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Influence of Partial Replacement of Micro-Silica by Fly-Ash on Strength Properties of Reactive Powder Concrete

Jidnyasa D. Kulkarni, Jyoti P. Bhusari

Abstract*: Reactive powder concrete (RPC) is the ultra-high strength concrete made by cementitious materials like silica fumes, cement etc. The coarse aggregates are completely replaced by quartz sand. Steel fibers which are optional are added to enhance the ductility. Market survey has shown that micro-silica is not so easily available and relatively costly. Therefore an attempt is made to experimentally investigate the reduction of micro-silica content by replacing it with fly-ash and mechanical properties of modified RPC are investigated. Experimental investigations show that compressive strength decreases gradually with addition of the fly ash. With 10 per cent replacement of micro silica, the flexural and tensile strength showed 40 and 46 per cent increase in the respective strength, though the decrease in the compressive strength was observed to be about 20 per cent. For further percentage of replacement, there was substantial drop in compressive, flexural as well as tensile strength. The experimental results thereby indicates that utilisation of fly-ash as a partial replacement to micro silica up to 10 per cent in RPC is feasible and shows quite acceptable mechanical performance with the advantage of utilisation of fly-ash in replacement of micro-silica.

Keywords*: Reactive powder concrete, RPC, Micro-silica, partial replacement, mechanical properties, fly-ash.

I. INTRODUCTION

Reactive powder concrete (RPC) is the generic name for a class of cementious composite materials developed by the technical division of Bouygues, in the early 1990s. It is characterized by extremely good physical properties, particularly strength and ductility [1]-[2].

Pierre Richard et.al. carried out study on composition of RPC very first time of its invention. The development of an ultra-high strength ductile concrete designated RPC was made possible by the application of a certain number of basic principles relating to the composition, mixing and post-set heat curing of the concrete. Principal conclusions from the study carried out were elimination of coarse aggregates along with optimization of the granular mixture gave a homogenous and dense cementitious matrix that exhibits high mechanical performances. Its compressive strength ranges from 200 MPa to 800 MPa. RPC not only has high strength but also has high ductility if steel fibers are incorporated in it [1].

Applications of RPC has been found in many structures such as Sherbrooke foot Bridge in Canada, Light rail transit station in Iowa, RPC foot slabs in Qinghai- Tibet railway. Pipe products for the conveyance of water, sewage and other liquids under pressure or gravity flow have been developed utilizing the enhanced properties of RPC [3]-[4]. D. Cizmar et.al (2006) checked the possibility of use of RPC (170 MPa) in construction of an arch bridge of span 432 m over Bakar strait (Croatia) [5]. YAN Guangjie (2009) designed the RPC barriers with reduced section size, one-third gravity as that of reinforced concrete barriers for highway median strip [6].

Further work in this area has been carried out by studying RPC under different curing conditions and changing proportions of different ingredients thereby changing the basic proportions suggested by Pierre Richard. S. Collepardi studied a modified RPC compared with original RPC basic composition mix, where a graded natural aggregate (max size - 8 mm) was used to replace the fine sand and/or part of the cementitious binder. Contrast observations were made that if the quality of the cement matrix, in terms of its w/c ratio, is not changed, the addition of the graded aggregate does not reduce the compressive strength. When considered for a given workability level, then replacement of the entire fine sand and part of the cementitious binder (cement and micro-silica) with the graded aggregate demanded higher w/c ratio, leading to decrease in the compressive strength [7]. Marios N. Soutsos replaced micro-silica by pulverised fly ash, GGBFS there adopting ternary blends. Flexural strengths between 30 and 60 MPa and fracture energies above 10000 Jm-2 have been reported which shows enhanced tensile strength and ductility [8]-[9].

Micro-silica is the key ingredient of RPC responsible for its high strength [10]. However, micro-silica is quite expensive and not so easily available at all places. The overall cost of the material in RPC becomes quite high. This may be one of the reasons of RPC not yet being popular in the construction industry as industry is largely interested in cost-effective supplementary cementing materials. Fly ash is also a pozzolanic material which is much more economical than micro-silica. Hence, the material cost would definitely decrease when fly ash is incorporated in any high performance concrete without much sacrificing the mechanical properties.

