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Experimental Study on Reactive Powder Concrete

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Abstract: Reactive Powder Concrete (RPC) was developed in France in the early 1990s and the world's first Reactive Powder Concrete structure, the Sherbrook Bridge in Canada, was erected in July 1997. Reactive Powder Concrete (RPC) is an ultra-high-strength and high ductility cementations composite with advanced mechanical and physical properties. It is a special concrete where the microstructure is optimized of gradation of all particles are in the mix to yield maximum density. The optimization of the Portland cement chemistry to produce the highest strength hydrate and they use extensively the pozzolanic properties of highly refined silica fume. They are most popular engineering material in a concrete. They used for buildings, industrial structures, bridges and dams. Every day the concrete is improving, to achieve better characteristics, lesser price and to be environmental acceptable.

Keywords —Elimination of coarse aggregate, steam curing, silica fumes, quartz powder, super plasticizer, RPC200

I. INTRODUCTION

. The ever-progressive construction industry is advancing from high performance concrete (HPC) to a more superior concrete due to innovation and flexibility in the composition and mix design of the concrete. As a result, this Thesis is focused on investigating the compressive and flexural Strength of Reactive Powder Concrete (RPC) as one of the current superior concretes in the construction industry. RPC has ultra-high-performance concrete invented by P. Richard and M. Cheyrezy in 1994, and they were the first produced. It has super high strength, high durability and more toughness. The compressive strength range of RPC is 200 MPa – 800 MPa, flexural strength of 6 MPa – 40 MPa, depending on the mix proportion and curing conditions used. In Malaysia, RPC has made its way into many markets in applications where these high characteristic strength and High durability can be utilized. It is used were the structural members in severe to environment. The use of RPC gives not only high mechanical performance of the structure but also provides a more life service due to its material properties. According to research by Lee N. P. & Chisholm D. H (2005), RPC is developed by Richard and M Cheyrezy (1994), particularly with the help 5 design principles, they are:

i. Improvement of homogeneity by elimination of coarse aggregate.

ii. Improvement of compacted density by optimizing the granular mixture and optional applying pressure before and during setting.

iii. Improvement of microstructure by heat treatment after hardening.

iv. Improve ductility through incorporation of steel fibers.

II. COMPONENTS OF RPC

1. CEMENT:

- In this study Ordinary Portland cement of 53 grades are used.
- The suitable Ordinary Portland cement for making RPC is of medium fineness. The particle size Cement should be 1 micron to 100 microns.
- The cement is to act as binding material.
- As per IS: 4031-1996 (PART 1 to 15) and the physical properties are:
  1. Fineness - 0.225 m2 /g
  2. Initial setting time - 30 min
  3. Final setting time - 600 min
  4. Specific gravity - 3.15

FIG 1: CEMENT

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2. *M SAND:*

- The particle size of manufactured sand having less than 2.36mm was used in production of RPC.
- The gradations are having the size between 2.36 mm and 1.18mm, between 1.18mm and 600 micron, and from 600- 0 micron, in various proportions.

FIG 2: M SAND

3. *QUARTZ POWDER:*

- It is in crystalline form.
- The size of particle is between 5 microns to 25 microns.
- The quartz is to give maximum resistance to heat.

FIG 3: QUARTZ POWDER

4. *SILICA FUME:*

- The main sources of silica fume are from ferrosilicon industries. Silica should contain less quantity of impurities.
- The particle size is ranges from 0.1 micron to 1 micron.
- The main function is to avoid small voids and also improve the flow properties of concrete.
- In the study Micro silica 920D have been used.

FIG 4: SILICA FUME

5. *STEEL FIBERS:*

- Steel fibers of length 13 to 36 mm and 0.15 to 0.5 mm diameter are selected to prepare reactive powder concrete.
- It improves ductility of the concrete.

FIG 5: STEEL FIBERS

6. *SUPER PLASTICIZER:*

- The super plasticizer are used in RPC is polycarboxylate.
- The Polycarboxylate will reduce the w/c ratio and also to increase the workability of the concrete.

