Mechanical Properties of Reactive Powder Concrete (RPC) with Mineral Admixture

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Abstract

Reactive powder concrete (RPC) is a special type of concrete, it is rather a mortar than an actual concrete mixture, because traditional coarse and fine aggregate are replaced by very fine sand with particle size in range of (150-400)µm.

In the present experimental investigation, compressive strength, splitting tensile strength and flexural strength of plain reactive powder concrete and reactive powder concrete reinforced with 1% and 2% steel fiber are compared, by using local available material and curing in 20°C and 80°C, and the experimental study was curried out on a two sets of samples. Each set consisted of (54) cubes of (50×50×50mm), (18) cylinder of (100×200mm) and (18) prism of (50×50×300mm). The results show that the maximum compressive strength is 74 MPa with 2% steel fiber and curing in 20°C. The addition of steel fiber by 1% and 2%increased the compressive strength, splitting tensile strength and flexural strength.

Keywords: **reactive powder concrete, steel fibre, compressive strength, flexural strength, tensile strength**

الخواص الميكانيكية لخرسانة المسحوق الفعال باستخدام مضافات معدنية

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الخلاصة

خرسانة المسحوق الفعال نوع خاص من الخرسانة اقرب ما يكون إلى عجينة السمنت لان الركام الخشن والناعم يستبدل بركام حجمه يتراوح بين 150-400)µm)ويتميز بأنه ذو مقاومة عالية جدا.

في هذا البحث تم دراسة بعض خواص خرسانة المسحوق الفعال كمقاومة الانضغاط ومقاومة الشد الانشطاري ومقاومة الانثناءباستخدام مواد متوفرة محليا من سمنت وركام وسيليكا وملدن ودراسة تأثير تغير نسب الألياف الفولاذية وبظروف معالجة مختلفة بدرجة 20 و 80 درجة مئوية. الدراسة العمليةأجريت على مجموعة من النماذج لكل نوع من المعالجة شملت (54) مكعب بأبعاد (50×50×50mm)، و(18) نموذج اسطواني بأبعاد (100×200mm)، و (18) نموذج خرساني بأبعاد (50*50*300mm)وقد وجد أنأقصى مقاومة يمكن الحصول عليها باستخدام المواد المحلية (74 MPa) عند إضافة 2% ألياف فولاذية ومعالجة بدرجة 20 مئوية.

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Introduction

Beginning with Richard and Cherezy (1995), Jörg Jungwirth (2002), Chang. et al(2009) and Malik. et. al.(2010), [1,2,3 and 4] many researchers have investigated the various aspects of RPC. However, proper selection ofmaterials, their proportioning and process of production influence the rheological properties and mechanicalperformances of RPC.

The term Reactive Powder Concrete (*RPC*) has been used to describe a fiber-reinforced, superplasticized, silica fume - cement mixture with very low water-cement ratio (*w/c*) characterized by the presence of very fine quartz sand (0.15-0.40 mm) instead of ordinary aggregate [5,6]. In fact, it is not a concrete because there is no coarse aggregate in the cement mixture. The absence of coarse aggregate was considered by the inventors to be a key-aspect for the microstructure and the performance of the *RPC* [5,6] in order to reduce the heterogeneity between the cement matrix and the aggregate. However, due to theuse of very fine sand instead of ordinary aggregate, the cement content of the *RPC*is as high as 900-1000 kg/m3.

The influence of Portland cement and silica fume type on the performances of reactive powder concrete (RPC) mixtures have been studied, only by using C_3A - free Portland cement, in combination with a white silica fume brand. The w/c ratio was as low as 0.18, and the compressive strength was as high as 200 MPa at 3 day after a thermal treatment at 160 °C. However a strong reduction in the early compressive strength was recorded. The replacement of the white silica fume by other silica fume types (grey or dark), as well as the substitution of the other Portland cements for the C_3A-free Portland cement caused an increase in the w/c and a reduction in the compressive strength (110-160 MPa). However, with these mixtures there was no reduction in the early compressive strength.[7]

Compressive strength and flexural strength of plain reactive powder concrete (RPC) and RPC reinforced with corrugated steel fibres and recron 3s fibres were investigated. Composition of RPC, which was optimized by trial and error method in previous work by varying different ingredient, was used with a water cement ratio of 0.22. Corrugated steel fibres were used 0.4 mm dia. and 13mm long and recron 3s fiber of triangular shape and 12 mm length were incorporated in the concrete.[8]

Purpose and Scope

The purpose of this work is to study some mechanicalproperties of reactive powder concrete (RPC)including compressive, flexure,splitting tensile strength of plain reactive powder concrete and reactive powder concrete reinforced with 1% and 2% steel fiber, by using local available material and curing in 20°C and 80°C.