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* Correspondence Author
Jidnyasa D. Kulkarni, Department of Civil Engineering, Sinhgad College of Engineering, Pune, India. Email: kulkarnijidnyasa@gmail.com
Jyoti P. Bhusari, Department of Civil Engineering, Sinhgad College of Engineering, Pune, India. Email: jpbhusari.scoe@sinhagad.edu

Therefore an attempt to experimentally investigate the feasibility of reduction of micro-silica content in RPC by replacing it with fly-ash is made in this experimental programme and mechanical properties of modified RPC are investigated. Both micro-silica and fly-ash are pozzolanic materials. Thereby it is expected that the replacement of micro- silica by fly-ash should not change the mechanical properties of RPC drastically. After experimental trials if this partial replacement of micro-silica by fly-ash proves to be feasible, it will lead to reduction in the overall project cost and also the problem of material availability will ease out.

II. MATERIAL SPECIFICATIONS

The RPC is prepared by mixing the constituent materials such as Portland cement, quartz sand, Micro-silica, high-range water-reducer, water and steel fiber. Some important specifications of the material used are:

A) Cement

Ordinary Portland Cement (OPC) of 53 grade confirming to the specification of IS 12269 (1987) is used [11]. The specific gravity of cement is 3.15 with the initial setting time of 55 minutes and the final setting time of 600 minutes.

B) Quartz sand

Quartz sand with maximum particle size limited to 600 µm and greater than 150 µm. This is in order to prevent interface with the largest cement particles which range from 80- 100 µm. The quartz sand has SiO2 of 99.9 percent with specific gravity of 2.6-2.7 and pH neutral.

C) Micro silica

Micro-Silica is a very reactive pozzolan. Its role in RPC facilitates three main functions as follows, filling the voids between the next larger class particles i.e. cement, enhancement of rheological characteristics and production of secondary hydrates by pozzolanic reaction.

Micro-silica of Silica Grade 920-D conforming IS 15388:2003 [12] having minimum 90% SiO_2 and with coarse particles greater than 45 micron limited to maximum 1 % is used. The specific surface is minimum 18 m^2/g, with bulk density of 500-700 $/m^3$. The particle size is less than 1µm in diameter, the average being about 0.15 µm.

D) Steel fibers

The straight copper- coated steel fibers of density 7850 Kg/m^3 procured from "Bekaert Industries Pvt. Ltd." has been used. The fibers have a nominal diameter of 0.2 mm and a nominal length of 13 mm with aspect ratio of 65. The tensile strength of the fibres is 2600 MPa and Modulus of Elasticity is 205 GPa**.**

E) Admixture

The very low water cement ratios are used in RPC and it necessitates the fluidizing power of high-quality third generation super-plasticizing agents. Master Glenium SKY 8233 is an admixture of a new generation based on modified polycarboxylic ether conforming IS 9103: 1999 [13] and having following properties; Relative Density: 1.08 ± 0.02 at 25°C, pH >6, Chloride ion content < 0.2%. It is compatible with all types of cements.

F) Fly ash

Fly-ash is the pozzolanic material generated as a by-product from thermal power plant operations. Class F fly ash is used, properties of which confirms the specifications given in IS: 3812 part- 1 2003 [10]. The salient properties are given in table I.

Table- I: Properties of Fly-ash

Properties of class-F Fly ash	Composition
SiO_2 content	60.56%
Specific gravity	2.20
Fineness	384 m^2/kg
Loss of Ignition	0.55

III. MIX PROPORTIONS

Mix design for RPC does not have any standardized procedure, as RPC is a powder form cementious mix which excludes the coarse aggregates and maintains a low water/cement ratio. Bhusari and Gumaste [14] worked on 112 trial mixes by changing the proportions on basic ingredients. It was seen that compressive strength and flexure strength is directly proportional to increase in micro-silica/cement ratio and the optimum of micro-silica/cement ratio was found as 0.25. From the experimental work conducted, the proportion 1: 1.5: 0.25 (c:qs:sf) with 0.3 water cement ratio gave the optimum result for various mechanical tests carried out on RPC though micro-silica/cement ratio of 0.2 also gave satisfactory results. Distinctive characteristics of reactive powder concrete including durability aspects were studied. An ANN model was developed for the mix design [15]-[16]. To understand the effect of replacement of micro-silica by fly ash on the strength of RPC, the basic proportion of 1: 1.5: 0.20 (c:qs:sf) with 0.28 water cement ratio is considered and mechanical properties in terms of compression, flexure and split tension are studied by conducing the relevant tests. Prior to this, compression test is performed to find optimum cement content and the test is conducted on specimens prepared from mixes given in Table II, consisting of three different cement proportions as follows,