7. *ACCELERATED CURING:*

FIG 6: ACCELERATED CURING

With the help of accelerated curing the concrete will achieve the early high compressive strength. The compressive strength of concrete of 28dyas can achieve in 28 hours with the help this method (As per IS 9013-1978- Method of making, curing and determining compressive strength of accelerated cured concrete test specimens). It is used in the prefabrication industry where the concrete gets high strength in early age strength so the formwork can be removed within 24 hrs hence it has cost saving benefits. Curing some of the curing techniques are steam curing, warm water curing, boiling water curing and autoclaving**.**

III. MIX DESIGN

Mix Design: The mix design of RPC is taken from P. Richard and M. Cheyrezy in 1995. The constituents of RPC are cement, silica fume/MIRHA, super plasticizer, water and steel fibers, MSand, quartz powder. The main intention of the above materials is to complete eliminates

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coarse aggregate to increase homogeneity, with chemical admixture enhancing compacted density by optimizing granular mixture and providing ductility by addition of steel Fibers.

	P. Richard and M. Cheyrezy			
	[1995]			
	Non fibred		12mmfibers	
Portland Cement	1	1	1	1
Silica fume	0.25	0.23	0.25	0.23
Sand	1.1	1.1	1.1	1.1
Quartz Powder	--	0.39	--	0.39
Super plasticizer	0.016	0.019	0.016	0.019
Steel fiber	--	--	0.175	0.175
Water	0.15	0.17	0.17	0.19
Compacting pressure	--	--	--	--
Heat temperature	20ºC	90ºC	20ºC	90ºC

Table -1: Mix Design

IV. METHODOLOGY

The materials are mixed in dry state for 2 minutes, and then add 80% of the mixing water is added and mixed it for 3 minutes, and then 15% of water and 70% of super plasticizer is added and mixed again for 3 minutes then the mixer machine is stopped for 1 minute. Then add remaining water and super plasticizer is added and mixing is continued for 5 minutes. For 1 minute the Steel fibers are added and mixed to get uniform distribution. The mixing total time is 15 minutes.

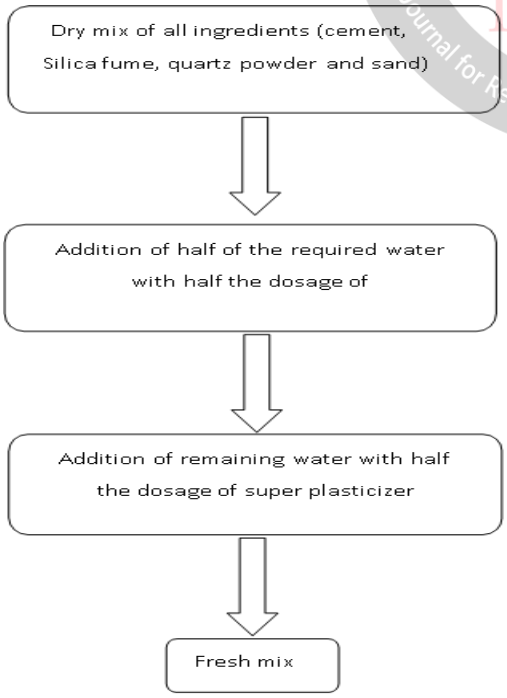

FIG 6: FLOW CHART OF METHODOLOGY.

CURING:

For 7, 28days the cubes are casted. Size of cube is 150x150x150 mm

V. TEST CONDUCTED ON REACTIVE POWDER CONCRETE:

The tests conducted on the reactive powder concrete are:

1. Compression strength test
2. Flexural strength test
3. Water absorption test

COMPRESSIVE STRENGTH:

- The compressive strength testing of the RPC cubes is tested using the 3000 KN testing machine as shown in Appendix D. A total of 3 cubes (150 x150 x 150) mm of each mix were tested to get the average compressive strength for the specified days of 3, 7, 28 days. At a pace rate of 3 KN/sec the load is applied.
- The ultimate strength can resist any more loads is recorded when the specimen failed to.
- The compressive strength can be calculated as per equation:

$$\textbf{Compressive strength} = \frac{\textbf{load (P)}}{\textbf{Cross sectional area}}$$

For RPC 200 formula of compressive strength test for 28 days:

$$R_{28} = 8.09+1.64(R_a)$$

FIG 7: COMPRESSION TESTING MACHINE.

