Effect of RPC Compositions on: Compressive Strength and Absorption

Ahmed Sultan Ali
Riparian University / Faculty of Engineering
Ahmed- Sltn2007@yahoo.com

Abstract

Concrete is a critical material for the construction of infrastructure facilities throughout the world. A new material known as Reactive Powder Concrete (RPC), or sometimes called Ultra-High Performance Concrete (UHPC), is becoming available that differs significantly from traditional concretes. It is an ultra high strength and high ductility composite material with advanced mechanical properties. It consists of special concrete whose microstructure is optimized by precise gradation of all particles in the mix to yield maximum density.

Different RPC mixes in the experimental investigation of the present study the mechanical properties of RPC including compressive strength, density and absorption.

The main variables used in the production of the different RPC mixes of the present research are three, namely, type of pozzolanic admixture (metakaolin, micro silica, and silica fume), type of fibers (steel and polypropylene fibers) and volume fraction of fibers (1.0,1.5, and 2.0)%.

The experimental results indicated that RPC mixes with silica fume gave the highest values of compressive strength and density and lowest value of absorption in comparison with RPC using micro silica or metakaolin where metakaolin was the third in such comparisons. However the RPC mixes used in the present investigation gave group compressive strength ranging between 164 -195 MPa.

It was also found that the use of steel fibers with high volume fraction (2%) in an RPC mix increases the compressive strength by 8% and density of the concrete by 2.5% and reduces its absorption by 13%, unlike an RPC mix using polypropylene fibers of lesser volume fraction.

Key Words: Absorption; Microstructure; Pozzolanic Admixtures; Fibers

الخلاصة

تعتبر الخرسانة من المواد الإنشائية المهمة في جميع أنحاء العالم، ويتوفر منها الآن نوع جديد يسمى خرسانة المساحيق الفعالة (Reactive Powder Concrete, RPC) ويسمى أيضا بالخرسانة فائقة الأداء (Ultra High Performance Concrete UHPC) حيث أنها تختلف كثيرا عن الخرسانة التقليدية. تمتاز هذه الخرسانة الجديدة بمقاومتها العالية وديمومتها ومرونتها الكبيرة وخواصها الميكانيكية الجيدة، حيث يراعى التدرج المثالي لمساحيقها لجعلها عالية الكثافة.

تم في هذا البحث إجراء فحوصات مختبرية على خلطات مختلفة من هذه الخرسانة للتعرف على بعض الخواص الميكانيكية المهمة لهذه الخرسانة مثل مقاومة الانضغاط والكثافة والامتصاص .

تم اعتبار وجود ثلاث متغيرات رئيسية عند تصنيع خلطات مختلفة من خرسانة RPC في هذا البحث وهي على الترتيب : نوع مادة البوزولانا المستخدمة (ميتاكائولين ، مايكروسليكا ، أو سيليكافيوم) ونوع الألياف المستخدمة (ألياف فولاذية أو ألياف البولي بروبلين) والنسبة الحجمية للألياف (2.0 , 1.5 , 1.0) % . أظهرت النتائج بان استخدام السليكافيوم في الخلطة الخرسانية يزيد من مقاومتها الانضغاطية وكثافتها ويقلل من درجة امتصاصها ، مقارنة بالنوعين الآخرين من البوزولانا (وهما المايكروسليكا والميتاكاؤلين) حيث يأتي الميتاكاؤلين ثالثا في هذه المقارنات. ان مقاومة الانضغاط التي تم الحصول عليها في هذا البحث لخرسانة المساحيق الفعالة تتراوح بين (164–195) MPa . لقد وجد أيضا بان استخدام ألياف فولاذية بنسبة حجم عالية(2%) في خلطة خرسانة RPC سوف يكسب الخرسانة مقاومة أنضغاط وأنحناء وكثافة أعلى بينما الخرسانة الحاوية على ألياف البولي بروبلين بنسبة اقل تكون ذات مقاومة أنضغاط وأنحناء وكثافة أقل.

الكلمات المفتاحية: امتصاص؛ المجهرية؛ البوز ولانية المواد المضافة؛ ألياف

Introduction

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 (0.15-0.40mm) instead of ordinary aggregate. However, due to the use of very fine sand instead of ordinary aggregate, the cement factor of RPC is as high as (900-1000 kg/m^3) (Craybeal & Hartmann, 2000P).

The steel fibers used in the RPC concrete are usually un-deformed 12mm long and 0.2 mm diameter wires with aspect ratio of (60). The volume of fibers in the mix can vary depending on the material properties desired.

In fact there are limited studies on Reactive Powder Concrete, and this presents a review of such studies.

- **Orgass, and Klug (2004)** investigated the influence of short steel fibers and a fiber mix of short and long fibers on the mechanical properties of Ultra High Performance Concrete (UHPC) especially regarding the ductility and the size effect. In this regard the fiber contents changed between 0 and 1% volume fraction. It was observed that highest compressive and flexural strengths were obtained on smallest specimens (prisms). In vibrated concrete the compressive strength was shown to decrease with the increase of the specimen slenderness. This phenomenon was not observed in self-compacting ultra-high performance concrete.
- **Jiwen-yn, *et al* (2006)** used Portland cement, active mineral powder, including high-quality silica fume whose surface ratio exceeded 200,000cm^2/g, low-need water super-fine fly ash, superplasticizer that has good compatibility with cement, whose rate of reduction of water was above 32 percent, and quartz sands whose grain sizes were 0.16 to 0.135mm, 0.135 to 0.63mm, 0.63 to 1.0 mm, that make up the most close-grained preparation the optimal mixture ratio, w/b ratio was 0.16 and curing temperature was 75C°.

