat curing period for the compressive, tensile, and flexural strengths.

Mix Number	Average Compressive Strength (MPa)	Average Tensile Strength (MPa)	Average Flexural Strength (MPa)
1	82.8	7.1	12.0
2	91.1	9.1	13.3
3	111.3	9.5	19.2

7 STRENGTH DESIGN APPROACH OF FIBER REINFORCED BEAMS

To evaluate the flexural and shear strength of reinforced beams composed of reactive powder concrete with steel fibers, two sets of beam specimens were cast and put to the test. The first group designated F1 to F7 was designed to ensure that they fail in flexure, while the second on designated S1 to S6 was designed to ensure shear failure. All beams are of 150 mm width, other details are listed in Table 3, and the cast beams are shown in Fig 2.

No international codes deal explicitly with the reactive powder concrete beam for calculating the flexural strength as well as the composite action of the RPC bars as main longitudinal tensile reinforcement. The proposed design equation was based on the reviewing of many codes, like The JSCE [18], Association of Japanese Civil Engineers Concrete Committee, AFGC SETRA-2002 [10], Association Française de Génie Civil, Federal Highway Administration, Publication No. FHWA-HRT-06-103 [19] The Canadian Code CHBDC [20] and Australian code explained by Gowripalan [21]. Also, the ACI 544.4R-88 stated the reinforced cases of traditional concrete can be regarded for RPC member [17]. Generally, the nominal flexural strength of a current research of RPC member can be evaluated by using the strain compatibility. Then, the internal forces should be equilibrated. Finally, the permanent mode of failure would take into consideration.

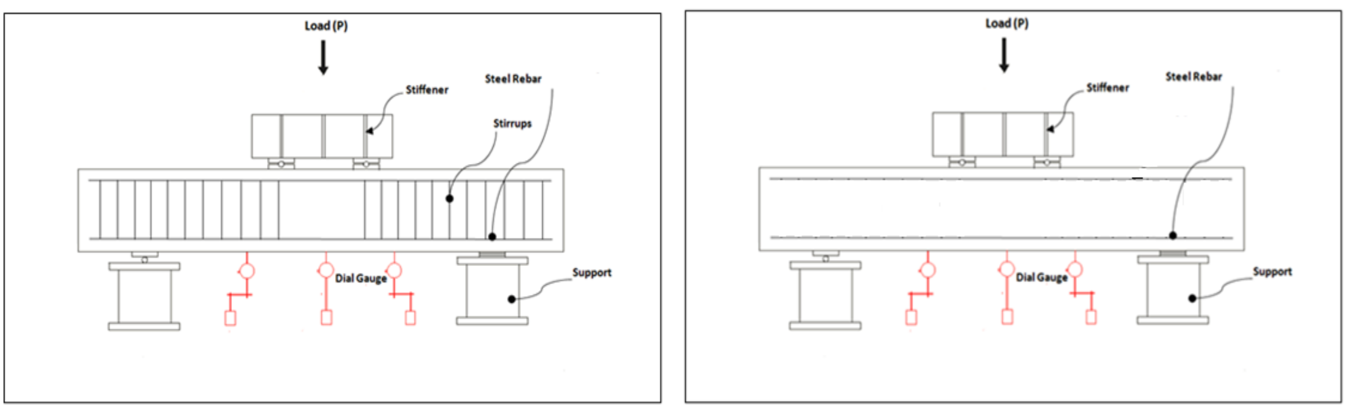
Table 3: Details of beam specimens

Beam Symbol	Reinf. State	Theo. Flexural Failure load (kN)	Main Bottom Reinf. ($A_r mm^2$)	Effective depth d (mm)	Shear span a(mm)	a/d ratio	Theo. Shear Failure load (kN)	Expected Failure Domain	Steel Stirrup for Shear span
F- 1	Under- Reinforced	122.1	226.2	154	385	2.5	267.5	Flexure	Ø10 @ 150 mm
F- 2		118.7	226.2	154	385	2.5	257	Flexure	
F- 3		114.9	226.2	154	385	2.5	246	Flexure	
F- 4		102.6	226.2	154	346	3.0	267.5	Flexure	
F- 5		77.1	226.2	154	616	4.0	267.5	Flexure	
F- 6		169.2	402.1	152	380	2.5	264	Flexure	
F- 7		224.5	628.3	150	375	2.5	265	Flexure	
S - 1	Over - Reinforced	361	1005	144	350	2.43	242	Shear	Without stirrups
S - 2		348.4	1005	144	350	2.43	230.7	Shear	
S - 3		335	1005	144	350	2.43	218	Shear	
S - 4		170	452	96	245	2.5	109	Shear	
S - 5		397	1144	165	412	2.5	277	Shear	
S – 6		699	2199	240	605	2.5	537.6	Shear	

(a) (b)

Fig. 2 Testing beam specimens (a) for flexure and (b) for shear

The width for all beam specimens was taken to be 150 mm. The design followed the same concepts and design philosophy for rectangular section design, as described in ACI 440.1R-06 [22].