Materials:

Cement: One type of cement was used, Ordinary Portland Cement, produced locally in accordance with Iraqi Specification (IQS:No5, 1984)[9].Thechemical and physical properties are given in table (1) and (2) respectively.

Table (1) : Chemical Composition of The O.P.C.

Property	Test result (Percentage)	Standard IQS, No.5
1.Oxide composition:		
Alumina, Al_2O_3	5.6	3-8
Silica, SiO_2	21.52	17-25
Ferric Oxide, Fe_2O_3	2.74	0.5-6
Lime, CaO	62.55	60-67
Sulphuric Anhydride, SO_3	2.54	Max. 2.8 %
Magnesia, MgO	3.23	Max. 5%
2.Compound composition:		
C_3A	12.07	11.96-12.3
C_2S	34.20	28.61-37.9
C_3S	36.44	31.03-41.05
C_4AF	7.98	7.72-8.02

Table (2) : Physical Properties of The O.P.C.

Property	Test result	Standard IQS, No.5
Fineness(Residue on sieve No. 170)	2 %	Max. 10%
Specific surface "Blaine"(cm^2/gm)	3358.5	Min. 2250
Initial setting time	140 (min.)	45 (min.)
Final setting time	385 (min.)	600 (max.)
Specific gravity	3.14	—
Compressive strength(MPa)		
at 3 days	19.22	16.0 (min.)
at 7 days	27.88	24.0 (min.)

Fine aggregate:

river sand pass from sieve(600μm) (No.30) and retained on sieve (150μm) (No.100) according to ASTM C 109/C 109M-02 [10].

Mixing Water:

Ordinary drinking (tap) water was used for concrete mixes.

Silica fume:

The Chemical and physical properties are given in tables (3) and (4).

Table (3) : Chemical Properties of Silica fume

Property	Percentage	Limit of ASTM C1240-03a[11]
Silica, SiO_2	95.95	Min. 85.0%
Sulphuric Anhydride, SO_3	0.22	Max. 4.0 %

Table (4) : Physical Properties of Silica fume

Particle size (typical)	<1 micron
Bulk density	As- produced : 130 to 430 kg/m^3 Densified: 480 to 720 kg/m^3
Specific gravity	2.2
Specific surface	15,000 to 30,000 m^2/kg

Chemical Admixture:

Hyperplast PC200 is a high performance super plasticizing admixture based on polycarboxylic. It can be used with all types of Portland cement to achieve highest concrete durability and performance.The main properties are shown in table (5).

Table (5): The Properties of HRWR

Type	Polycarboxylic
Name	Hyperplast PC200
Color	Light yellow liquid.
Specific gravity	1.05±0.02
Dosage	(0.75-2.50) liter per 100 kg of cementitious.

Mix Proportions

The investigated mixes were prepared depended on the original mix of reactive powder concreter coined by the inventors Richard and Cheyrezy 1994 [12], the mix proportions by (Kg/m^3) are shown in table (6)

Table (6): The mix proportions

Material (Kg/m^3)	Mix 1	Mix 2	Mix 3
Cement	955	955	955
Silica	229	229	229
Fine sand (150-600 µm)	1051	1051	1051
Superplasticizer	19	19	19
Steel fibers	0	95.5	191
Water	347	347	347
w/c	0.36	0.36	0.36
w/(c+sf)	0.29	0.29	0.29

Curing:

All sample were curing in two conditions

a-Room temperature at 20°C.

b-steam curing: at 20°C in 1 day then at 80°C in 1 day finally at 20°C up to 28 day.

Discussions

Compressive Strength Test

Compressive strength of concrete is the most useful and important property of concrete. Many other properties of concrete such as durability, resistance to shrinkage Young's modulus, imperviousness etc. are dependent on the compressive strength of concrete.

The purpose of the compression test is to determine the crushing strength of hardened concrete and is conducted on cube specimens of 50x50x50mm size as the RPC does not contain coarseaggregate and maximum size of particle is 800 µmaccording to ASTM C 109/C 109M-02 [10]. Here to determine the average compressive strength, three cubes of each concrete mix are tested after 3,7, and 28 days, testing under compression testing machine of 180tones capacity.