  Results showed that concrete's 28-day compressive strength was 168.6MPa, bending strength was 20.6MPa.
- ***Schachinger et al* (2008)** studied the effect of subjecting UHPC to a temperature of 90°C during its early ages (for 24 to 48 hours). It was shown that such heat treatment accelerated the pozzolanic reaction of silica fume with $Ca(OH)_2$ and resulted in high strength development of UHPC. The compressive strength of a heat treated UHPC was observed to increase from 220 to 280 MPa over 8 years' storage in water. The compressive strength was 250 MPa at an age of six years which was 58% more than the 28 day strength of 160 MPa. This was attributed to the slow, but continuous, pozzolanic reaction of the silica fume and the increase in C-S-H phase change length.

Experimental Work

The different mixes of Reactive Powder Concrete (RPC) were classified into two main types; RPC using steel fibers and RPC using polypropylene fibers. In either type, three different kinds of admixtures (namely, metakaolin, micro silica, and silica fume) were used separately. This gave an over all six groups of mixes (G1… to G6). In addition, each one of these six groups was sub-divided into three different mixes where a certain percentage of fibers (1.0%, 1.5% or 2.0%) were used in each mix. Therefore the total number of RPC mixes considered in this experimental investigation was eighteen (18).

From each specific RPC mix, the following kinds of specimens were taken;

1- Three cubes (50×50×50) mm which were tested under uni-axial compression to assess the compressive strength of RPC at 3,7, and 28 days of age.

2- Three cubes (50×50×50) mm were tested for absorption.

Materials

Cement

Sulfate resisting portland cement is usually used in RPC because it contains low C_3A content(Collepardi *et al.,*1999P).The results of The chemical test of this type of cement are listed in table (1), was indicate that the chemical compositions of the used cement are conformed to the ASTM standard specification for Portland cement(ASTM C150-02a 2002).

Fine Aggregate

For RPC, very fine sand with maximum size 600μm was used. This sand was separated by sieving; its grading satisfied the fine grading in accordance with the B.S. specification No. 882/1992(ASTM 311-02 2002).

Table (2) illustrates the sieve analysis of the separated fine sand. The specific gravity, sulfate content, and absorption of fine aggregate, was 2.7, 0.09%, and 0.74%, respectively, the latter being within the requirements of the Iraqi specification No.45/1

Fibers

Two types of fibers were used in this study, **steel** and **polypropylene fibers**. Table (3) shows the characteristics of these fibers used in the present investigation.

Mineral Admixtures

Three types of mineral admixtures were used in this research: **Metakaolin (MK), Micro Silica (MS), and Silica Fume (SF)**. Table (4) shows the Chemical Composition of these mineral admixtures, and table (5) shows the Chemical requirement of pozzolan ASTM C618

Chemical Admixture

Three types of superplasticizers were tried in this study (Glenium ***51, Structuro335***, and ***Structuro480).*** First of all Gleniume 51 was tried, it was found that large quantities were needed to reach the required slump flow and the w/cementitious. After many trials it was found that the optimum dosage is 6.7% (by weight of cement) of Structuro 335 plus 2.3% (by weight of cement) of Structuro 480 for mixes containing steel fibers. On the other hand it was found that mixes with polypropylene fibers need little more percentage of HRWRA, the suitable percentage was 7% (by weight of cement) of Structuro 335 plus 2.5% (by weight of cement) of structuro 480.

Tables (6), show the properties of these superplasticizers.

Strength Activity Index for Mineral Admixture

In order to find the suitable percentages of silica fume, micro silica and high reactive metakaoiln as a partial replacement by weight of cement, the strength activity (some times calls pozzolanic activity) was tested in accordance with ASTMC311-02. Three different percentages (10, 15, and 20%) of each type of mineral admixture were used in the present experimental investigation.

Table, (7) shows w/c or w/cementitious ratio and strength activity index for various mixes.

Mixing, Casting and Curing of Concrete

The required quantity of mineral admixtures (Metakaolin (MK), Micro Silica (MS), and Silica Fume (SF). was mixed in dry state with the required quantity of cement.

This operation was continued for 15 minutes to ensure that mineral admixture powder were thoroughly dispersed between the cement particles, and then the HRWRA was added until all particles were fully coated with HRWRA and water was added and mixing continued until uniform mix was obtained, finally when steel fibers were used, they were introduced, and dispersed uniformly(Ohama,1997).

Concrete casting was carried out in three layers then compacted by using a vibrating table to ensure removing the entrapped air as much as possible. After that specimens were covered with nylon sheets to prevent moisture loss and remain undisturbed until final set had occurred. The specimens were demoulded at 24 hours after casting.