(a) (b)

Fig. 3 Layout of beam testing, (a) for flexure and (b) for shear

7.1 Failure's Modes

All the flexural beams were designed to fail in the under-reinforcement case, and the flexural beams (F-1 _ F-7) were designed to fail by the concrete crushing. Experimental test work of those beams had failure type identical to the design aim; i.e., by concrete crushing. The concrete crushing occurred at the central beam's location. The beam failure occurred when the principal cracks in the bottom surface became wider and faster than other cracks. The crushing failure is shown in Fig. 4.

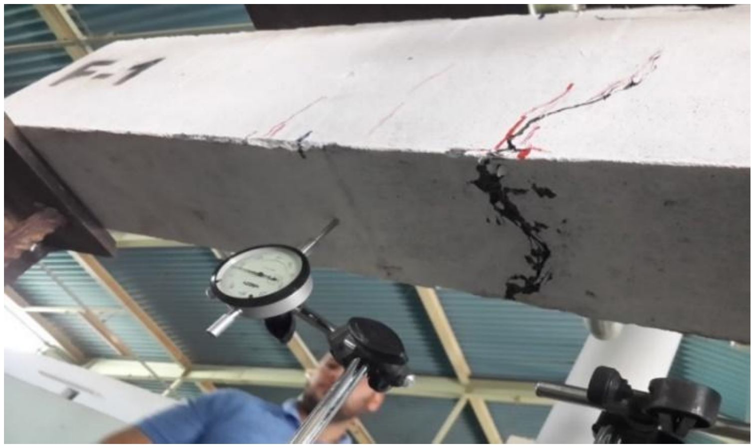
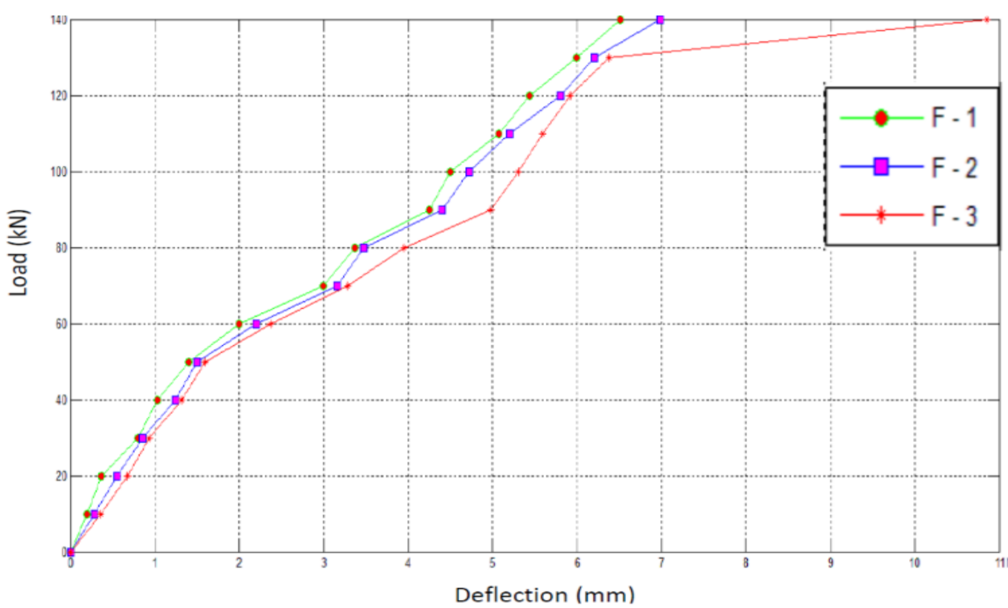


Fig. 4 Crushing failure obtained (F-1)

