International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in ISSN: 2321-7758

Vol.4., Issue.5., 2016
(Sept.-Oct.)

RESEARCH ARTICLE

ISSN: 2321-7758

AN EXPERIMENTAL STUDY ON STRENGTH & DURABILITY OF REACTIVE POWDER CONCRETE

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ABSTRACT

Reactive Powder Concrete (RPC) is composed of very fine powders (cement, sand, and silica fume), steel fibres (optional) and superplasticizer. A very dense matrix is achieved, and this compactness gives RPC ultra-high strength and durability properties. In the present study, performance of reactive powder concrete without quartz powder and containing silicafume as a replacement for cement at the percentage of 0%, 5%, 10% , 15% and 20% by each is investigated. To compare the results of cement replaced mixture, specimen without cement replacement (RPC) are also casted. Performance of the various mixes is tested by the Compressive strength, Flexure strength and Tensile strength. The results show improvement in compressive strength, flexural strength and Tensile strength in cement replaced mixes.

Keywords : Reactive Powder concrete, steel fibers , silicafume

1. INTRODUCTION

Concrete is a versatile and critical material for the construction of infrastructure facilities throughout the world composed mainly of water, aggregate, and cement. Often, additives and reinforcements are included in the mixture to achieve the desired physical properties of the finished material. This is the most widely used material in construction field. Adding or replacing these constituent materials of concrete new type of concretes can be generated.. A new developing materials known as Reactive powder concrete (RPC) is available that differs significantly from traditional concrete. RPC has no large aggregates and contains small steel fibers that provide additional strength and in some cases can replace traditional steel reinforcement. Reactive powders concrete (RPC) will allow the concrete industry to optimize material use, generates economical benefits and built structures that are strong and durable.

A comparison of the physical, mechanical and durability properties of RPC and high performance concrete (HPC) shows that RPC possesses better (Both compressive and flexural strength) results compared to HPC. HPC leads the way to achievement of the maximum compressive strength of the order say 120-150 Mpa or so. However, at such a level of strength, the coarse aggregate becomes the weakest link in concrete. In order to increase the compressive strength of concrete even further, the only way is to remove coarse aggregate. This philosophy has been employed in what today known as Reactive powder concrete.

1.1.CHARACTERISTICS OF REACTIVE POWDER CONCRETE

RPC is considerably more expensive to produce than regular concrete, its more isotropic nature and greater ductility make it competitive with steel, over which it has a significant cost advantage, for many structural applications. RPC beams can be designed with an equal moment capacity to steel beams at comparable mass and cross-sectional dimensions. The following are the some attempts to prepare RPC

- Enhancement of homogeneity by the elimination of coarse aggregates.
- Enhancement of the compacted density by optimizing the granular mixture and optionally applying pressure before and during setting.
- Enhancement of the microstructure by heat treatment after hardening.
- Improved ductility through the incorporation of steel fibers.

1.2. OBJECTIVES OF THE STUDY

- The principal objective of this study is to prepare Reactive powder concrete (RPC 120) by adding silica fume in different volume proportions (0%, 5%, 10%,15%,20%) for partial replacement of cement.
- To investigate the mechanical properties such as compressive strength, tensile strength and flexural strength of reactive powder concrete.
- To investigate the durability properties such as Acid-Alkali attack by measuring % loss of weight for reactive powder concrete.

2. EXPERIMENTAL PROGRAM

2.1 MATERIALS USED:

The different materials used in this investigation are:

- Cement
- Aggregates
- Steel fibers
- Mineral admixtures –silicafume
- Chemical admixture - Super plasticizer
- Water

2.1.1 CEMENT: Cement is a binding material, which is the combination of two raw materials called calcareous and argillaceous materials. Zuari-53 grade ordinary Portland cement conforming to IS: 12269 was used. The physical properties of the cement are listed in Table – 1.