From table (7), Fig.(1) and Fig.(2), the compressive strength reach up to 74 MPa for 2% fiber reinforced for 20°C curing. Curing in hot water (80 °C) gives a compressive strength at 3 day equal to (80-90) % of that of 28 day. The compressive strength at 7 day equal to (93-97)% of that of 28 day. In 20 °C curing the compressive strength at 3 day equal to (57-65)% of that of 28 day compressive strength and at 7 day equal to (75)% of 28 day compressive strength.

Table (7): The compressive strength at different ages.

Mix No.	Compressive Strength (MPa)									
	Curing at 20°C					Curing at 80°C				
	3 days	% of 28days	7 days	% of 28days	28 days	3 days	% of 28days	7 days	% of 28days	28 days
1	35.1	64.2	41.2	75.3	54.7	43.4	83.1	48.4	92.7	52.2
2	38.5	57.8	50.0	75.1	66.6	52.0	81.9	59.2	93.2	63.5
3	48.5	65.5	56.0	75.7	74.0	60.2	94.0	62.0	96.9	64.0

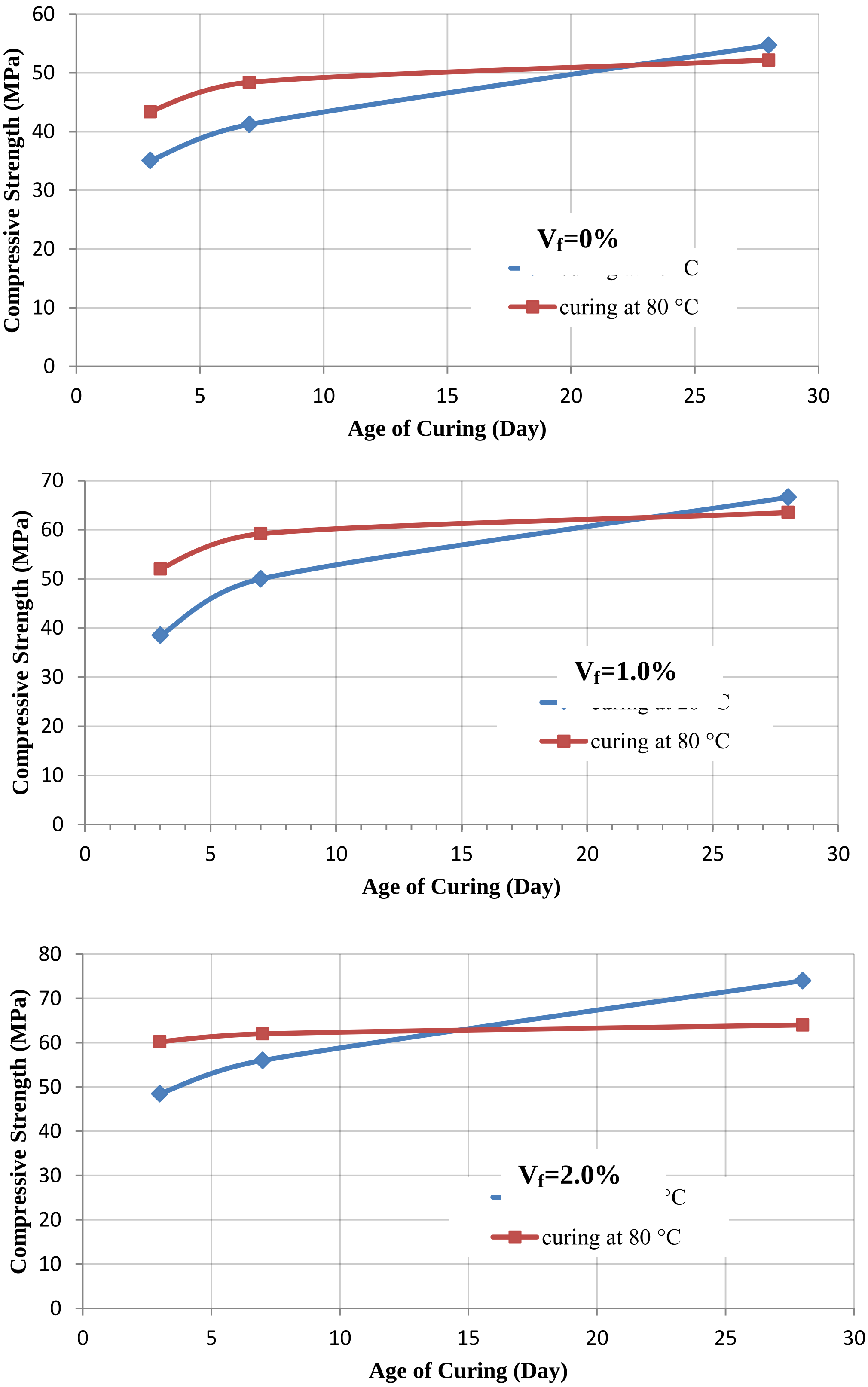

Fig.(1)The Relation between Cube Compressive Strength and Age of Curing

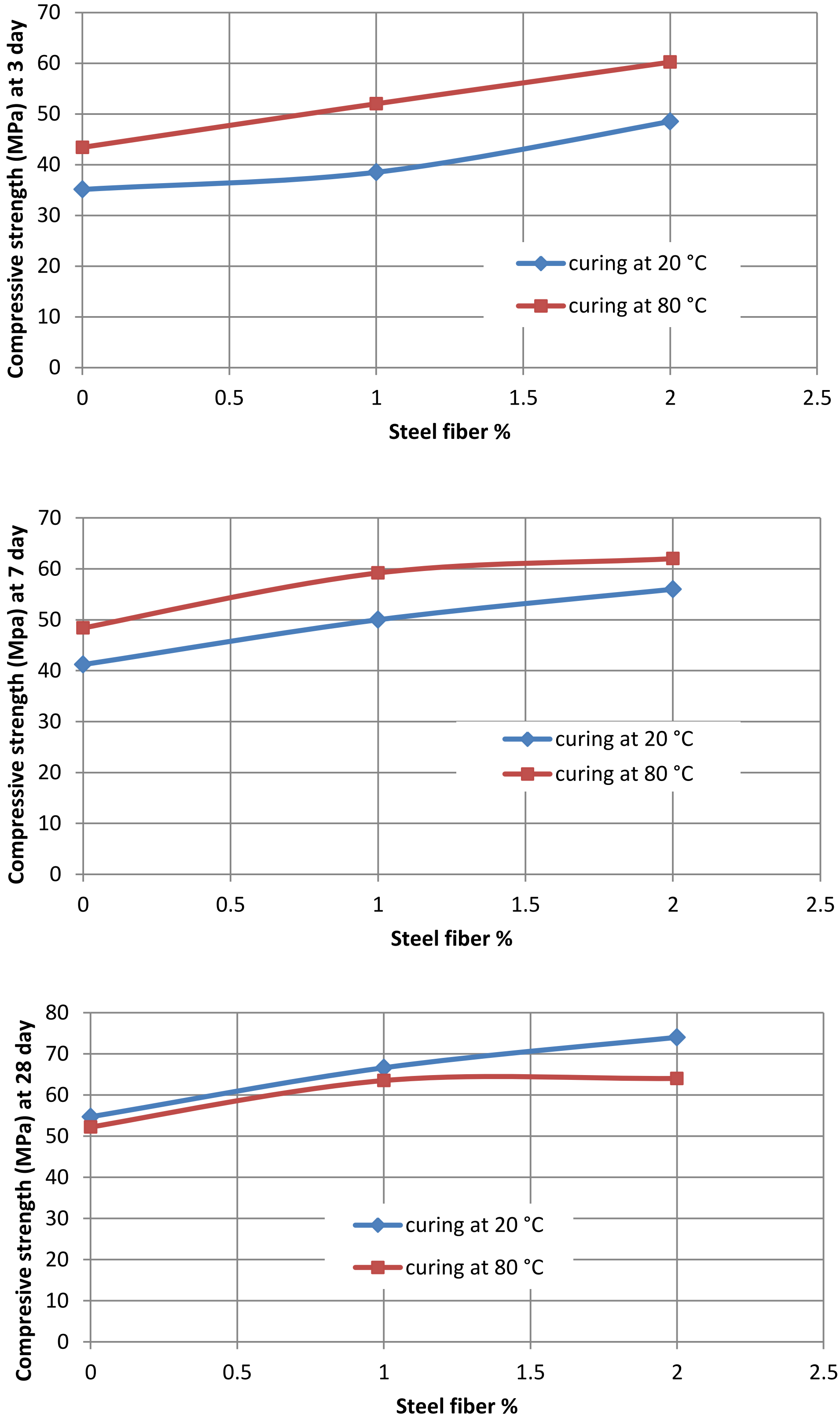

Fig.(2)The Relation between Cube Compressive Strength and percentageof steel fiber