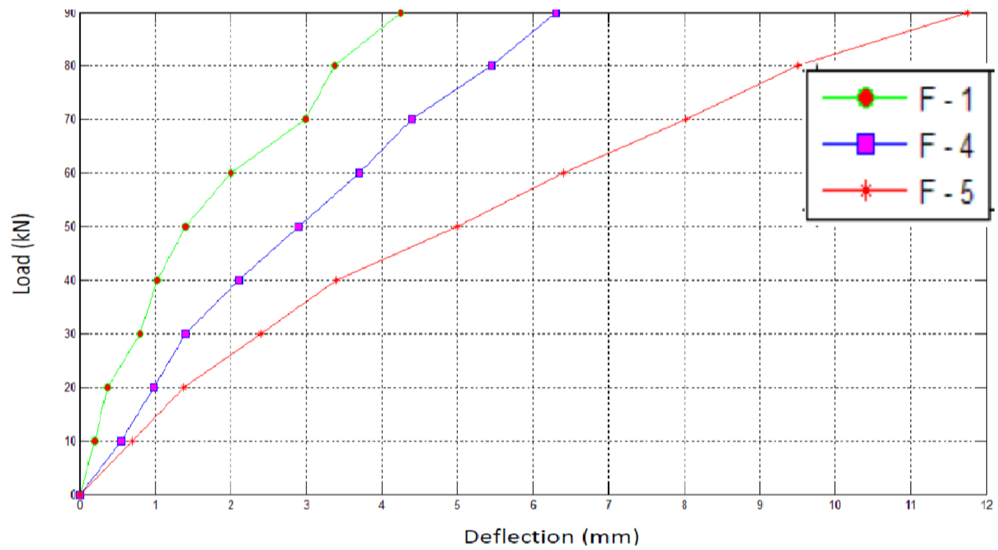
7.2 Load - mid span deflection relationship

The deflection behavior is studied. The approximate value of the serviceability experimental loads corresponding to a limitation of deflection is shown. Comparing the experimental curves (Figs 5-a to 5-c), and for the same load level, the increasing deformations with the lower amount of reinforcement were noticed and vice versa. [23].

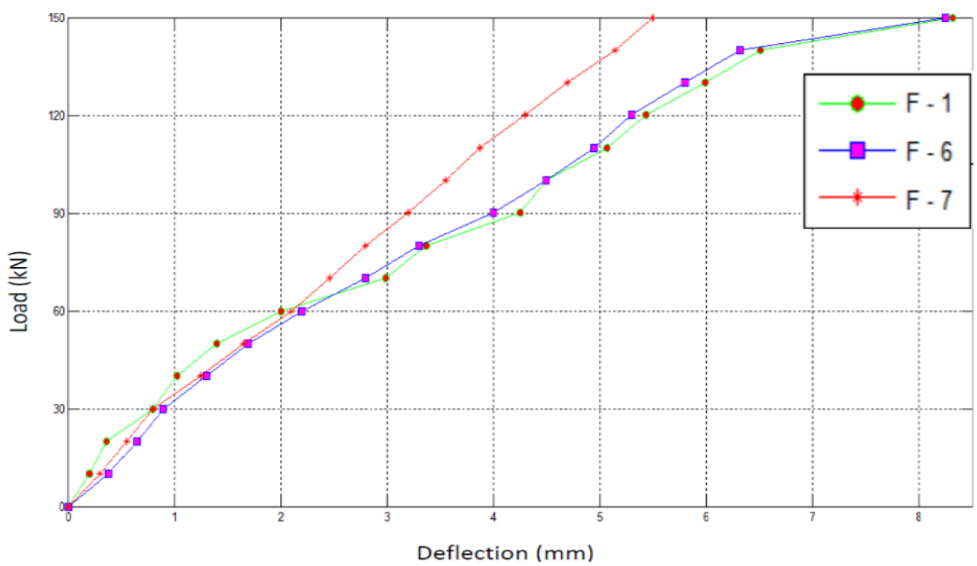


a**:** First group (effect of compression strength)

Fig 5: Variation of load deflection



(b) Second group (effect of span to depth ratio)



(c) Third group (effect of long. with Reinforcement)

