ISSN 2229-5518

Mechanical Properties of Reactive Powder Concrete (RPC) With various combinations of fibers and ultrafine

Ph.D. Abdulamir Atalla Almayah, Hussein Sadiq Latief

ABSTRACT— Reactive powder concrete (RPC) represents a promising material in the near future of construction industry because of its preferable properties upon the other kind of concrete. However, no code specifies the mixing requirements nor the mechanical strength of flexural members made from this material. In the present work, an attempt is made to find the best proportions of the components of the RPC such that maximum compression strength is achieved.

Different curing environments and durations and their effect on compression, tensile and flexural strengths of RPC are explored. The experimental testing shows that increasing the amount of steel fiber from 20% to 23.75% (Vf/C) increases the compression, tension and flexural strengths by about 34.3%, 33.8% and 60%, , respectively.

In normal curing, it is observed that the action of silica fume in increasing compression strength of RPC may delay to 91 days.

Index Terms—Reactive powder concrete, high performance concrete, steel fiber reinforced concrete, Hot Curing, Normal Curing.

1 INTRODUCTION

In the past few decades, the development in super plasticizer admixtures leads to develop high strength and durable concrete. This aim can be realized by using silica fume material and high range water reducing (HRWR) agent to produce a packing volume concrete. In this procedure, the dense microstructures can makes packing density is the volume of solids in a unit Volume, Fig. 1.

Using the above aids, compression strength of more than 200 MPa and greater durability may be obtained [2]. Reactive powder concrete is a generation classified as Ultra High Performance Concrete [3] and [2] .

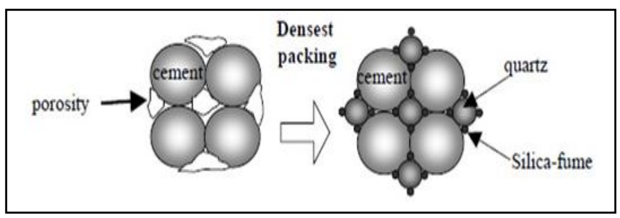

Fig 1 Packing volume design [1]

It was first introduced by Richard and Cheyrezy in (1994), and manufactured in the early (1990) by academics at Bouygues research laboratory in France [4].

This new concrete material is composed of cement, fine sand of maximum size of (600 μm), and silica fume, high tensile steel fibers with suitable aspect ratio, superplasticizer, and low water to cement or water to binder ratios.

- *Ph. Dr. Abdulamir Atalla Almayah is an assistant Doctor of civil engineering at Basrah University, Basrah, Iraq.*
- *Hussein Sadiq Latief is currently pursuing master's degree in civil engineering in Basrah University, Basrah, Iraq, PH-009647711380557. E-mail: husseinsadiqs7@gmail.com*

ISSN 2229-5518

This means that RPC is not an ordinary concrete because it contains no coarse aggregate. Some studies, today, try to get the same properties by using coarse aggregate.

The ductility of RPC comes from the existence of steel fibers. Then, three main characteristics which are high strength, high durability and ductility paid this type of concrete to stand up in the forefront. The nuclear waste containment structures, high-raise building, bridges of long span and marine structures can be considered as the best options for using such kind of concrete.

Richard and Cheyrezy (1995) [2] presented the following parts to develop RPC:

1. Utilizing the fine sand, without gravel material, to perfecting the concrete consistency.
2. The silica fume is utilized to increase the pozzolanic interaction.
3. Getting the optimized granular mixture such that maximum volume packing is achieved.
4. Increasing the compaction state by using presetting pressure.
5. Heat treatment is used to improve the microstructure.

2 Experimental Works

The production of reactive powder concrete that meets the requirements of workability, durability and strength improvement places more inflexible conditions on material collection than for lesser strength concrete. Reactive powder concrete has been manufactured using an extensive range of feature materials based on the consequences of trial mixes. In general, reactive powder concrete contains more Portland cement contented and lower water/cementations ratio (W/C).

The experimental phase of present study aims to explore the properties of the RPC and predict its beneficial action when implemented with steel rebar in beam members. The experimental work schedule can be divided into two main activities:

The measuring of properties of RPC by testing cubes, cylinders and prisms to find the strength of RPC in compression, tension and flexure. The effect of curing state, i.e. hot and normal curing and the workability of the fresh mixture and the effect of age on these strengths are also investigated. This activity is accomplished by using three trial mixes of RPC.