Splitting Tensile Strength Test

An indirect test of tensile strength of concrete has been standardized by ASTM C 496-96 [13] and is in general use in this tests specimen of cylindrical shape of diameter 100 mm and 200 mm inlength are tested under a compressive load across the diameter along its length till the cylinder splits. To determine the average split tensile strength, in the present work, 3 cylinders of each mix are tested under compression testing machine of 180tones capacity after removing the specimens at the age of 28 days from the curing tank. Cylindrical specimen is placed in the machine, along its length, keeping plywood strip between the cylinder and the testing machine bearing surfaces at the top and bottom ofcylinder. Load is gradually applied and maximum load at which the specimen fails is noted. The magnitude of the tensile strength is worked out with the help of $2P/\pi LD$. Where P is applied load at failure, D is the diameter in mm and L is the length of specimen in mm. Fig.(3) show the splitting failure of the tested specimen with 0%, 1% and 2% of steel fiber.

a- 0% steel fiber **b- 1% steel fiber** **c- 2% steel fiber**

Fig.(3)The specimen after splitting test

Table (8) show the splitting tensile strength at 28 days and percentage of increase from mix (1), the addition of steel fiber 1% and 2% increased the splitting tensile strength by 17.56 % and 25.32 % respectively in curing in 20°C, and increased it by 26.62 %and 42.13 % respectively in curing in 80°C.

Table (8): The Splitting Tensile Strength at 28 days.

Mix No.	Splitting Tensile Strength(MPa)			
	Curing at 20°C	Percentage of increase	Curing at 80°C	Percentage of increase
1	5.41	0.0	4.77	0.0
2	6.36	17.56%	6.04	26.62%
3	6.78	25.32%	6.78	42.13%

Flexural Strength Test

The purpose of flexural strength test is to have an idea of the load at which a concrete member in bending may crack due to Tension. It gives an idea of tensile strength of concrete. The tensile strength of concrete in bending is known as flexural tensile strength or modulus of rapture, and is equal to bending moment at failure divided by the section modulus of a beam under test.In the present work, beam samples of each mix casted of size 50x50x300 mm in size are tested under simply supported condition keeping the span of 275 mm a third point load test is conducted on universal testing machine. The maximum load atwhich beam fails is recorded and flexural strength is calculated.

Table (9) show the Modulus of Rapture at 28 days and percentage of increase from mix (1), the addition of steel fiber 1% and 2% increased the flexural strength by 14.19% and 40.46 % respectively in curing in 20°C, and increased it by 11.9 % and 45.47 % respectively in curing in 80°C.

Table (9): The Modulus of Rapture at 28 days.

Mix No.	Modulus of Rapture (Flexural Strength) (MPa)			
	Curing at 20°C	Percentage of increase	Curing at 80°C	Percentage of increase
1	9.02	0.0	9.83	0.0
2	10.30	14.19%	11.0	11.9%
3	12.85	40.46%	14.30	45.47%

Mode of Failure

Flexural specimen failed at plane approximately in the middle of the specimen. The addition of steel fiber gives a monition to failure by appearance of crack in the tension face of specimen before the failure happened, while the specimen without steel fiber failed suddenly. Fig.(4) show the flexure specimen after tested, at different fiber volume percentage.

a-0% steel fiber

b- 1% steel fiber

c- 2% steel fiber

Fig.(4)Mode of failure of flexure test

Conclusion

1. The compressive strength reach up to 70 MPa, that equaled to 30% of compressive strength of RPC 200 of Richard and Cheyrezy [12]that is may be because of high percentage content of C_3A in local cement while RPC 200 have free C_3A.
2. Addition of steel fibers does not affect the finishibility of reactive powder concrete.
3. Addition of steel fibers increased the compressive strength, flexural strength and splitting tensile strength.
4. Curing in high temperature water 80 °C increased the compressive strength at early ages and decreased it at 28 day compare with curing in 20 °C.
5. Curing in hot water at 80 °C gives a compressive strength at 3 day equal to (80-90)% of that of 28 day, and at 7 day equal to (93-97)% of that of 28 day. compressive strength compare with curing in 20 °C gives a compressive strength at 3 day equal to (57-65)% of 28 day compressive strength and at 7 day equal to (75)% of 28 day compressive strength.

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