Fig 5: Continued

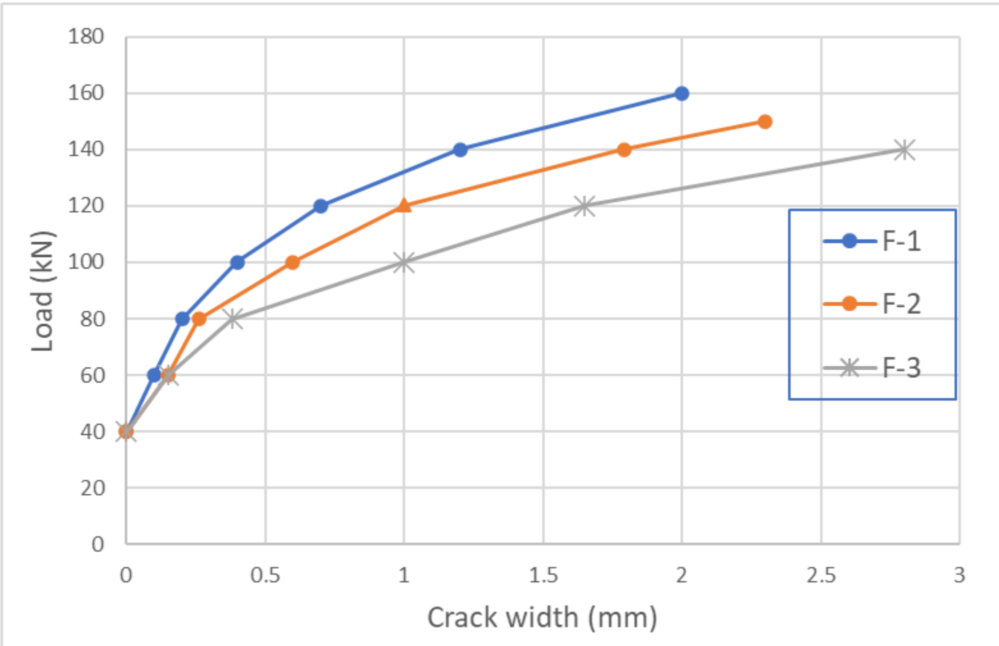
7.3 Crack Width

A microscope crack meter as shown in Fig 6 was used to measure the experimental crack width. The readings were recorded for each load step at the flexural zone. The nature of the flexural cracks is noticed to be wider and at small spacing in the region enclosed by two loads. Table 4 outlines the loads corresponding to crack width of 0.5 mm for the various cases. Figs. 7-a to 7-c demonstrate the changes in the initial crack's width of the flexural zone as measured by a microscope crack meter, at the soffit point of tested beam.

Table 4: Experimental load equal to 0.5 mm of crack width

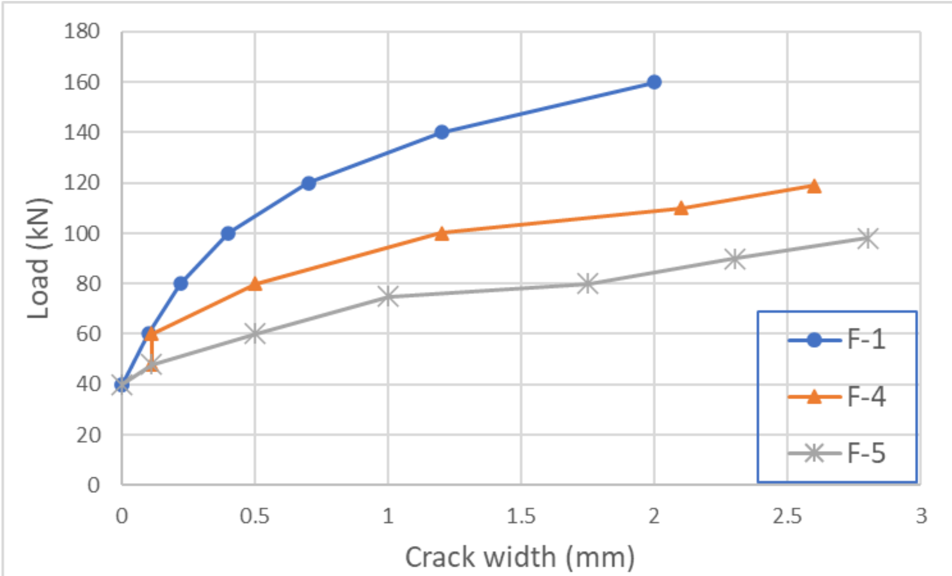
Group	Control	Effect of f'c		Effect of a/d		Effect of Long. Reinf.	
Beam symbol	F - 1	F - 2	F - 3	F - 4	F - 5	F - 6	F - 7
P_{exp}(kN)	158.8	152.3	137.2	117.3	95.4	195.1	251.6
$P_{s,c}$ (kN)	105	96	87	80	70	140	160
$P_{s,c}/P_{exp}$(%)	66	63	63.4	68.2	73.4	71.7	63.6