1) C-850: cement content -850 kg $/m^3$
2) C-955: cement content- 955 kg/m^3
3) C-1100: cement content-1100 kg/m^3

Table- II: Mix Proportions for deciding cement content

	Nomenclature	C-850	C-955	C-1100
Proportions in kg/m^3	*Cement*	850	955	1100
	Steel fiber	170	191	220
	Quartz-sand	1275	1433	1650
	Admixture	16.5	18.15	20.9
	Micro-silica	195.5	220	253
	Water	238	267.5	308

Optimum cement content is found to be 955 kg/m^3 as per the results given in section V- (1).

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Variation of proportion of fly ash with respect to micro-silica is now done as replacement and accordingly four different mixes are formed which are designated as per the percentage replacement of silica by fly ash.

- Mix1: RPC_{10} -10% micro-silica is replaced by fly-ash.
- Mix2: RPC_{15} -15% micro-silica is replaced by fly-ash.
- Mix3: RPC_{20} -20% micro-silica is replaced by fly-ash.

- Mix4: RPC_B - 0% replacement (No fly ash) which is considered as the control specimens in each test.

Detailed proportions of above mentioned four samples are given in Table III,

Table- III: Proportions with partial replacement of micro-silica by fly-ash

	Nomenclature	RPC_0	RPC_{10}	RPC_{15}	RPC_{20}
Proportions in kg/m^3	*Micro-silica*	**195.5**	**175.95**	**166.17**	**156.40**
	Fly-ash	-	**19.5**	**29.3**	**39.1**
	Cement	955	955	955	955
	Quartz sand	1433	1433	1433	1433
	Steel fiber	191	191	191	191
	Admixture	18.15	18.15	18.15	18.15
	Water	267.5	267.5	267.5	267.5

IV. EXPERIMENTAL PROGRAM

Uniaxial compression test, flexural strength test, and split tensile test is conducted on RPC specimens as per the specifications of IS 516: 1959 [17] and IS 5816: 1999 [18].

A) Uniaxial compression test

In this test cube specimen of size 100 mm x 100 mm x 100 mm is subjected to compression on the compression testing machine at a rate of 140 kg per sq.cm per min. until the specimen breaks and corresponding failure load is noted. Specimens before the test and after the test are as shown in Fig. 1.

(a)Specimen before the test

(b) Specimen after the test
Fig. 1. Compression test on RPC

B) Flexural strength test

In this test beam specimens of size 100 mm X 100 mm X 500 mm are casted and subjected to four point loading in flexural testing machine. The maximum load applied to the specimen is noted. Specimen after the failure is shown in the Fig.2.

Fig. 2. Specimen after the failure in flexure test

C) Split tensile test

Here cylindrical mould of 150 mm diameter and 300 mm height is used for preparing the specimens. The test is carried out on the universal testing machine. Compressive load is applied to the cylinder horizontally and maximum load taken by cylinder till the cylinder splits is noted. The specimen after the failure is shown in the Fig.3,

Fig. 3. Specimen before and after the failure in tension test

V. RESULT AND DISCUSSION

The results of compression test, flexural test and split tensile test are given in this section. Each data represented here is the average test results of minimum three specimens.

1) Results of compression test to find optimum cement content

The results of compression test on RPC cubes with different cement content are given in Table IV. According to results obtained from test performed, it is observed that as cement content increases, the compressive strength also increases but after certain increase in cement content, strength decreases again.

This can be attributed to the fact that more than necessary addition of the cement increases the amount of fine particles and also increase temperature during hydration process of the concrete, which leads to the formation of micro-cracks leading to the increase in the pores which indicates the increment of capillary porosity and reduction in compressive strength.