The best curing treatment is by steaming the RPC at 90˚C and 95 percent relative humidity for 48 hours. This type of curing was used in this investigation, then placed in water and left until the age required for testing.

Determination of Workability and Water Reduction

Workability was measured via a flow table test similar to that described in ASTM C230-83O(1983P).

Water reduction was determined by increasing the dosage of superplasticizer while maintaining the same workability to reference mixture (150±5).

Concrete Mixes

In order to study the influence of the different mixture ratios on the strength and absorption of Reactive Powder Concrete, the following had been considered:

1- Three types of mineral (pozzolanic) admixtures [namely: Metakaolin (MK), Micro Silica (MS), and Silica Fume (SF)].
2- Two types of fibers (namely: Steel Fibers and Polypropylene Fibers).
3- Three proportions of fibers (1.0%, 1.5%, 2.0% by volume) for each type of mineral admixture.

This gives 18 different mixes which were used in this investigation addition to the Reference and HRWRA mix.

Tables (8) and (9) list the proportions of materials used in these mixes.

Concrete Tests

Compressive Strength Test

The compression tests were carried out on a standard 50 mm cubic specimens tested after curing at the ages of 3,7, and 28 days for each mix. The average of three cubes was adopted for each age.The testing was completed in an Averey–Dension 2000 kN capacity compression testing machine(Federal Highway Administration, 2006).

Absorption Test

Based 8on B.S.1881: part 122(1989), the absorption test was carried out on (50×50×50) mm cube specimens at age of 28 days.

Density

Density was found by weighing the specimen after demoulding and air drying then its weight was divided by the measured volume of the specimen. 50 mm cubes were used to determine the density.

Results and Discussions

Water Reduction

The optimum dosages of HRWRA and water reductions for different Reactive Powder Concrete mixes which contain steel fibers (i.e. mixes S1 to S9) are shown in Table (10). Table (11) shows the optimum dosages of HRWRA and water reductions for different Reactive Powder Concrete mixes which contain polypropylene fibers (i.e. mixes P1 to mix P9).

Results indicate that Ref. mix needed a lesser dosage of HRWRA which was just 6% by weight of cement, while the dosage for RPC mixes with steel fibers was 9%, and that for RPC mixes with polypropylene fibers was 9.5% by weight of cement.

Compressive Strength

The test results for compressive strength of various mixes of Reactive Powder Concrete investigated in this study were summarized in Tables (12) and (13). The tables show compressive strength values at three ages (3, 7 and 28 days). Figures (1) and (2) show the variation in the compressive strength of these different mixes as a function of age.

Generally, all RPC mixes showed initial rapid strength gain during early ages followed by a gradual decrease in the rate of strength gain, while the reference mix showed somehow steady development in compressive strength. This can be attributed to the effect of water reduction on compressive strength that is RPC mixes because of their low water cemntitous ratio gain strength more rapidly than mixes with higher water cement ratio, as the cement grains are closer together and a continuous system of gel is established more rapidly.

Also the results show that the addition of pozzolanic mineral admixtures (metakaolin, micro silica and silica fume) can cause a considerable increase in compressive strength at early ages. That is mainly due to the high pozzolanic reaction of particles of these materials with calcium hydroxide released from cement hydration leading to pore size and grain size refinement processes which can strengthen the microstructure and reduce the microcracking.

Steam curing for 48 hours has a significant effect on strength gain with respect to age. This improvement in strength was related with a more densified microstructure of the cement matrix(Federal Highway Administration, 2006).

- *Effect of pozzolanic admixture type*:Results demonstrated that at 28 day age the RPC mixes which contain silica fume based complex admixture possessed the highest compressive strengths than with micro silica or metakaolin (at the same type of fibers and same volume fraction). Figure (3) shows the effect of pozzolanic admixture type on compressive strength of RPC mixes with steel fibers. For example a comparison of three mixes S1, S4, and S7 which contain steel fibers of 1.0 % volume fraction indicates that mix S7 with silica fume has a compressive strength of (97, 120, and 188) MPa at (3, 7, and 28) day age respectively, while mix S4 with micro silica has strength values of (112.5, 119, and 164) MPa at same ages respectively,
- *Effect of volume fraction of fibers*: A general indication can be realized from results shown in tables (11) and (12) that the ultimate strength is only slightly affected by the presence of fibers. Table (10) shows that RPC mixes (S1, S2, and S3) which contain metakolin and steel fibers at (1.0, 1.5, and 2.0%) volume fraction respectively have compressive strength equal to (146, 151, and 155) MPa respectively at the age of 28 days. This result insures that fiber content has no significant effect on compressive strength. The same behavior can be seen for RPC mixes (S4, S5, and S6) with other percentages and type of fibers.

Results also indicate that the use of polypropylene fibers with various volume fractions does not generally lead to significant increase in compressive strength.

-*Effect of type of fibers:* Type of fibers can also have insignificant effect on compressive strength, but it can be seen from results that polypropylene fibers have less effect than steel fibers and this can be explained as polypropylene fibers is a weak material which produces a concrete with poorer workability, more bleeding and segregation, with relatively higher entrapped air.