Fig. 6 Measuring crack width

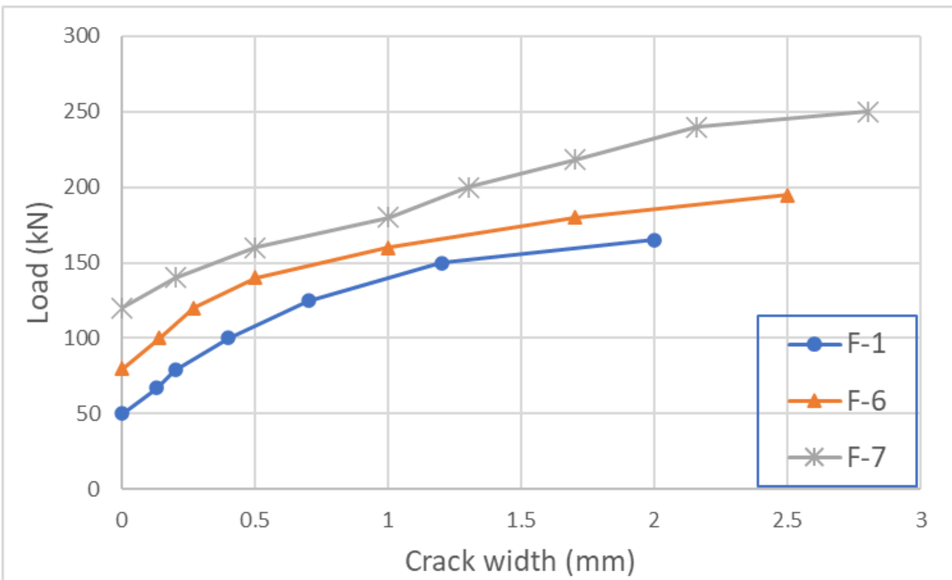


a: Crack width, for 1st Group (f'c)

Fig 7: Relation between applied load and crack width



b: Crack width, for 2nd Group



c: Crack width, for 3rd Group (effect of Longitudinal Reinforcement)

Fig 7: Continued

8 FLEXURAL STRENGTH CHARACTERISTICS

8.1 Effect of compression strength of RPC (f 'c)

From the comparison of the measured values of the maximum loads of the three elements of the first group (f'c), it is noted that the flexural strength of the RP reinforced concrete beams decreases when (f'c) decreases Show that in Fig. 8 this is obvious, because the compression strength of concrete, as in the normal concrete, constitutes one of the two forces, which with the tensile force in steel bars, are the components of the moment at the critical section.

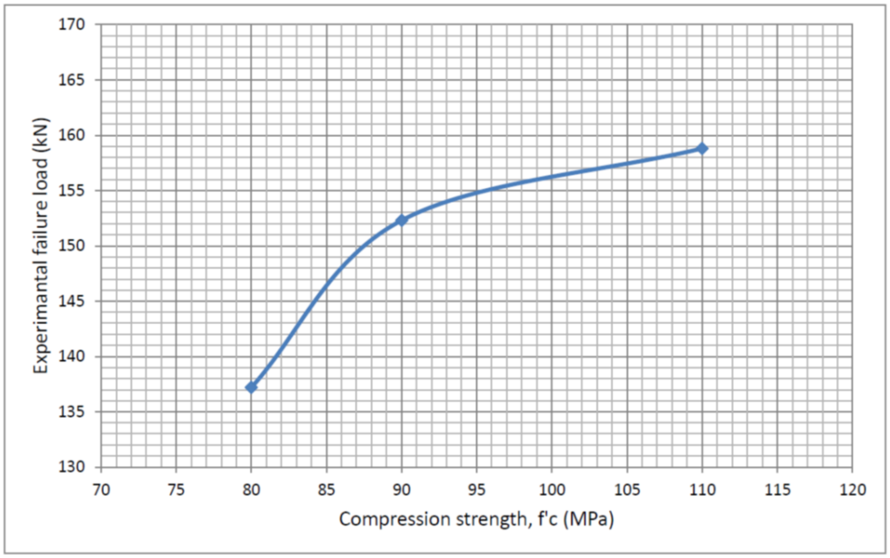


Fig. 8 Relation between experimental flexural failure load and Compression strength

8.2 Effect of Shear Span to Effective Depth Ratio

As observed in Fig. 9, while the (a/d) ratio increases, the shear strength of typical reinforced concrete beams decreases. This decrease is related to a number of flexural transfer mechanisms that largely rely on the a/d ratio.