Table 1. Properties of Ordinary Portland cement

S.No	Properties	Results	IS : 12269-1987
1.	Specific gravity	3.15	
2.	Standard consistency	31%	
3.	Initial setting time	34 min	Minimum of 30min
4.	Final setting time	210 min	Maximum of 600min
5.	Compressive strength A. 3 days strength B. 7 days strength C. 28 days strength	 29.4 Mpa 44.8 Mpa 56.53 Mpa	 Minimum of 27 Mpa Minimum of 40Mpa Minimum of 53Mpa

2.1.2 FINE AGGREGATES:

The standard sand used in this investigation was obtained from pennar river, Nellore. The standard sand shall be of quartz, light grey or whitish variety and shall be free from silt. The standard sand shall (100 percent) pass through 2-mm IS sieve and shall be (100 percent) retained on 90-micron IS Sieve and the sieves shall conform to IS 460 (Part: 1):1985.

The physical properties of sand is given by

Table 2. Properties of Fine aggregate

Colour	Grayish White
Specific gravity	2.60
Absorption in24 hours	0.80%
Shape of grains	Sub angular

2.1.3 COARSE AGGREGATES

According to IS 383: 1970, coarse aggregate may be described as crushed gravel or stone when it results from crushing of gravel or hard stone. The aggregate passing through 20 mm IS sieve and retained on 10 mm IS sieve was taken.

The physical properties of gravel is given by

Table 3. Properties of Coarse aggregate

Colour	Grayish White
Specific gravity	2.64
Shape of grains	Angular

2.1.4 STEEL FIBERS : Stainless steelfibers are manufactured fibers composed of stainless steel. Composition may include carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulfur (S), and other elements. To enhance the RPC ductility, some mixes were produced with micro-fibers of straight carbon steel wire, 13 mm in length and 0.2 mm in diameter, with a minimum on-the-wire tensile strength of 2,000 MPa. These were supplied by "ASTRRA CHEMICALS, CHENNAI". The properties of steel fibers used in this investigation is given in following table.

Table 4. Properties of Steel fibers

Colour	Brown
Specific gravity	1.22

Fig.1 Steel fibers of Hooked type.

2.1.5 SILICA FUME : Conventionally, the reactive silica used for RPC has been silica fume, which is an industrial byproduct of the manufacture and purification of silicon, zirconia and ferro-silicon alloys in submerged-arc electric furnaces. Escaping gaseous SiO oxidises and condensates as extremely fine (0.03 – 0.2 μm) spherical particles of amorphous silica, neatly fulfilling the requirements listed above. The general properties of the silica fume used in this study are given in following Table.

Table 5. Properties of Silicafume

Colour	Pure white
Specific gravity	2.2
Shape of grains	Spherical

2.1.6 SUPER PLASTICIZER : The job of SP is to impart a high degree of flow ability and deformability to concrete. "**VARAPLAST SP 123**" is utilized in this project, which is a product of AKARSH SPECIALITIES Company,Chennai. Super plasticizer is a chemical compound used to increase the workability without adding more water i.e. spreads the given water in the concrete throughout the concrete mix resulting to form a uniform mix.

Table 6. Properties of Chemical admixture

Colour	Grey
Specific gravity	>1450Mpa
Shape of grains	Hooked

2.1.7 WATER: Portable water was used in the experimental work for both preparing and curing. The pH value of water taken is not less than 6.

2.2 . MIX DESIGN FOR PRESENT INVESTIGATION.

RPC120 mix design (parts by mass)

1. Considerable numbers of trial mixtures were prepared to obtain good RPC and HPC mixture proportions.
2. Particle size optimization software, LISA[developed by Elkem ASA Materials] was used for the preparation of RPC trial mixtures.
3. Various mixture proportions obtained from the available literature were also studied.
4. The selection of best mixture proportions was on the basis of good workability and ideal mixing time.
5. Finalized mixture proportions of RPC120 is shown in below Table.

Table 7 Mix proportion for RPC 120

Components	**Low temperature curing**	**High temperature curing**
Cement	1	1
Sand	1.1	1.1
Steel fibres [optional]	0.175	0.175
w/b ratio [as required for workability]	0.11-0.26	0.17-0.23

Super-plasticiser [% solids on cement]	0.6-16	1.9-2.5

MOULDS USED FOR CASTING: Cubes moulds of 100 x 100x 100mm for RPC made of cast iron were used for testing of compressive strength.