Absorption

The results of absorption test carried out on different RPC mixes (at ages of 7 and 28 days) which contain either steel or polypropylene fibers are shown in Tables (14) and (15) respectively. In general, the percentage absorption of all RPC mixes is less than the percentage absorption of the Ref. mix and HRWRA mix. This is due to the pore size and refinement processes related to pozzolanic reaction together with the effect of superplasticizer admixture which have a great effect on reducing the percentage of absorption

- *Effect of pozzolanic admixture type*: Results show that RPC mixes with silica fume have the smallest percentage of absorption in comparison with RPC mixes having either micro silica or metakaolin (with same type of fibers and same volume fraction).This behavior is attributed to the fine particles of silica fume compared with micro silica or metakaolin. Figure (4) shows the effect of mineral admixture on absorption of RPC mixes with steel fibers, while Figure (5) shows the effect of mineral admixture on absorption for RPC mixes with polypropylene fibers.

- *Effect of volume fraction of fibers*: Results indicate that adding fibers to RPC mixes tends to slightly increase absorption, accordingly higher volume fraction leads to higher absorption. This is due to the increase in the w/cementitious ratio needed to ensure the required workability.

-*Effect of type of fibers:* Using polypropylene fibers in RPC mixes gives significant increase in absorption compared to similar mixes using steel fibers. This is because of the nature of the polypropylene fibers which have pores inside it that absorb water.

Density

The density results shown in Tables (14) and (15) indicate that densities of RPC mix ranging from 2389 kg/m^3 to 2510 kg/m^3. This difference is due to the different component of RPC mixes used in this study. Also the addition of pozzolanic admixture gives an increase in the value of density due to the chemical reaction of these materials with calcium hydroxide which reduces the capillary voids and microcracks. Also the ultra fine particles of these materials may act as fillers leading to an increase in density of RPC by 13%.

- *Effect of pozzolanic admixture type*: Results indicate that RPC mixes with silica fume have higher values of density and this is due to its ultra fine particles which act as a good filler.

- *Effect of volume fraction of fibers*: For RPC mixes with steel fibers, the increased in the volume fraction of fibers leads to higher density of the mix, this is because of the high density of steel fibers. On other hand the increase in the polypropylene fibers leads to a lower density of the mix and this is because of the low density of such fibers which means replacement of some concrete contents with a lighter material (but the variations in the percentages of fibers which were adopted in this research are as small as have no significant effect on the densities values of RPC mixes with polypropylene fibers).

-*Effect of Type of fibers:* It can be seen from the results that using steel fibers leads to increased density, while addition of polypropylene fibers leads to lower density (comparing with mixes with steel fibers) and this, as mentioned before, is due to the significant difference in the densities of the two types of fibers.

It seems that mixes with higher densities (especially mixes with steel fibers) have higher compressive strengths.

Conclusions

1- The RPC mixes with silica fume (SF) exhibit the highest cube compressive strength (195 MPa at 28 days age for RPC mixes at 7 days with steel fibers and 187 MPa at 28 days for RPC mixes with polypropylene fibers). On the other hand mixes with metakaolin (MK) exhibit the lowest value of cube compressive strength (89 MPa at 3 day age and 155 MPa at 28 day age for mixes with steel fibers, and 88 MPa at 3 day age and 148 MPa at 28 days age for mixes with polypropylene fibers).

2- According to the second variable which was the type of fibers, RPC mixes with steel fibers exhibit higher values of cube compressive strength (195 ,173 ,155 MPa at 28 days age for RPC mixes with SF, MS, and MK respectively, and percentage of steel fibers 1.5%).

3- According to the third variable (percentage of fibers), the results show that the cube compressive strength of RPC will be increased by not more than 6% when the percentage of fibers in the mix is increased from 1.0% to 1.5%.

4- The density of RPC is also found to be slightly affected by the three variables of the present investigation; which are the type of pozzolanic admixture (MK , MS, SF), type of fibers (steel or polypropylene) and percentage of fibers (1.0% , 1.5% , 2.0%). The highest density (2510 kg/m^3) was obtained for RPC mix containing SF and 1.5% steel fibers.

5- The absorption test results indicated that the lowest absorption (0.18% at 3 days age and 0.11% at 28 days age) was obtained for RPC mix containing SF with steel fibers of 1.0% volume fraction.

References

ASTM 311-02; 2002 "***Standard Test Method for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland Cement Concrete***", Annual Book of ASTM Standard American Society for Testing and Materials, Vol.04.02.

ASTM C 150-02a; 2002 "***Standard Specification for Portland Cement***", Annual Book of ASTM Standards, Vol. 04. 02.

ASTM C230-83; 1983 "***Standard Specification for Flow Table for use in Tests of Hydraulic Cement***", Annual book of ASTM standards, vol. 04.02.

B.S. 1881, Part 122; 1989 "***Method of Determination of Water Absorption***", Standard Institute.

B.S. 882; 1992 "***Specification for Aggregates From Natural Sources for Concrete*** ", British Standards Institute.

Collepardi S., Coppola L., Troli R., and Zaffaroni P.; 1999 "***Influence of the Super Plasticizer Type on the Compressive Strength of Reactive Powder Concrete for Precast Structures***", Published by : Congress International BIBM' 99 Veneziea, 25-28 Maggio.