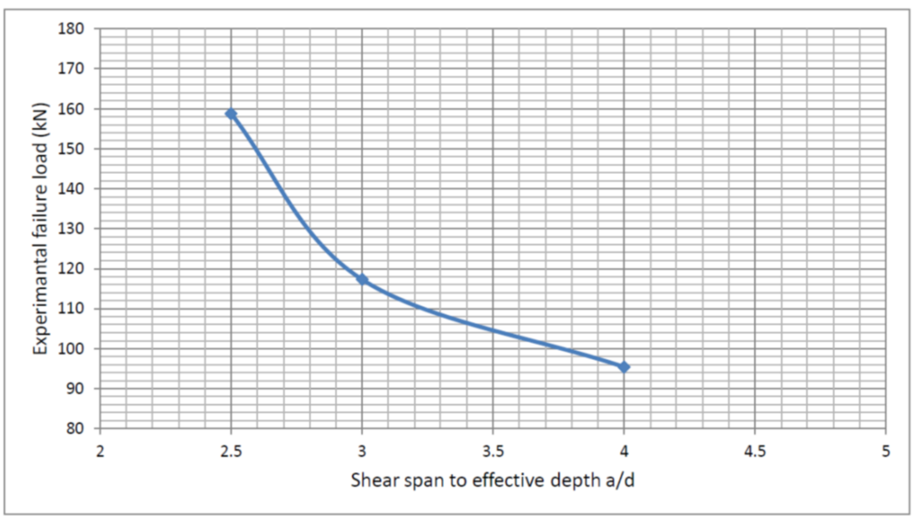


Fig. 9 Flexural load vs. shear span to effective depth ratio (a/d)

8.3 The impact of the longitudinal reinforcement ratio

The impact of the steel reinforcement ratio (w) of the tested RPC beams on the flexural strength is shown in Fig. 10. The steel reinforcing values were chosen in relation to the relevant maximum load. It is clear that raising (w) causes the flexural strength to rise, as seen in Table 4.

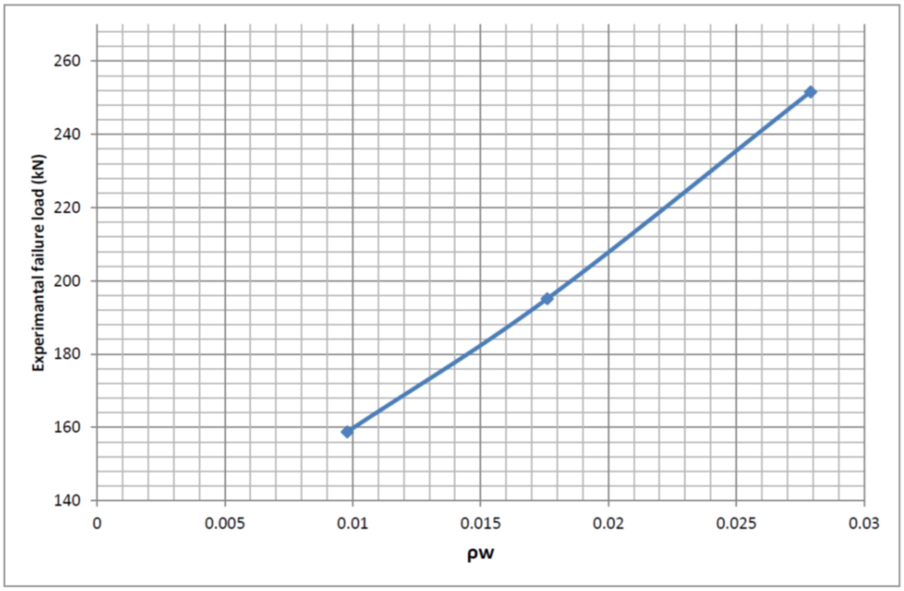


Fig. 10 Longitudinal Reinforcement Ratio versus flexural

9 CHARACTERISTICS OF SHEAR STRENGTH

9.1 Impact of compression strength on shear strength

As of Fig. 11 it is experiential that the failure shear load of RPC beam specimens through longitudinal rebars and without shear reinforcement increases with the RPC compression strength. This increment tends to be less pronounced as compression strength increases.