As shown in the graph, at cement content 955 kg/m^3, RPC gives better strength than strength at 850 kg/m^3 and 1100 kg/m^3. Thereby for the further experimentation the cement is taken as 955 kg/m^3 for all mix proportions which are given in Table III,

Table- IV: Compressive Strength for optimum cement content

Mix	Block	28-Day Compressive Strength, MPa	Average Strength MPa	Coefficient of variance
C-850	A1	85.71	**82.14**	**3.13**
	B1	79.59		
	C1	81.63		
	D1	81.63		
C-955	A2	117	**112.46**	**4.92**
	B2	104.08		
	C2	112.24		
	D2	108.16		
C-1100	A3	65.30	**86.73**	**3.53**
	B3	71.43		
	C3	71.43		
	D3	67.34		

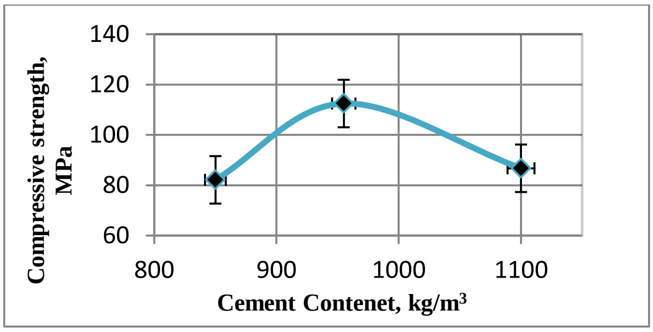

Fig. 4. Determination of cement content

2) Compressive strength test

The results of the compression test on RPC specimens after the replacement of micro-silica by fly-ash are given in Table V.

Table- V: Compressive strength of specimens: Partial replacement of Micro-Silica with fly-ash

Mix	Block	28-Day Compressive Strength MPa	Average Strength MPa	% Decrease in Strength	Coefficient of variance
RPC $_B$	A4	117	112.46	-	**4.92**
	B4	104.08			
	C4	112.24			
	D4	108.16			
RPC$_{10}$	A5	87.75	90.47	**-19.60%**	**3.75**
	B5	89.79			
	C5	93.68			
	D5	85.71			
RPC$_{15}$	A6	73.46	79.96	**-28.90%**	**7.90**
	B6	79.59			
	C6	77.55			
	D6	65.30			
RPC$_{20}$	A7	73.46	73.46	**-34.70%**	**9.48**
	B7	69.38			
	C7	77.55			
	D7	61.22			

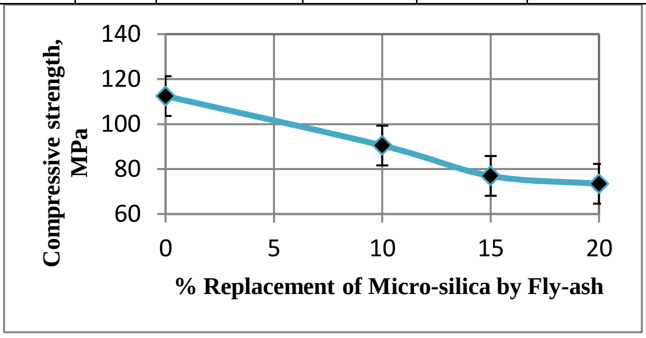

Fig. 5. Compressive strength

It is observed that with the increase in the percentage of replacement of micro-silica by fly ash, there is a decrease in the compressive strength. For 10 percent replacement, the decrease in the strength is only about 20 percent. Further increase in the fly ash by 15 and 20 percent decreases the strength by about 30 and 35 per cent respectively.

The increase in compressive strength of RPC is based on the packing density principle when compared with normal concrete, wherein the micro-silica packs itself within the pores of cement particles. Now the average particle size of fly-ash is almost as same as that of cement. Hence when micro-silica is replaced by fly ash, strength has decreased, since fly ash is not so efficient in micro filling, Also the delayed pozzolanic activity of fly-ash at early stages may be the reason for lower strengths of the specimens.

3) Flexural strength test

The results of the flexural test on RPC beams specimens after the replacement of micro-silica by fly-ash are given in Table VI,

Table-VI: Test results of flexural test

Mix	Beam	28-Day Flexural Strength MPa	Average Strength MPa	% Increase/ Decrease in Strength	Coefficient of variance
RPC $_B$	A1	13.76	13.57	-	**1.33**
	B1	13.55			
	C1	13.40			
RPC$_{10}$	A2	18.89	18.86	**+38.9%**	**2.42**
	B2	18.39			
	C2	19.30			
RPC$_{15}$	A3	8.55	8.82	**-35.00%**	**2.03**
	B3	8.89			
	C3	8.62			
RPC$_{20}$	A4	7.76	8.14	**-40.00%**	**4.55**
	B4	8.16			
	C4	8.50			

