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Influence evaluation of key mix design parameters of reactive powder concrete on compressive strength

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ABSTRACT: Reactive powder concrete (RPC) is a new type of high performance concrete (HPC) which due to using fine powder and pozzolanic materials as well as high amount of materials which are hydraulically active, is known as this name. RPC characteristics have a high sensitivity to type and characteristics of materials used in RPC; therefore, in order to achieve desired physical and mechanical properties, it is necessary to carefully consider selection of materials and mix proportions. The purpose of this research was to investigate the effect of water to ementitious materials ratio (W/CM), amount of cementitious materials (CM), silica fume to cementitious materials ratio (SF/CM), cement type and grading of silica sand on compressive strength of RPC. To do so, 21 RPC mixes were designed and made. In each step of this research, one of the effective parameters were studied and accoding to obtained results, the next steps were performed. RPC specimens were cured in 90 oC water for 7 days. Results showed that by using cement type V, cementitious materials of 1100 kg/m3, water to cementitious materials ratio equal to 0.2, silica fume to cementitious materials ratio equal to 0.2 and use of silica sand with the the finest grading, the highest compressive strength can be achieved.

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1. INTRODUCTION

Reactive powder concrete (RPC) is a new cementitious materials and it is classified as ultra-high performance concrete (UHPC). It was first made in early 1990s by Richard and Cheyrezy [1]. This type of concrete was first used in Sherbrooke bridge construction in Canada. RPC [1, 2]. concrete is produced by using high amount of cement materials, very fine powder material such as silica and quartz sands with maximum size of 0.6 mm and puzzolanic materials such as silica fume, low water- to-cement ratio (W/CM) and by using significant amount of superplasticizer. RPC has advantages over other common concretes as below [1-6].

1. By removing coarse aggregate and using very fine aggregates in range of 0.1 to 0.6 mm, homogeneity of mix is increased and also the transition zone between aggregate and cement paste is improved.

2. By reducing W/CM and reaching it to 0.2 and less and by using superplasticizer, mechanical properties such as compressive and bending strength are improved.

3. Adding puzzolanic materials especially silica fume consumes weak $Ca(OH)_2$ by creating pozzolanic reactions with $Ca(OH)_2$ causes powerful extra silicate calcium hydrate (C-S-H) chains formation; also, silica fume leads to fill voids between C-S-Hs. The two abovementioned functions cause increase in mechanical properties and concrete durability.

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2. Use of steel fibers in cement paste causes improvement in mechanical properties especially ductility, rupture modulus tensile strength of RPC.

5. Imposing load on concrete before setting of concrete and also using thermal curing or autoclave causes improvement in microstructure of concrete.

6. An increase of matrix compactness by optimizing the grain-size distribution of all the powers used.

The objective of this study is to evaluate effect of water to cementitious materials ratio (W/CM), amount of cementitious materials (cement+ silica fume) (CM), silica fume to CM ratio (SF/CM), cement type and silica sand gradation on compressive strength of RPC. To do so, current study is divided into several steps. In each step, one of the abovementioned parameters is investigated and with respect to results new mix designs are designed and made for the next step.

2. EXPERIMENTAL STUDY

2.1. Materials

The following materials were used in the mixtures designed for the purposes of this study.

- Cement: in order to investigate the effect of cement type on compressive strength, Portland cements type I-525, I-425, II and V produced by Shahrekord cement factory were used to make concrete mixes. Specific gravity of the cements is 3.15.

- Silica Fume: silica fume produced by Azna ferrosilicon factory is used. The silica fume has Amorphous silica (SiO_2) more than 90%, which is very useful for pozzolanic reactions. Used silica fume has particles size smaller than 1 micron, specific weight of 2.2 and specific surface of 15-20 m^2/gr.

- Superpasticizer: Structuro 335 superplasticiser based on carboxylic ether polymer with a specific gravity of 1·08, obtained from FOSROC Company

- Silica Sand: To investigate silica sand gradation on RPC compressive strength, silica sand from Chiruk company with 4 gradation types is used in this research.

2.2. Mix Designs

In the current research, to evaluate effect of key mix design parameters of RPC on compressive strength, 21 RPC concrete mixes including 3 W/CM (0.17, 0.2 and 0.23), 5 amounts of CM (900, 1000, 1200, 1300, 1400 and 1500 kg/m^3), 4 SF/CM (10%, 15%, 20%, 25%), 4 cement types (I-425, 1-525, II and V) and 4 silica sand, were designed and made. Mixture proportioning of all mixes are presented in Table 1. Workability is considered as an important parameter of RPC concrete. In RPC concrete, due to high speed of losing workability, an appropriate slump flow should be used when casting. In this research, to compare mix designs, the amount of superplasticizer of all mix designs was set such that spread diameter in small slump flow test becomes equal to 200±10 mm.