Federal Highway Administration; 2006 "***Material Property Characterization of Ultra-High Performance Concrete***", U.S. Department of Transportation.

Graybeal B.A., Hartmann P.E.; "***Ultra-High Performance Concrete Material Properties***", Transportation Research Board Conference, November 200, pp 1-14.

Ohama,Y.,1997"Recent progress in Concrete-Polymer Composition". Advance in cement -based Materials, Elsevier Science Ltd., New York, pp. 4-31

Orgass L.M., and Klug Y.; 2004 "***Steel Fiber Reinforced Ultra-High Strength Concretes***", Dipl.–Ing., Institute for Structural Concrete and Building Materials, University of Leipzig, MFPA Leipzig GmbH, Lacer No. 9, 12 pp.

Schachinger I., Hilbig H., and Stengel T.; "***Effect of Curing Temperature at an Early Age on Long-Term Strength Development of UHP***C",2nd International Symposium on Ultra High Performance Concrete, Kassel, 05-07 March 2008, pp 205-212.

Washer G. , Fuchs P., Rezai A., Ghasemi H.,"***Ultra sonic Testing for Quality Control of Ultra-High Performance Concrete***", Turner-Fairbank Highway Research Center, Mclean, VA 22101, ASCE , Structures , 2006 , 8 pp.

Table (1) Percentage of oxide composition and main compounds (Bogues Equation) of the cement used throughout this work*

Limit of ASTM Specif. C150-02a/2002	Content (percent)	Abbreviation	Oxide Composition
-	62.54	CaO	Lime
-	22.25	SiO_2	Silica
-	3.50	Al_2O_3	Alumina
-	4.88	Fe_2O_3	Iron Oxide
≤ 6.0 %	2.09	MgO	Magnesia
≤ 2.3 %	2.02	SO_3	Sulfate
≤ 3.0 %	1.41	L.O.I.	Loss on Ignition
≤ 0.75 %	0.59	I.R.	Insoluble Residue
-	0.88	L.S.F.	Lime Saturation Factor
Main Compounds (Bogue's equations)			
-	-	C_3S	Tricalcium Silicate
-	-	C_2S	Dicalcium Silicate
5.0	1.47	C_3A	Tricalcium Aluminate
-	-	C_4AF	Tetracalcium Aluminoferrite

Table (2) Grading of the Separated Fine Sand Compared with the Requirements of B.S.882: 1992

Limits of B.S 882:1992 fine grading	Cumulative passing%	Sieve size (mm)
100	100	9.52
100	100	4.75
80-100	100	2.36
70-100	100	1.18
55-100	100	0.600
5-70	50	0.300
0-15	10	0.150

*Table (3) Characteristics of Fibers Used**

Modulus of Elasticity (GPa)	*Tensile strength (MPa)*	*Diameter of Fiber (mm)*	*Length of fiber(mm)*	*Specific Gravity(kg/m^3)*	*Type of fibers*
210	1800	0.18	13	7800	Straight Steel fibers
3500-3900 MPa	320-400	18 micron	12	230 m^2 /kg	Polypropylene Fibers

**Manufacturer properties*

Table (4) Chemical Properties of the Mineral Admixtures used

Oxide Contents% by Weight of SF	Oxide Contents% by Weight of MS	Oxide Contents% by Weight of MK	Oxide Composition
98.07%	95.95	51.34	SiO_2
0.01%	0.02	33.4	Al_2O_3
0.01%	0.01	2.3	Fe_2O_3
0.23%	1.12	3.00	CaO
0.01%	0.01	0.17	MgO
-	0.22	0.15	SO_3
-	-	-	Na_2O
0.08%	0.07	-	K_2O
-	2.5	7.8	L.O.I

Table (5) Chemical requirement of pozzolan ASTM C618

Pozzolan Class N	Oxide Composition
70	SiO_2+Al_2O_3+Fe_2O_3 min.percent
4	SO_3 (max. percent)
3	Moisture content max. percent
10	Loss on ignition max.

Table (6) Typical Properties of superplasticizers *used*

*Structuro 480**	*Structuro 335**	*Glenium 51**	**Superplasticizer Type**
-	-	Hardening accelerator	**Subsidiary effect**
Opaque liquid	Light yellow colored liquid	Light brown	**Appearance**
-	-	Approximately 20%	**Solids in aqueous solution**
1.01 @ 20C°	1.06 kg/ltr @ 20C°	1.1 g/cm^3 @ 20C°	**Density**
-	-	128 cps @ 20C°	**Viscosity**
< 0.1%	< 0.1%	0.00	**Chloride content**
-	-	6.6	**pH value**

****Manufacturer Properties***

Table (7) Strength - Activity Index for Test Mortars

S.A. I	**w/c to give flow 110±15**	**SF% by wt. of cement**	**MS% by wt. of cement**	**MK% by wt. of cement**	**Mix**
---	0.50	---	---	---	Reference
150	0.35	---	---	---	HRWRA
164	0.30	---	---	10	Metakaolin (MK)
168	0.32	---	---	15	Metakaolin (MK)
160	0.35	---	---	20	Metakaolin (MK)
155	0.31	---	10	---	Micro Silica (MS)
172	0.34	---	15	---	Micro Silica (MS)
152	0.37	---	20	---	Micro Silica (MS)
180	0.35	10	---	---	Silica Fume (SF)
165	0.39	15	---	---	Silica Fume (SF)
148	0.45	20	---	---	Silica Fume (SF)