3 Materials

The main properties of materials used in producing the RPC are obtained. They can be obtained by either an experimental testing or from technical sheets furnished by the manufacturer. The target concrete strength was 110 MPa. To ensure the good production of concrete, a quality control plan was prepared.

3.1 Cement

Portland cement (Al jeser) was used, which is commonly available in the local market satisfying ASTM C150 requirements.

3.2 Silica Fume

Silica fume has become one of the necessary ingredients for making ultra-high performance concrete. Micro silica is much more reactive than fly ash or any other natural pozzolana. Micro-silica in sacks of 20 kg of brand (MEYCO ® MS 610) was used. The micro silica has SiO_2 content of more than 85%, and mean particle size under 0.1 μm.

3.3 Fine Aggregates

The fine sand used was from a local supplier of Amara city. The maximum size of the sand is 600 μm.

3.4 Water

ISSN 2229-5518

The water used for concrete mixing was that commonly used for drinking purposes in the region of south of Iraq. This water is produced by Reverse Osmosis purification technique.

3.5 Hyper plasticizer

High performance Flo - Crete PC600 was used as an additive. This additive belongs to the third generation of high-range water reducing agent for concrete and grout. It meets the requirements of ASTM – C – 494[5] type G.

3.6 Steel fiber

Hooked high tensile steel fiber of 0.85 mm diameter and 50 mm length, i.e. of aspect ratio is 60, were used as fibers in the concrete mixes. The fibers were produced by Yutian Zhitai Steel Fiber Manufacturing Co., Ltd in China. Its tensile strength is 1000 MPa. According to ASTM-A820, this type of steel fibers is classified as (Type II). [6]

4. Mixing

The present work adopted the mix proportions suggested by Hakeem [7] as a starting reference. Two other trials mixes are suggested, tested, and compared with the aforementioned reference mix. The proportions of the reference mix together with the two new suggested mixes are listed in Table 1.

For each mix, sets of six cubes of (100×100×100) mm^3 for compression strength, three prisms of (540×150×150) mm^3 for flexural strength, and three cylinders of 150 mm in diameter and 300 mm in length for tensile strength are prepared.

Table 1

Amounts of materials used for trail mixes

Materials	Trails Mix 1	Trails Mix 2	Trails Mix 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 procedure of mixing can be summarized as follows:-

1- Mixing of all dry materials.
2- Addition of about 75 % of total water + 50 % of hyper plasticizer.
3- Mixing the components for about 5 minutes.
4- Addition of the remaining liquid quantity (25 % of total water + 50 % of hyper plasticizer).
5- Addition of steel fibers.
6- Further mixing for about 5 minutes.

The above procedure was suited to the precast industries [8] .The similar procedure was recommended in the ACI Committee report 544. [9]

5. Casting and Curing

Each one of the three mixes is prepared, mixed and poured in molds of beams, cylinders, cubes, prisms to determine the concrete mechanical properties. After 48 hours of placing the concrete, all samples were de-molded and subjected to a curing

Fig 2 Sample Preparation

until the time of test Fig 2.

6. Compression Strength of RPC

The compressive strength was measured using three cubes at 7 days and three cubes at 28 days in hot curing in water of 60 °C temperature[10]. Similar samples subjected to normal curing are tested in 28, 56, and 91 days. In case of cylinder specimen, the testing of RPC has a concern in their end conditions. The existing of steel fibers and workability of the mix prevented the obtaining a clean surface, Fig 3.

Table 2

Experimental Compressive Stress at (Long Term and Normal Curing)

Age (day)	No.	Density (kg/m³)	Load (kN)	Strength (MPa)	Average Strength (MPa)
	1	2492	746.6	74.7	
28	2	2499	741.5	74.2	75.5
	3	2508	776.5	77.7	
	1	2510	758.5	75.9	
56	2	2508	724.5	75.5	75.2
	3	2551	741.5	74.2	
	1	2508	964.7	96.5	
91	2	2507	805.0	80.5	85.7
	3	2520	800.4	80.1	

In normal curing Table 2, the effect of silica fume in increasing the compression strength of RPC may not appear until an age of 91 days Fig 4. This can be justified due to the fact that the silica mainly reacts with the results of hydration process, so it remains inactive until the hydration is completed.