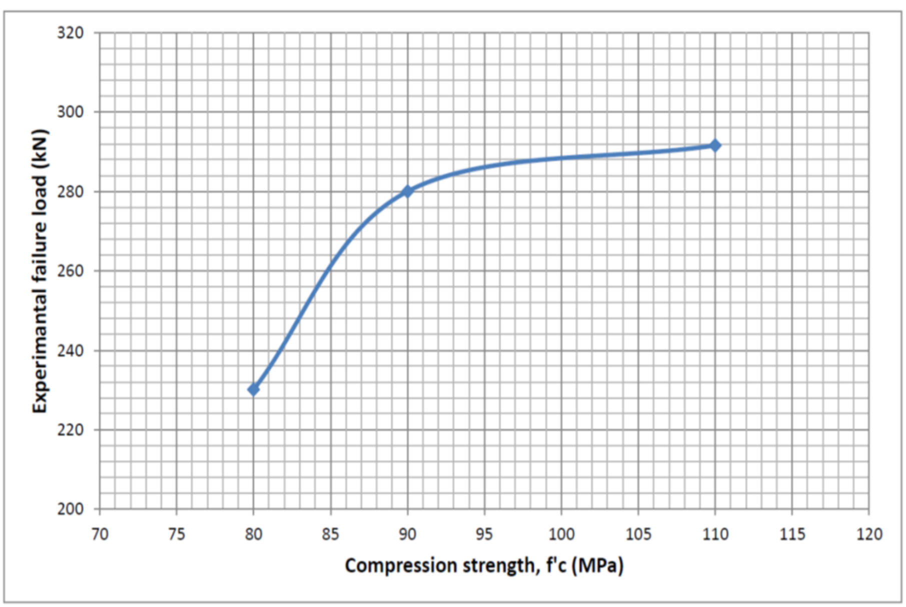


Fig. 11 Compression strength (f'c) versus Shear load

9.2 Effect of Size of beams

Since concrete resists shear forces in beams primarily, it may be necessary to investigate the impact of increasing beam depth while maintaining all other parameters constant in order to understand the relationship between sizes and shear failure in reactive powder concrete beams. As the size of the beam cross section rises, it is discovered that the shear strength of the RPC reinforced beams improves, as illustrated in Fig. 12.

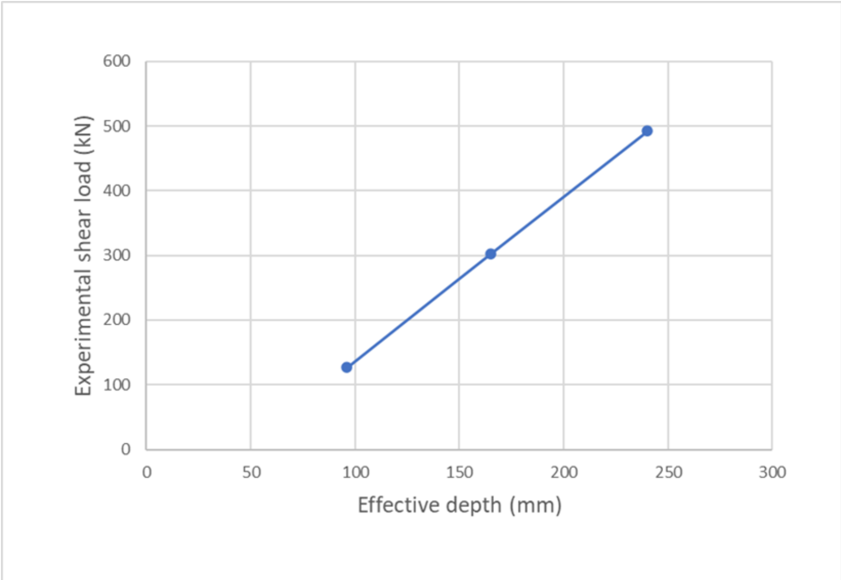


Fig. 12 Size Effect versus failure shear load

The ratio between the experimental load and theoretical load decreases with increasing the size effect and may be less in actual sizes, as can be noted from Table 4. Therefore, more tests should be conducted on beams with the actual size.

10 CONCLUSIONS AND RECOMMENDATIONS

The following are the primary inferences:

1. The maximum loads of experimental work applied on beams are always larger than the theoretical load calculated using the equations of ACI and JSCE by (20 – 30 %) which means that the equations of the codes are conservative.
2. 2. As the amount of steel reinforcement grows, the effect of steel fiber on raising the load on the beams will diminish, thus the difference between theoretical results and experimental results decreases as the area of steel reinforcement increases.
3. The experimental load that caused the shear failure is greater than the theoretical load (calculated from the design equations) in percent ranging from 5% to 22%.
4. The ratio between the experimental load and theoretical load decreases with increasing the size of the beam and may be less than 1.0 for beams of actual sizes. Therefore, more tests should be conducted on beams with the actual size.
5. Shear strength increases as compression strength of RPC increases, but the increment rate tends to be less for higher values of compression strength.

11 ACKNOWLEDGEMENTS

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REFERENCES

[1] Yuichi Uchida, Junichiro Niwa, Yoshihiro Tanaka and Makoto Katagiri (2004)," Outlines of Recommendations For Design And Construction of Ultra High Strength Fiber Reinforced Concrete Structures" By JSCE ", Concrete Committee of Japan Society of Civil Engineers.