Table (8): Water Reduction for RPC Mixes with Steel Fibers

Water Reduction %	Water Cementious Ratio to Obtain Flow of 150±10%	Dosage of HRWRA % by Weight of Cement	Mix
-----	0.4	-----	Ref.
57.5	0.17	6	HRWRA
56.5	0.174	9	S1
55.5	0.178	9	S2
55	0.179	9	S3
56.5	0.174	9	S4
56	0.176	9	S5
55	0.18	9	S6
53.5	0.186	9	S7
52.7	0.189	9	S8
52.5	0.19	9	S9

Table (9): Water Reduction for RPC Mixes with Polypropylene Fibers

Water Reducti on %	Water Cementious ratio to Obtain Flow of 150±10%	Dosage of HRWRA % by Weight of Cement	Mix
-----	0.4	-----	Ref.
57.5	0.17	6	HRWRA
56	0.175	9.5	P1
55	0.18	9.5	P2
54	0.183	9.5	P3
56	0.175	9.5	P4
55.2	0.178	9.5	P5
54	0.183	9.5	P6
53	0.187	9.5	P7
52.7	0.189	9.5	P8
52.5	0.19	9.5	P9

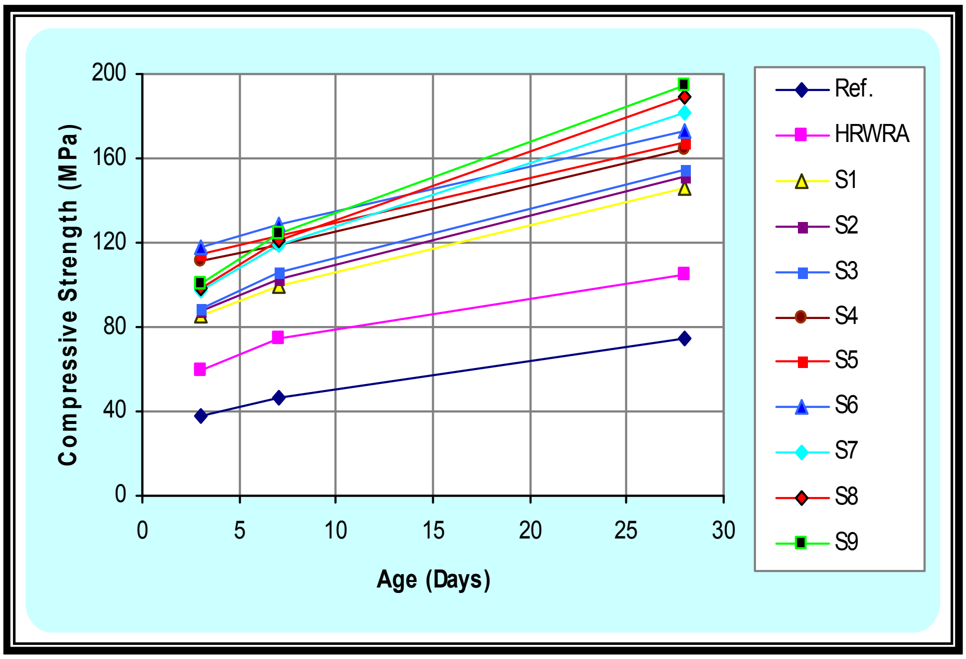


Figure (1): Compressive Strength Development of RPC with Steel Fibers

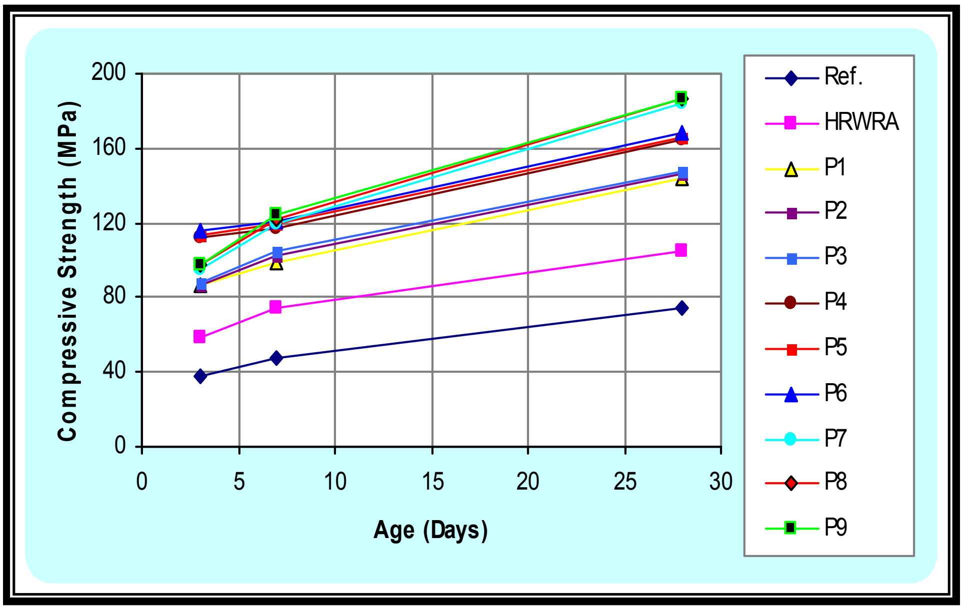
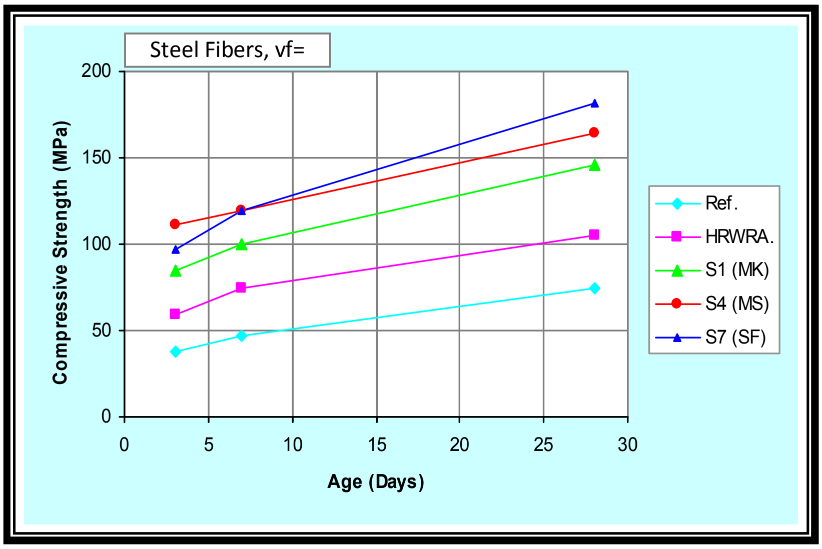
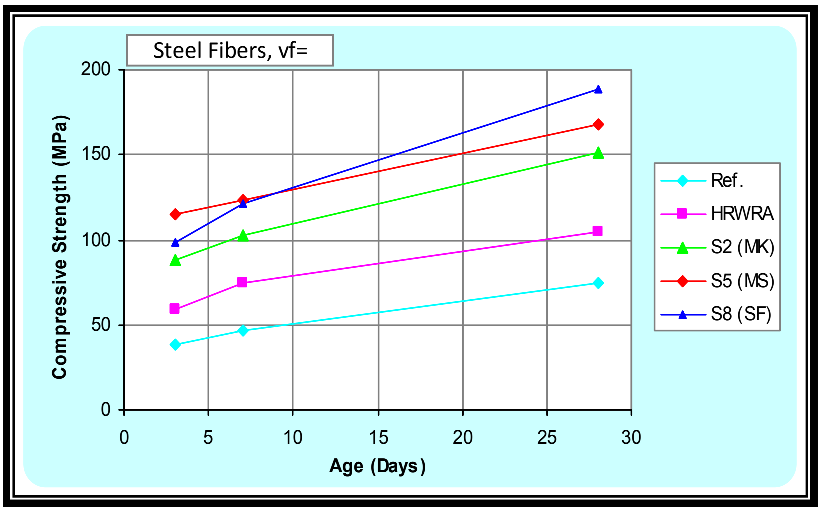


Figure (2): Compressive Strength Development of RPC with Polypropylene Fibers





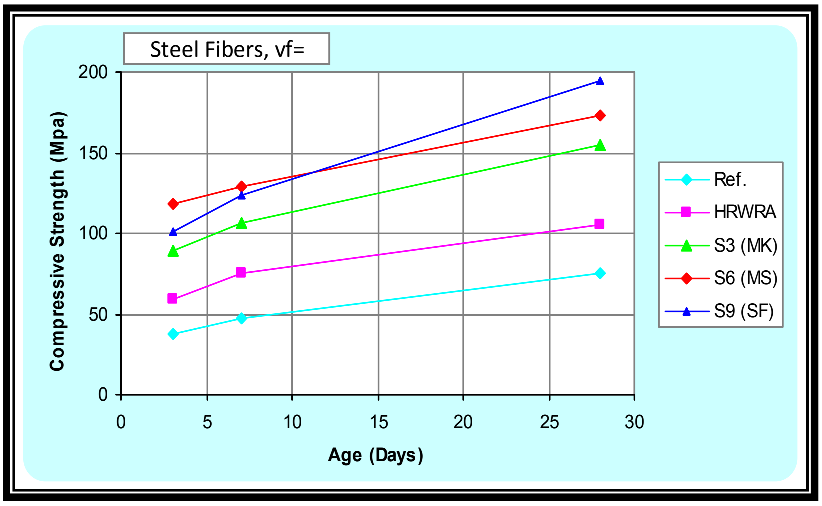


Figure (3): Effect of Pozzolanic Admixture Type on Compressive Strength of RPC Mixes with Steel Fibers