Flexural Strength Test:

- For the flexural strength, the beam will be tested using 1800 KN flexural testing machine at a pace rate of 0.2 KN/sec, according to the standard test method ASTM 1609. A total 3 beams of each mix were tested after the 28th day of curing to get the average flexural strength.

Calculation of Flexural Strength from Lab Test

The Flexural Strength is given by

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1. **fb = Pl/bd2**

   (When a > 13.3 cm)

2. **fb = 3Pa/bd2**

   (When a < 13.3 cm)

Where,
a = the tensile side of the specimen at the center line is measured at a distance of line of fracture and the nearest support (cm)
b = specimen width (cm)
d = depth failure point (cm)
l = supported length (cm)
P = the Maximum specimen Load (kg)

The modulus of rupture value can be obtained by the center point load test arrangement is smaller than three-point load test configuration by around 15 percent. Moreover, it was observed that low modulus of rupture is achieved when larger size concrete specimen is considered. The percentage of compressive strength of concrete is about 10 to 15 percent in modulus of rupture. It was influenced by mix proportions, size and coarse aggregate volume used for specimen construction. Finally, the following equation can be used to compute modulus of rupture, but it must be determined through laboratory test if the design:

$$f_r = 7.5\sqrt{f'_c} \rightarrow \text{Equation-1}$$

Where: **fr -** Modulus of rupture
fc'- concrete compressive strength
As per ASTM standard the loading rate can be computed based on the following equation:

$$r = \frac{Sbd^2}{L} \rightarrow \text{Equation-2}$$

Where,
r: loading rate.
S: rate of increase of extreme fiber
b: average specimen width
d: average specimen depth
L: span length

The cross section of the tested specimen at each end and at center to calculate average depth and height is measured.

Computation of Modulus of Rupture

The modulus of rupture is given by:

$$MR = \frac{3PL}{2bd^2} \rightarrow \text{Equation-3}$$

Where:
MR is the modulus of rupture.
P is ultimate applied load indicated by testing machine.
L is the specimen span length.
b is the specimen the average width of the fracture.
d is the specimen average depth of fracture.

FIG 8: FLEXURAL STRENGTH TESTING MACHINE.

WATER ABSORPTION:

A water absorption test was carried out on 150mm cube specimen at the age of 28 curing as per ASTM C 642. The specimens were weighed before drying. The drying was carried out in a hot air oven at a temperature of 105oC.The specimens is dried were cooled at room temperature and when immersed in water. The specimens are taken out at regular interval of time, surface dried using a clean cloth and weighed. The process is continued till the weights became constant. The difference between the measured water saturated mass and oven dried mass expressed as % of oven dry mass gives the WA. The water absorption was calculated as

% of water absorbed = (Ws x Wd) x 100/Wd Where, Ws = fully saturated condition weight of specimen Wd = weight of oven dry specimen.

Please include a brief summary of the possible clinical implications of your work in the conclusion section. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. Consider elaborating on the translational importance of the work or suggest applications and extensions.

VI. RESULT

1. COMPRESSION STRENGTH:

For RPC 200 with steel fibers

Specimen number	with steel fibers [1day]	with steel fibers [28day]
Formulae	___________	R_{28}= 8.09+1.64(R_a)
FRpc-1	71.42 N/mm²	125.58 N/mm²
FRpc-2	70.20 N/mm²	123.15 N/mm²
FRpc-3	70.18 N/mm²	120.32 N/mm²

RESULT:

- The compressive strength of cubes for 1days = **70.6 N/mm²**.

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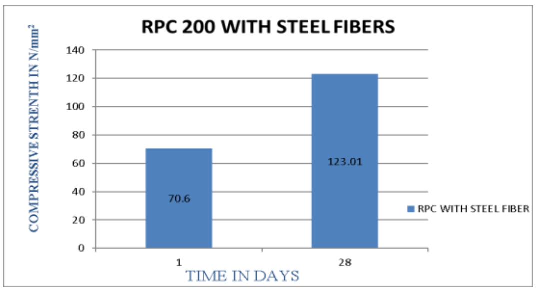
- The compressive strength of cubes for 28days = **123.01N/mm²**.