Cylindrical moulds of 100 mm in diameter and 200 mm height for RPC were used for concrete specimens for testing of Split tensile strength.

Prism moulds of dimension 500 x 100 x 100mm were used for the testing of flexural strength.

2.3 . TESTS FOR FRESH PROPERTIES OF CONCRETE:

2.3.1 WORKABILITY TEST: The workability of concrete was found by using slump cone test. The slump apparatus consists of a conical shape frustum of top diameter 10cm and bottom diameter 20cm with a height 30cm. The concrete mix is placed in slump cone in three equal layers. Each layer was tampered by given 25 blows with a bullet end tamping rod. After completion of last layer excess concrete was removed and level. Immediately the slump cone was raised upwards, this allows the concrete subside. The subsidence of concrete was known as SLUMP. The slump value can be measured by taking the difference between height of subside concrete and mould height.

Figure 2 Slump cone test apparatus.

2.4 .TESTS FOR HARD PROPERTIES OF CONCRETE

2.4.1 COMPRESSIVE STRENGTH OF CONCRETE: Compressive strength was found out as per IS 516-1959. The compressive strength test was conducted after 28 days of curing. Standard cast iron moulds of dimensions 150 x 150 x 150 mm were used to cast the specimen.

Figure 3 Compression testing machine

2.4.2 SPLIT TUBE TENSILE STRENGTH OF CONCRETE: This is also sometimes referred as “Brazilian test”. This test is carried out by placing a cylindrical specimen of dimensions 150mm diameter and 300mm length horizontally between the loading surfaces of a compression testing machine and load is applied until failure of the cylinder along the vertical diameter. When load is applied along the generatix, an element on the vertical diameter of the cylinder is subjected to a vertical compressive stress of $\frac{2P}{\rho LD}\left[\frac{D^2}{r(D-r)}-1\right]$ and a horizontal stress of $\frac{2P}{\rho LD}$ where P= compressive load on cylinder, L= length of cylinder, D= diameter of cylinder and r and $(D-r)$ are the distances of the element from the two loads respectively.

2.4.3 FLEXURAL STRENGTH OF CONCRETE : Prismatic specimens 500×100×100mm were tested according to IS: 516(1959). The flexural strength of the specimen is expressed as the modulus of rupture f_b, which if ‘a’ equals the distance between line of fracture and the near support, measured on the centre line of the tensile side of the specimen, in cm, is calculated to the nearest 0.0005 MPa as follows:

$$f_b = \frac{P\times l}{b\times d^2}$$

when ‘a’ is greater than 20.0 cm for 15.0 cm specimen, or

b = measured width in cm of the specimen,

d = measured depth in cm of the specimen at the point of failure.

L = length in cm of the span on which the specimen was supported, and

P = maximum load in kg applied to the specimen.

If 'a' is less than 17.0 cm for a 15.0 cm specimen, or less than 11.0 cm for a 10.0 cm specimen, the results of the test be discarded.

Figure 4 Flexural strength by One-point method.

Figure 5 Flexural strength by One-point method.

2.5 TESTS FOR DURABILITY PROPERTIES OF CONCRETE

2.5.1 ACID ATTACK TEST : The concrete cube specimens of various concrete mixtures of size 150 mm were cast And after 28 days of water curing, the specimens were removed from the curing tank and allowed to dry for one day. The weights of concrete cube specimen were taken. The acid attack test on concrete cube was conducted by immersing the cubes in the acid water for 90 days after 28 days of curing. Hydrochloric acid (HCL) with pH of about 2 at 5% weight of Water was added to water in which the concrete cubes were stored. The pH was maintained throughout the period of 90 days. After 90 days of immersion, the concrete cubes were taken out of acid water. Then, the specimens were tested for compressive strength. The resistance of concrete to acid attack was found by the % loss of weight of specimen and the % loss of compressive strength on immersing concrete cubes in acid water.