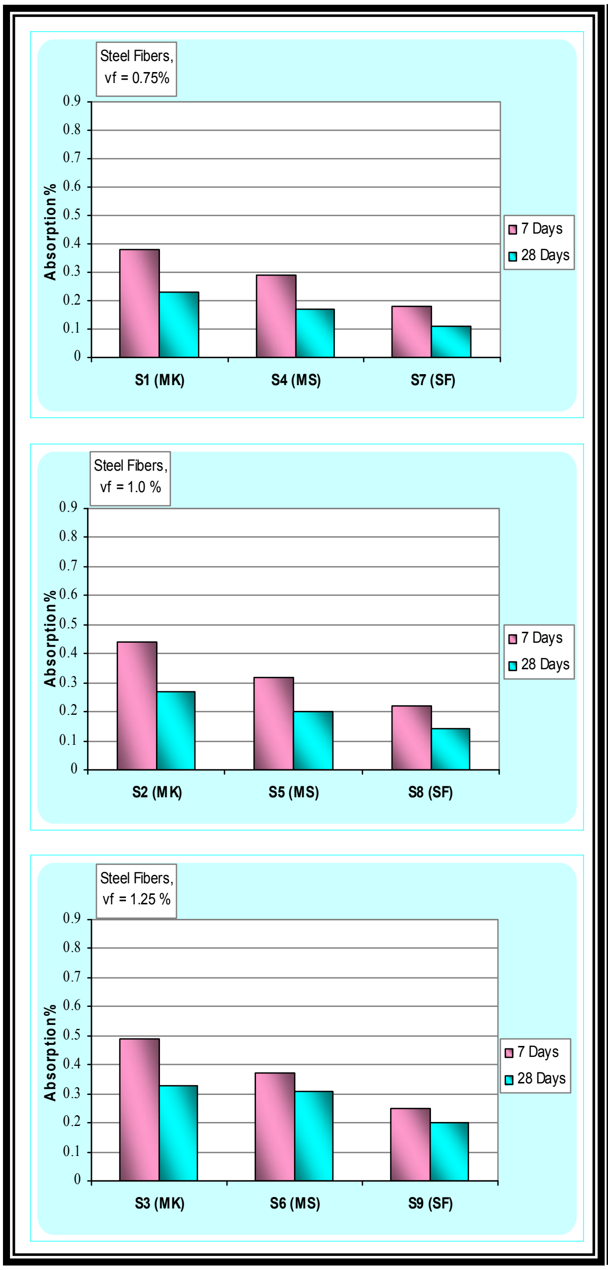


Figure (4): Effect of Pozzolanic Admixture on Absorption of RPC Mixes with Steel Fibers.

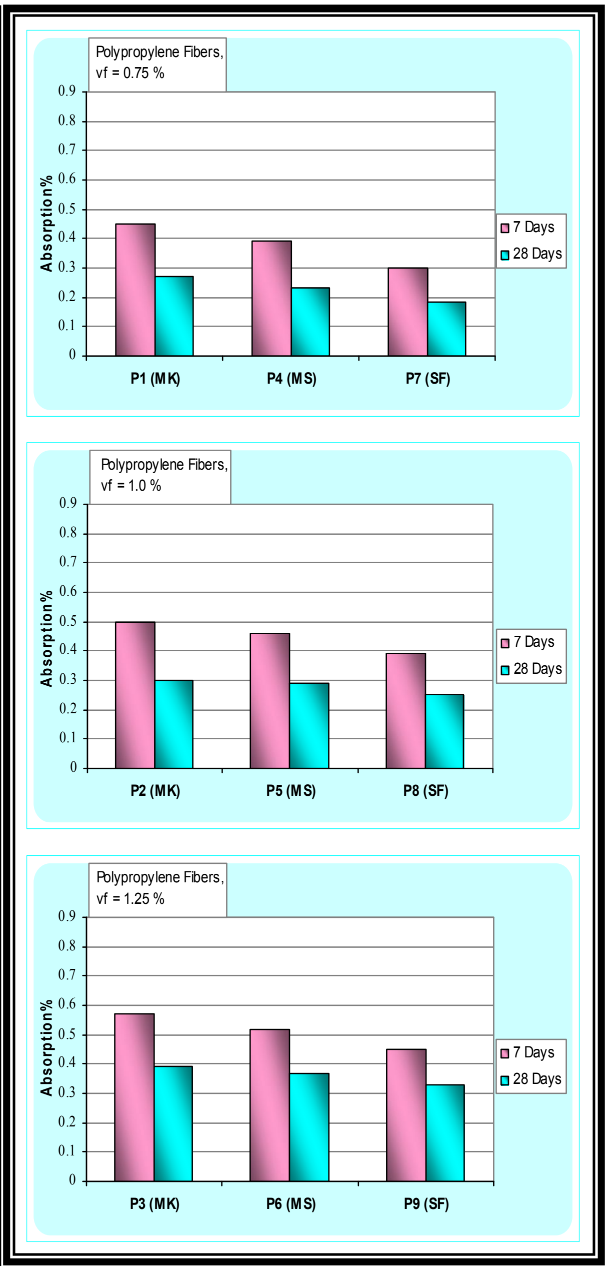


Figure (5): Effect of Pozzolanic Admixture on Absorption of RPC Mixes with Polypropylene Fibers.