2.3. Specimens Preparation

Using mixer with high circulation speed in RPC concrete causes improvement in quality of concrete. In current research, to make concrete specimens, a special mixer with maximum circulation speed of 360 rpm is used. To make concrete mixes, mix method is considered as following: 1) All superplasticizers are added to water and mixed together; 3). All dry materials (cement, silica fume and silica sand) are poured into mixer respectively and mixed with speed of 120 rpm for 2 minutes; 3) All of water and superplasticizer are added to mixer and mixed with speed of 240 rpm for 2 minutes; 4) Mixer is turned off for 10 seconds and then, operation is continued with speed of 360 rpm for 4 minutes; 5) Then, slump flow test of made concrete is performed and in case of reaching to desired slump flow, casting is performed, otherwise, the tested concrete is re-made by changing amount of superplasticizer to supply the slump flow. Specimens made from each of concrete mix were cured in 90 ^{0}C water for 7 days.

3. RESULTS

As mentioned in previous section, in each step of the current study, one of the parameters was investigated and based on obtained results, next step was performed. Mix1 to Mix12, Mix.13 to Mix.15, Mix.16 to Mix.18 and Mix.19 to Mix.21 were made to study effect of W/CM and CM, cement type, SF/CM and silica sand gradation on compressive strength of RPC, respectively. Based on the obtained results, the following conclusions were made:

1. Obtained compressive strengths of Mix.1 to Mix.12 show that the highest compressive strength is related to a concrete mix in which W/CM=0.2 and CM=1100 kg/m^3 (Mix.6). Also, use of W/CM lower than 0.2 causes decrease in concrete compressive strength, since in this state there is not enough water available for hydration of cement particles; also, pozzolanic reactions are not completely done due to lack of water. Also, with increase in W/CM from 0.2 to 0.23, RPC concrete compressive strength is decreased, which is due to the reason that basically the amount of water in concrete is needed to the extent that it can hydrate cement particles and overuse of this amount is harmful for concrete and has negative impact on concrete properties including compressive strength.

Table 1. Mixture proportioning of RPC mixes

Mix. No.	W/CM	Amount of used Materials (kg/m^3)					f'_c
		C	SF	W	S	SP	
Mix.1	0.17	960	240	217.5	800	72.0	108
Mix.2	0.17	1040	260	195	682	65.0	110.5
Mix.3	0.17	1120	280	215.6	568	56.0	120.0
Mix.4	0.17	1200	300	237.0	460	45.0	129.0
Mix.5	0.20	800	200	178.5	1055	53.75	118.0
Mix.6	0.20	880	220	206.0	940	35.0	132.0
Mix.7	0.20	960	240	230.4	820	24.0	127.0
Mix.8	0.20	1040	260	249.6	673	26.0	124.0
Mix.9	0.23	720	180	190.0	1138	42.5	103.0
Mix.10	0.23	800	200	219.0	1025	27.5	105.5
Mix.11	0.23	880	220	245.0	881	20.0	116.0
Mix.12	0.23	960	240	269.0	742	17.5	113.0
Mix.13	0.20	880	220	206.0	940	43.75	111
Mix14	0.20	880	220	206.0	940	38.75	119
Mix.15	0.20	880	220	206.0	940	36.0	104
Mix.16	0.2	990	110	204	940	40.0	111
Mix.17	0.2	935	165	205	940	37.5	120
Mix.18	0.2	825	275	204	940	40.0	130.5
Mix.19	0.20	880	220	207.2	940	32.0	125.0
Mix.20	0.20	880	220	207.9	940	30.3	120.5
Mix.21	0.20	880	220	208.5	940	28.75	114.0

2. Mix.6, Mix.13, Mix.14 and Mix.15 have the same mix design property (W/CM=0.2, SF/CM=0.2 and CM=1100 kg/m^3); but cement type of the mixes are V, I-525, I-425 and II. The results indicate that the highest compressive strength and the lowest amount of superplasticizer dosage is related to a mix design in which Portland cement type V is used.

3. Regarding that silica fume is a proper pozzolanic material to increase RPC concrete compressive strength, in performed curing conditions in this research, that is, 7 days curing in 90 ^{0}C water, the highest compressive strength is related to a mix design in which silica fume is replaced for 20 percent of cementitious materials (SF/CM=20%), since 20 percent of silica fume in cement hydration can has the highest impact on decrease in weak Calcium hydroxide ($Ca(OH)_2$) and increase in formation of C-S-H crystals.

4. Mix.6, Mix.19, Mix.20 and Mix.21 have the same mix design property (W/CM=0.2, SF/CM=0.2 and CM=1100 kg/

m^3); but silica sand gradation of the mixes are different. The results presented in Table 1 show that silica sand gradation have significant effect on RPC compressive strength. The highest RPC compressive strength is related to a mix design in which the finest gradation is used. In concrete with very high strength, the finer aggregates are, the stronger transition zone between cement paste and aggregate become and therefore, compressive strength is increased. Also, when aggregates become finer, aggregates specific surface are increased and hence, the amount of super plasticizer use is increased to supply desired workability.

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