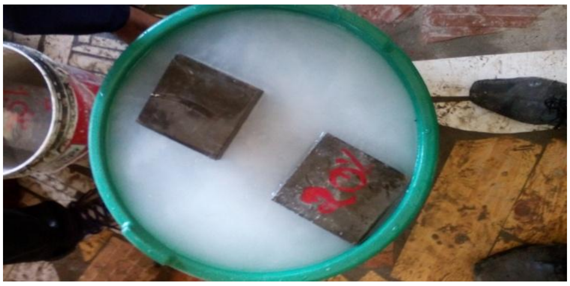


Figure 6 Aid curing of concrete cubes

2.5.2 ALKALINE ATTACK TEST:

To determine the resistance of various concrete mixtures to alkaline attack, the residual compressive strength of concrete mixtures of cubes immersed in alkaline water having 5% of sodium hydroxide (NaOH) by weight of water was

found. The concrete cubes which were cured in water for 28 days were removed from the curing tank and allowed to dry for one day. The weights of concrete cube specimen were taken. Then the cubes were immersed in alkaline water continuously for 90 days. The alkalinity of water was maintained same throughout the test period. After 90 days of immersion, the concrete cubes were taken out of alkaline water. Then, the specimens were tested for compressive strength. The resistance of concrete to alkaline attack was found by the % loss of weight of specimen and the % loss of compressive strength on immersion of concrete cubes in alkaline water.

Figure 7 Alkali curing of concrete cubes.

3.RESULTS AND DISCUSSIONS

3.1. WORKABILTY TEST RESULTS

Table 8 Slump values for RPC 120 with varying % of silicafume.

% Silica fume added added	Slump in ''mm''
	RPC 120
0%	65

5%	68
10%	75
15%	82
20%	85

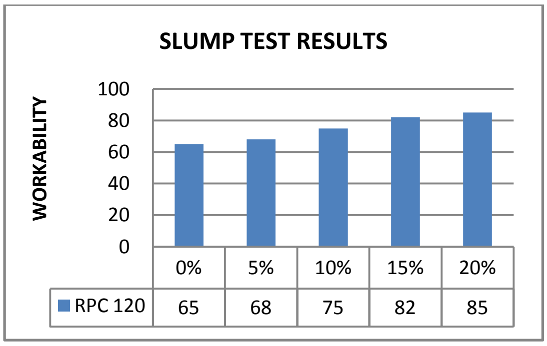


Figure 7 Slump values for RPC 120 with varying % of silicafume.

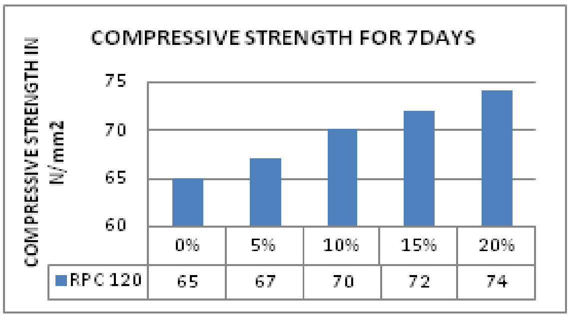
The Slump values are gradually increases with increase of percentage of Silica fumes to cement content. The above values shows the different slump values at different percentages of silicafume. The high workability is obtained at 20% of silicafume replacement for Reactive Powder Concrete.

3.2 COMPRESSIVE STRENGTH TEST RESULTS

Table 9 Compressive strength test values for RPC 120 with varying % of silicafume.

% Silica fume added added	Compressive strength (N/mm^2)	
	7days	28days
0%	65	107
5%	67	112
10%	70	115
15%	72	120
20%	74	123

From above table we can notice that the average compressive strength of Reactive Powder Concrete attain more than target strength at 20% of Silica fumes replacement with cement quantity.