[2] Graybeal B. and Marshall D. (2008), "Cylinder or Cubes: Strength testing of 80 to 200 MPa (11.6 to 29 ksi) Ultra-High-Performance Fiber-Reinforced Concrete", ACI Materials Journal, Technical Paper, No. 105-M68 .

[3] Fujikake F. , Takanori S. , Nobuhito U. , Tomonori O. and Makoto Katagiri (2005)," Nonlinear Analysis for Reactive Powder Concrete Beams Under Rapid Flexural Loading ", Journal of Advanced Concrete Technology, Vol.4 , No.1 , PP. 85-97, Japan Concrete Institute.

[4] Anjan k.M., Asha U. Rao, Narayana Sabhahit "Reactive Powder Concrete Properties with Cement Replacement Using Waste Material", Indian International Journal of Scientific & Engineering Research Volume 4, Issue 5, May-2013.

[5] Behzad Nematollahi, Raizal Saifulnaz M. R., Mohd. Saleh Jaafar & Yen Lei Voo " A review on ultra-high performance „ductile" concrete (UHPdC) technology", 2010, International Journal of Civil and Structural Engineering, Volume 2, No. 3, Malaysia.

[6] Raffaello, Fico (2008)," Limit States Design of Concrete Structures Reinforced with FRP Bars", Ph.D. thesis, University of Naples Federico II.

[7] Augustine K. Banson (2013)," Precast Bridge Deck Joints Using Frp and Ultra-High-Performance Concrete", M.Sc. Thesis, The School of Graduate and Postdoctoral Studies, The University of Western Ontario, London, Ontario, Canada.

[8] (IS 456:2000), July (2000), "Indian standard code of practice for plain and reinforced concrete", Fourth Revision, Bureau of Indian standards, New Delhi.

[9] Jacques Resplendent (2002), "First Recommendation for Ultra-High-Performance Concrete and Examples of Application", French recommendation, AFGC-SETRA work group.

[10] Naser Hakeem Tu'ma (2016)," Behavior of Reactive Powder Concrete Beams Reinforced with Fiber Reinforced Polymer Bars" University of Baghdad, College of Engineering.

[11] Almayah A. Atalla and Lateef H. Sadiq. "Mechanical Properties of Reactive Powder Concrete (RPC) With various combinations of fibers and ultrafine" International Journal of Scientific & Engineering Research Volume 9, Issue 12, December-2018.

[12] A committee in the Iraqi Ministry of Construction and Housing “Resident Engineer's Guide to Construction Projects”, in Arabic, second edition, 2015.

[13] Maha M. S. Ridha (2010), "Shear Behavior of Reactive Powder Concrete Beams”, Ph.D. Thesis, Building and Construction Engineering Department, University of Technology.

[14] ASTM C 494/C 494M – 05a “Standard Specification for Chemical Admixtures for Concrete” ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, United States 2006.

[15] ASTM A 820/A 820M – 04 “Standard Specification for Steel Fibers for Fiber-Reinforced Concrete” ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States, May 2004.

[16] Federal Highway Administration (FHWA) (2006)," Material Property Characterization of Ultra-High-Performance concrete", PUBLICATION NO. FHWA-HRT-06-115, USA.

[17] ACI 544.4R-88 (1999), “Design Considerations for Steel Fiber Reinforced Concrete”, American Concrete Institute.

[18] Yuichi Uchida, Junichiro Niwa, Yoshihiro Tanaka and Makoto Katagiri (2004),” Outlines of “ Recommendations for Design and Construction of Ultra High Strength Fiber Reinforced Concrete Structures ” By JSCE“, Concrete Committee of Japan Society of Civil Engineers

[19] Federal Highway Administration (FHWA) (2006)," Material Property Characterization of Ultra-High-Performance concrete", PUBLICATION NO. FHWA-HRT-06-115, USA.

[20] Ali H. Aziz and Dhia B. Ghailan (2007), "Shear Behavior of RC Beams with Full or Partial SFRC Shear Span", Journal of Engineering and Development, Vol. 11, No. 2, ISSN 1813-7822.

[21] Gowripalan N, Ian R Gilbert (2000), "Design Guidelines for Ductal Prestressed Concrete Beams", REFERENCE ARTICLE, VSL (Aust) Pty Ltd, Australia.

[22] ACI 440.1R-06 (2006), “Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars”, American Concrete Institute.

[23] Bae B.I., H.K. Choi, C.S. Choi (2012), "FE Analysis of Behavior of Steel Fiber Reinforced Ultra-High-Performance Concrete Columns Under Reversed Cyclic Loading", 15WCEE, LISBOA 2012, Seoul, Republic of Korea.