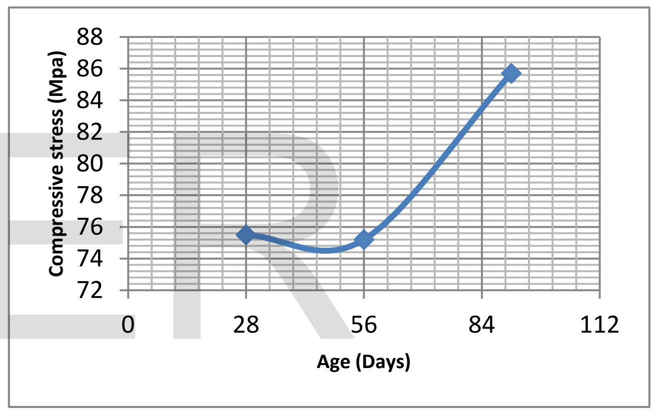

Fig 4 Experimental Compressive Stress at (Long Term and Normal Curing)

Table 3
Experimental Compressive Strength at (7 days and Hot Curing)

Trail Mixes	No.	Density (kg/m³)	Load (kN)	Stress (MPa)	Average
	1	2274	801.0	80.1	
Trail -1	2	2461	804.8	80.5	81.0
	3	2362	820.9	82.1	
	1	2522	1144.0	114.4	
Trail -2	2	2454	1120.6	112.1	112.4

	3	2482	1106.8	110.7	
	1	2479	1189.7	119	
Trail -3	2	2487	1170.1	117.0	117.6
	3	2463	1168.7	116.9	

The maximum compression strength of RPC experienced hot curing was 119 MPa at 7 days, Fig 5. Increasing the hot curing period may results in adverse action (Table 4).

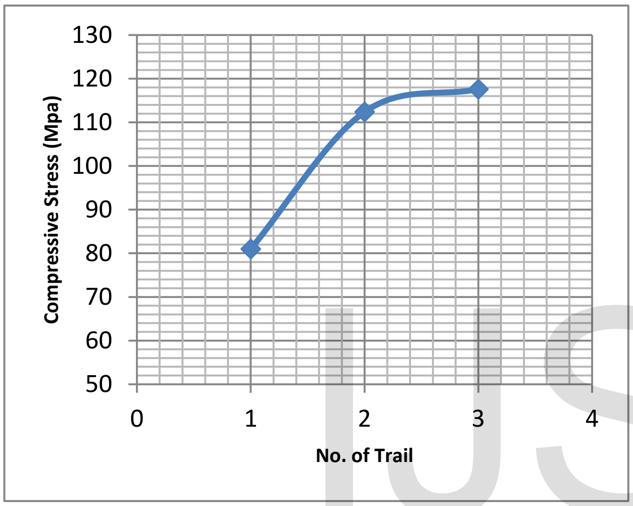

Fig 5 Experimental Compressive Strength at (7 days and Hot Curing) for different trails

Same behavior of reactive powder concrete (RPC) at 28 days with hot curing for same trails (Table 4).

7. Tensile Strength and Flexural Strength

The tensile strength of the concrete had taken wide range of values. In this work, it was evaluated by splitting tensile tests on cylindrical specimens of 150 mm dia. × 300 mm height and by the flexural tensile strength of prismatic specimens of 150×150×540 mm, Fig 6. The flexural strength was carried out by the three point load. The obtained date was mentioned in the Table 4,Fig 7.

Fig 6 Split exural tensile test

Table 4
Experimental values for the compressive, tensile and flexural strengths for three trails (28 day and hot curing).

Trail -1

Trail Mixes	No.	Density (kg/m³)	Load (kN)	Stress (MPa)	Avg.
Cubes	1	2405	813.1	81.3	
(Compressive strength)	2	2453	832.3	83.2	82.84
	3	2438	840.0	84.0	
Cylinders	1	2329	435.3	6.16	
(Tensile strength)	2	2406	605.9	8.6	7.1
	3	2378	450.4	6.4	
Prisms	1	2305	85.5	11.2	
(Flexural strength)	2	2323	103.0	13.5	12.0
	3	2346	86.6	11.3	

ISSN 2229-5518

Trail -2

Trail Mixes	No.	Density (kg/m³)	Load (kN)	Stress (MPa)	Avg.
Cubes	1	2553	872.3	87.3	
(Compressive strength)	2	2501	918.4	91.8	91.1
	3	2586	941.1	94.1	
Cylinders	1	2413	653.0	9.2	
(Tensile strength)	2	2389	601.1	8.5	9.1
	3	2409	694.2	9.8	
Prisms	1	2336	105.4	13.74	
(Flexural strength)	2	2338	98.58	12.85	13.3
	3	2398	101.2	13.19	