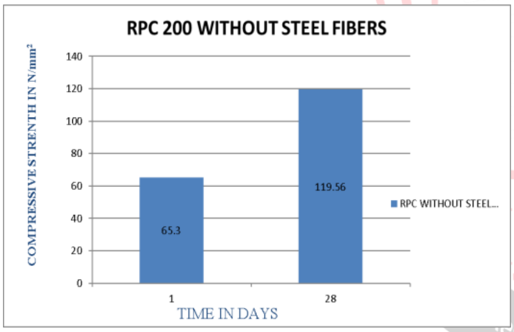
For RPC 200 without steel fibers

Specimen number	Without steel fibers [1day]	Without steel fibers [28 days]
Formulae	__________	$R_{28} = 8.09+1.64(R_a)$
RPC-1	66.19 N/mm²	121.83 N/mm²
RPC-2	65.53 N/mm²	119.31 N/mm²
RPC-3	64.20 N/mm²	117.56 N/mm²

RESULT:

The compressive strength of cubes for 1days = **65.30 N/mm²**

The compressive strength of cubes for 28days = **119.56 N/mm²**



2. FLEXURAL STRENGTH:

For RPC 200 with Steel Fibers

Specimen number	For 28days(with steel fibers)
FRPC-1	22 N/mm²
FRPC -2	24 N/mm²
FRPC -3	21 N/mm²

RESULT:

The flexural strength of cubes for 28days= **22.33 N/mm²**

For RPC 200 without Steel Fibers

Specimen number	For 28days (without steel fibers)
Rpc-1	15 N/mm²
Rpc-2	12 N/mm²
Rpc-3	10 N/mm²

RESULT:

The flexural strength of cubes for 28days= **12.33 N/mm²**

3. Water Absorption

For RPC 200 with Steel Fibers

Specimen number	For 28days (with steel fibers)
FRPC-1	0.763%
FRPC -2	0.519%
FRPC -3	0.951%

RESULT:

The water absorption for 28days= **0.744%**

For RPC 200 without Steel Fibers

Specimen number	For 28days (without steel fibers)
RPC-1	0.478%
RPC-2	0.489%
RPC-3	0.645%

RESULT:

The water absorption for 28days= **0.53%**

VII. ADVANTAGES

The advantages of Reactive powder concrete:

- Due to High ductility property, RPC always competes with steel.
- The concrete becomes void proof and no leakage of gas or liquid occurs because of fine ingredients.
- The dead load of structure is reduced due to high shear capacity along with high strength.
- RPC members are great resistance to seismic forces.
- RPC's high strength combined with high shear capacity reduces dead load and limitless structural member shape.
- By its ductile tension failure mechanism, RPC will resist to all stresses except direct primary tensile stresses
- RPC upgrades seismic performance reduces inertia loads with lighter members. Reduced cross sections of members provide higher energy absorption.
- Low and non-interconnected porosity reduces transfer of mass, making penetration of liquid/radioactive or gas elements.

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VIII. STRUCTURES CONSTRUCTED ON RPC:

- World's first Reactive powder concrete structure is precast prestressed pedestrian bridge constructed in July1997.
- In Europe RPC is used to construct bridges and Viaducts to reduce their cross-section area.
- Qinghai-Tibet Railway Bridge is constructed with PRC.
- Portugal has used it for sea wall anchors.
- Australia used it in a vehicular bridge.
- France used it in building power plants.
- Sidewalks of Qinghai-Tibet Railway Bridge.
- In Europe RPC is used in nuclear power plants, weapons factories.

IX. Conclusion

- The results of the compressive strength testing showed that the compressive strength of maximum RPC 200 with steel fibers age 1 day and 28 days at 90° c curing temperature was obtained at 70.6 MPa and 123.01 MPa. The results of the compressive strength testing showed that the compressive strength of maximum RPC 200 without steel fibers age 1 day and 28 days at 90° c curing temperature was obtained at 65.30 MPa and 119.56 MPa.

- The results of the flexural strength testing showed that the compressive strength of maximum RPC 200 with steel fibers age of 28 days at 90° c curing temperature was obtained at 22.33 MPa. The results of the flexural strength testing showed that the compressive strength of maximum RPC 200 without steel fibers age 28 days at 90° c curing temperature was obtained at 12.33 MPa.

- It is observed that in water absorption of RPC 200 with steel fibers at 28 days is 0.77%.

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