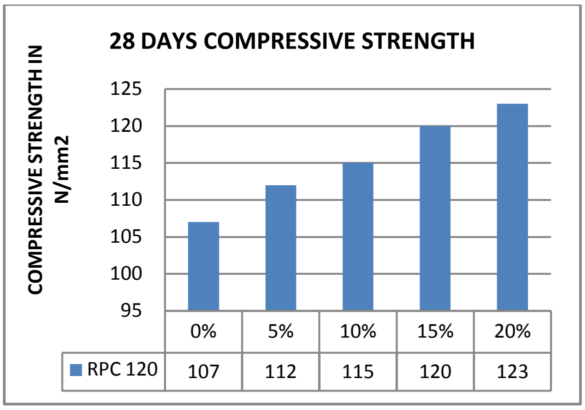


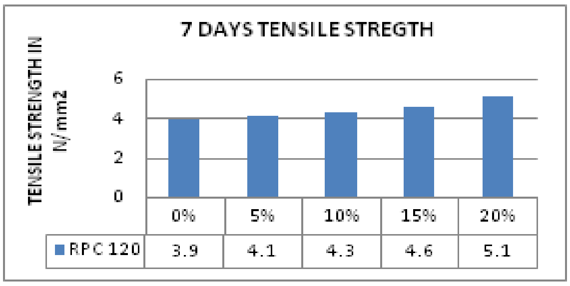
Figure 8 Compressive strength test values of RPC 120 varying % of silicafume for 7& 28 days curing.

3.3 TENSILE STRENGTH TEST

Table 10 Tensile strength test values for RPC 120 varying % of silicafume.

% Silica fume added added	Tensile strength (N/mm^2)	
	7days	28days
0%	3.9	6.4
5%	4.1	6.9
10%	4.3	7.2
15%	4.6	7.6
20%	5.1	8.4

From above table we can notice that the average tensile strength of Reactive Powder Concrete attain more than target strength at 20% of Silica fumes replacement with cement quantity.



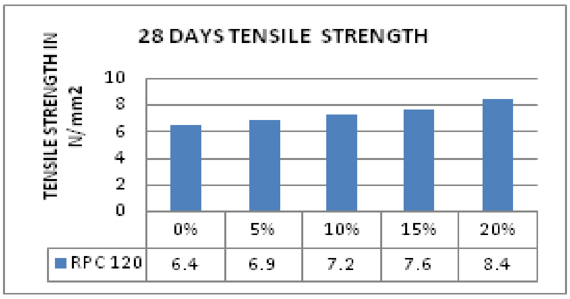


Figure 9 Tensile strength test values of RPC 120 varying % of silicafume 7& 28 days curing.

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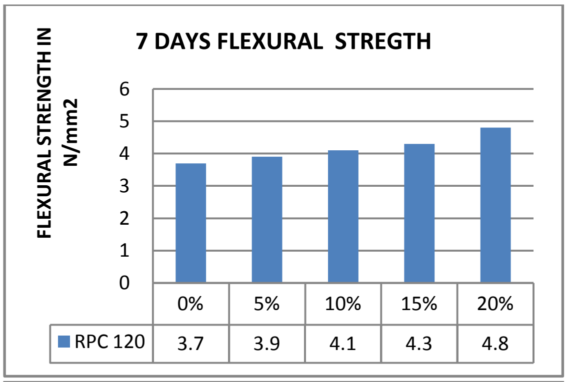
3.4 FLEXURAL STRENGTH TEST RESULTS

Table 11 Flexural strength test values for RPC 120 varying % of silicafume.

% Silica fume added added	Flexural strength (N/mm^2)	
	7days	28days
0%	3.7	6.1
5%	3.9	6.5
10%	4.1	6.8
15%	4.3	7.1
20%	4.8	7.6

The average Flexural strength of Reactive Powder Concrete attain more than target strength at 20% of Silica fumes replacement with cement quantity.