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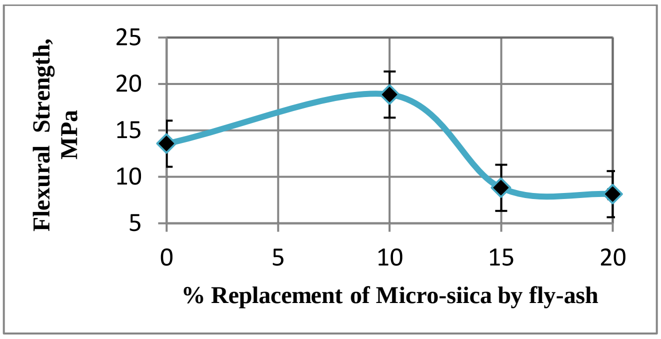

Fig. 6. Flexural strength

The results show that that 10 per cent replacement of micro-silica by fly ash gives the maximum flexural strength of about 19 MPa which is about 40 per cent greater than the controlled specimen. Further increase of fly-ash by 15 and 20 per cent reduces the flexural strength by 35 and 40 per cent respectively.

4) Split tensile test

The results of the split tensile test on RPC cylinder specimens after the replacement of micro-silica by fly-ash are given in Table VII,

Table-VII: Test result of split tensile test.

Mix	Cylinder	28-Day Tensile Strength MPa	Average Strength MPa	% Increase /Decrease in strength	Coefficient of variance
RPC_B	A1	6.55	7.1	-	**6.72**
	B1	7.40			
	C1	7.35			
RPC_{10}	A2	10.13	10.39	**+46.30%**	**3.31**
	B2	10.26			
	C2	10.78			
RPC_{15}	A3	6.702	6.67	**-6.05%**	**3.23**
	B3	6.868			
	C3	6.44			
RPC_{20}	A4	6.106	6.31	**-11.13%**	**3.38**
	B4	6.292			
	C4	6.532			

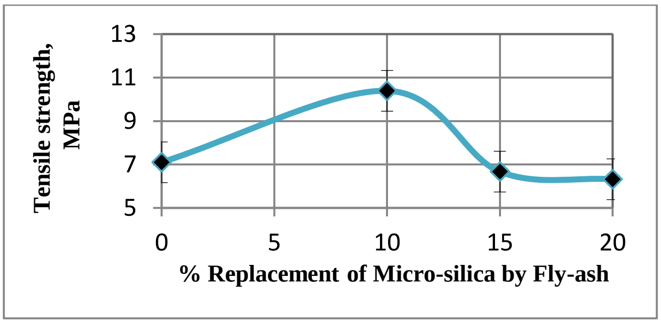

Fig. 7. Tensile strength

The results show that that 10 per cent replacement of micro-silica by fly ash gives the maximum tensile strength of about 10.5 MPa which is about 46 per cent greater than the controlled specimen. Further increase of fly-ash by 15 and 20 per cent reduces the strength by 6 and 11 per cent.

VI. CONCLUSION

From the experimental study conducted and the test results obtained, following conclusions can be made.

- The optimum content of cement for basic RPC composition is found to be 955 kg/m^3.
- Compressive strength is observed to be gradually decreased with addition of the fly ash. But for 10 percent replacement the decrease in the compressive strength was only 20 percent. For the same proportion the flexural and tensile strength showed considerable increase in the respective strength which was 40 and 46 percent respectively.
- For the mixes with 15 and 20 percent replacement, decrease in the strength is observed for all the three tests.
- Analysing as whole, replacement of micro-silica by fly-ash by up to 10 per cent in reactive powder concrete can be practically possible to achieve overall good mechanical properties.

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AUTHORS PROFILE

Ms. Jidnyasa D. Kulkarni, is presently working as 'Specification Engineer' at Constrotech, Pune. She obtained her bachelor's degree in Civil engineering from Sinhagad College of engineering, Vadgaon (bk), Pune. Her area of interest is research in the field of construction material and construction management.

Prof. Jyoti P. Bhusari is presently serving as a professor at Sinhgad College of Engineering, Pune, India and has been teaching UG and PG students since last 23 years. She obtained her bachelor's degree and post graduation in Structural Engineering from M. S. University, Vadodara, and completed her doctoral research in Civil Engineering from Shivaji University, Kolhapur. Her research work is mainly in the domain of characterization of special concretes and finite element analysis. She has several research publications to her credit published in reputed journals. She is member of Indian Society for Technical Education, New Delhi, Fellow Member of Indian Institute of Bridge Engineers (IIBE).