Trail -3

Trail Mixes	No.	Density (kg/m³)	Load (kN)	Stress (MPa)	Average
Cubes	1	2478	1104.0	110.4	
Compressive strength	2	2563	1112.6	111.3	111.3
	3	2490	1120.3	112.0	
Cylinders	1	2375	660.5	9.4	
Tensile strength	2	2328	645.7	9.2	9.5
	3	2386	698.9	9.9	
Prisms	1	2458	158.2	20.62	
Flexural strength	2	2528.3	150.55	19.63	19.2
	3	2396	132.6	17.3	

Maximum density of about (2500 kg/m³) is obtained for third mixture, despite the absence of gravel. This can be attributed to the action of silica fume and steel fiber.

Increasing the steel fiber from 20% to 23.75% (Vf/C) is found to increase the compression, tension and flexural strength by about 34.3%, 33.8% and 60%, respectively. These increments are attributed to the effect of steel fibers in delay of appearance of micro cracks. The fibers in mixture cause delayed appearance of micro cracks Table 4. Results show that the flexural strength is always greater than the splitting tensile strength that it was expected. It seems that the splitting test was nearer to the correct tensile strength of concrete than the modulus of rupture relative to the average tensile strength of 4.167 of ($0.4\sqrt{fc'}$).

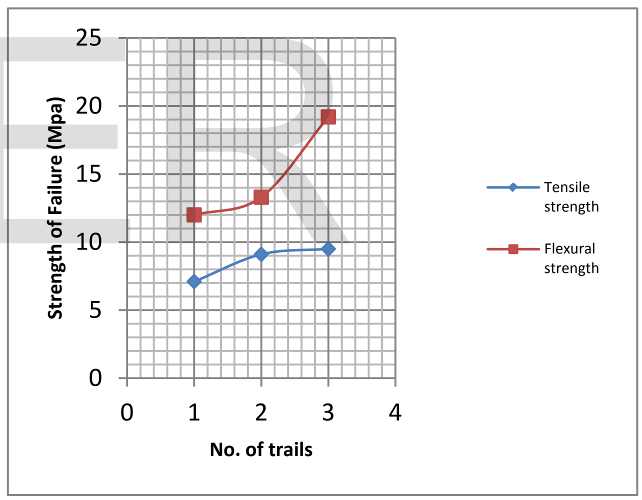

Fig 7 Experimental Tensile and Flexural Strength at (28 days and Hot Curing) for different trails

8 CONCLUSIONS

The main conclusions that can be drawn are:

1 - Increasing the steel fiber from 20% to 23.75% (Vf/C) is found to increase the compression, tension and flexural strength by about 34.3%, 33.8% and 60%, respectively.

These increments are attributed to the effect of steel fibers in delay of appearance of micro cracks.

2– Reactive powder concrete reaches its maximum compression strength (119 Mpa) after 7 days of hot curing at 60° C water.

3- Increasing the hot curing period beyond 7 days is found to decrease the compression strength (111 MPa at 28 days).

4 - In normal curing, the effect of silica fume in increasing the compression strength of RPC may not appear until an age of 91 days.

5 - Maximum density of about (2500 kg/m^3) is obtained for third mixture, despite the absence of gravel. This can be attributed to the action of silica fume and steel fiber.

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

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

[6] Lavanya S. Prabha, J.K. Dattatreya, M. Neelamegam and M.V.Seshagiri Rao (2010)," Study on Stress-Strain Properties of Reactive Powder Concrete Under Uniaxial Compression", S.Lavanya Prabha et. al. / International Journal of Engineering Science and Technology, Vol. 2(11), PP: 6408-6416.

[7] Naser Hakeem Tu'ma (2016)," BEHAVIOR OF REACTIVE POWDER CONCRETE BEAMS REINFORCED WITH FIBER REINFORCED POLYMER BARS" University of Baghdad, College of Engineering.

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

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

[10] Davood Mostofinejad, Mojtaba Rostami Nikoo, Seyed Arman Hosseini "Determination of optimized mix design and curing conditions of reactive powder concrete (RPC)" Department of Civil Engineering, Isfahan University of Technology (IUT), Isfahan, Iran