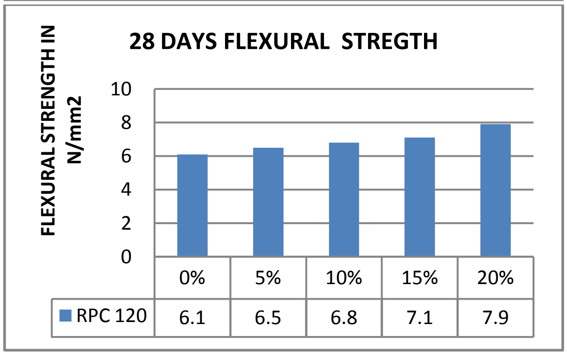


Figure 10 Flexural strength test values of RPC 120 varying % of silicafume 7& 28 days curing.

3.5 ACID ATTACK TEST RESULTS

3.5.1 %LOSS OF WEIGHT REDUCTION OF CUBES AFTER 28 DAYS ACID CURING:

Table 12. % loss of weight reduction of cubes in acid curing after 28 days

% Silica fume added added	% loss of weight reduction		
	Initial weight	Final weight	% loss in weight
0%	2.4	2.22	7.5
5%	2.55	2.48	2.7
10%	2.72	2.65	2.57
15%	2.8	2.73	2.5
20%	2.85	2.78	2.45

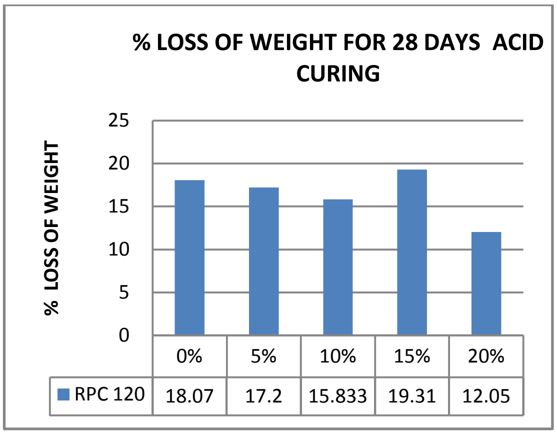


Figure 11 % loss of weight reduction of cubes in acid curing after 28 days

3.6 ALKALI ATTACK TEST RESULTS

3.6.1 %LOSS OF WEIGHT REDUCTION OF CUBES AFTER 28 DAYS ALKALI CURING:

Table 13. % loss of weight reduction of cubes in alkali curing after 28 days

% Silica fume added added	% loss of weight reduction		
	Initial weight	Final weight	% loss in weight
0%	2.4	2.22	7.5
5%	2.57	2.48	3.5
10%	2.7	2.62	2.96
15%	2.8	2.72	2.86
20%	2.86	2.78	2.79

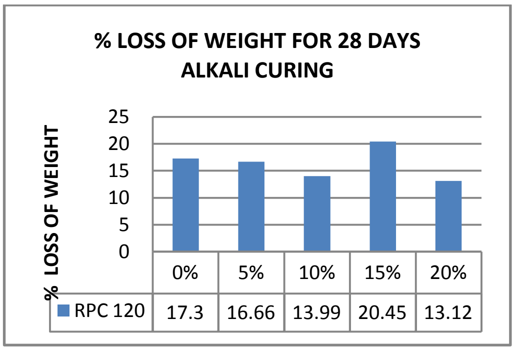


Figure 12 % loss of weight reduction of cubes in alkali curing after 28 days

5. CONCLUSIONS

- The addition of Steel Fibres in Reactive Powder Concrete will give more strength than High Performance Concrete
- For dealing with Steel Fibres in Reactive Powder Concrete there is a necessity of suitable super plasticiser to achieve workability.
- The use of Reactive Powder Concrete as conventional concrete gives more strength with less Thickness.
- It has more weight than High Performance Concrete and less amount of Reinforcement is required for casting.
- Reactive Powder Concrete is suitable where the thickness is fixed and strength required more.
- It reduces the requirement of Reinforcement than convention concrete, which is Economical than conventional concrete.
- It allows for design of extremely subtle and light structural elements, which brings savings in costs of other load bearing parts of the structure, transport and the assembly itself.
- It is resistant against aggressive environmental conditions and extreme climatic conditions.

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