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Experimental Investigation on Properties of Reactive Powder Concrete

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Abstract – Reactive powder concrete is a unique type of concrete with extremely high ductility and strength. To achieve the highest strength, it makes considerable use of the pozzolanic capabilities of highly reactive silica fume and Portland cement optimization. The size influence of RPC's coefficient and law were investigated in this paper. The compressive strength of RPC is calculated using size-effect factors.

Keywords – Reactive Powder Concrete, Compressive Strength, Homogeneity

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INTRODUCTION

Reactive powder concrete (RPC) is a new generation concrete and it was developed through microstructure enhancement techniques for cementitious materials. As compared to ordinary cement- based materials, the primary improvements of RPC include the particle size homogeneity, porosity, and microstructures. Compressive strength in the range of 200 to 800 MPa, fracture energy in the range of 1200 to 40,000 J/m^2 and ultimate tensile strain on the scale of 1% are among the mechanical parameters that can be attained. RPC has been reported to have exceptional flexural strength and ductility. It has a ductility of around 250 times that of traditional concrete. The RPC is an ultra-high performance concrete because of its low permeability, thick microstructure and outstanding mechanical qualities (very high compressive strength, flexural strength, fracture energy, and toughness). RPC appears to be a promising material for particular pre-stressed and precast concrete members in the present day. As a result, this material can be used to construct industrial and nuclear waste storage facilities. RPC applications have certain cost advantages, despite the fact that RPC production costs are often high. It is possible to minimise or eliminate passive reinforcement using steel fibres. Furthermore, because of RPC's better mechanical qualities, concrete element thickness can be reduced, saving both material and money.

To obtain ultra-high strength with very low water/cement ratios, RPC cement dosage is often as high as 800–1000 kg/m^3. A large amount of cement not only increases production costs, but it also increases hydration heat and can cause shrinkage problems. Mineral admixtures may be a viable option for resolving these issues in RPC. The primary goal of this study is to see how mineral admixtures affect the mechanical properties of the RPC. Furthermore, the goal of this study was to reduce cement and silica fume use in order to reduce material prices and negative impacts (heat of hydration, shrinkage and environmental problems).

Experimental Program: Work Plan Flow- The mixture design of high-performance concrete is a critical factor that impacts its structural performance to a significant extent. Furthermore, there is no such thing as a standard mixture design for high-performance concrete. Each application necessitates a unique mixture design. For the present study, experimental work is done as per the flow chart given in fig. 2.1.

► MATERIAL SPECIFICATION AND SELECTION-

1) Composition of Reactive Powder Concrete-

Steel fibres, super plasticizers, and very fine powders (cement, sand, quartz powder, and silica fume) make up RPC. When applied at its recommended dosage, the super plasticizer reduces the water to cement ratio (W/C) while enhancing concrete workability. The granular packing of dry fine powders is optimised to create a dense matrix. The compressive strength of these reactive powder concretes ranges from 200 to 800 MPa.

2) Basic Principles for the Composition of RPC:

a) The removal of coarse particles in order to improve homogeneity.

b) Granular mixture optimization for increased compaction density.

c) Making use of silica fume's pozzolanic characteristics.

d) The use of a superplasticizer as an alternative to minimise the W/C ratio and improve compaction.

e) Microstructure improvement via post–set heat treatment.

f) Small steel fibres are added to increase ductility.

► SELECTION OF COMPONENTS-

1) **Sand:** The desired maximum and minimum particle sizes establish the particle size range indirectly. To avoid interference with the largest cement particles (80-100µm) and silt content in natural sand, the maximum particle size is limited to 600 µm, while particle sizes below 150 µm are avoided for the minimum value. Crushed sand with extremely angular grains or natural quarry sand with more spherical grains are screened to produce fine sand. RPC can be done with either sort of sand.

2) **Cement:** Because of the high cement factor, the type of cement used can have a significant impact on RPC performance. The optimum cement, according to published practise, contains a high percentage of C3S and C2S (di- and tricalcium silicates) and very little C3A (tricalcium aluminate). This is understandable given that C3A has minimal inherent value as a binding agent and is mostly used in cement as a flux during the calcination process. In this study, ordinary Portland cement that is readily accessible was used.

3) **Silica Fume:** The absence of aggregates is the major characteristic of silica fume. As a result, non-compacted silica fumes are used. The quality of water in slurry surpasses the total amount of water required for the mixture, so it can't be used. Carbon and alkalis are the most harmful pollutants. The particle size is a secondary consideration. The best results are obtained with Elkem India (P) Ltd.'s silica fume, which is devoid of contaminants and completely disaggregated.

RPC typically uses a fume/cement ratio of 0.27 to 0.3. This ratio corresponds to the best filling performance and is near to the dosage required for complete lime consumption as a result of total cement hydration. However, with RPC concrete, cement hydration is incomplete, and the amount of silica fume accessible exceeds the pozzolanic reaction's requirements. Elkem India (P) Ltd. provided silica fume under the brand name "Elkem Micro Silica Grade 920-D."The properties are given in table 1.

TABLE 1: PROPERTIES OF "ELKEM MICRO SILICA GRADE 920-D"

Sr. No.	Properties	Units	Specification	Specification Limit
1	SiO_2	%	Min. 85	87.3
2	Moisture Content	%	Max. 3	0.7
3	Loss of ignition @975 °C	%	Max 6	1.8
4	Available Alkalis (Na_2O)	%	-	0.5
5	Particle size > 45µ	%	Max. 10	0.7
6	Pozzo activity index (7d)	%	Min. 105	182
7	Sp. Surface	m^2/g	Min. 15	20.3
8	Bulk Density	Kg/m^3	500-700	600
9	Density	mg/m^3	-	2.2

4) **Quartz Sand:** Additional silica is required to change the CaO/SiO2 ratio in RPC mixes designed to be cured at temperatures above 90°C, including autoclaving at high pressures. Powdered quartz flour with a mean particle size of 10 - 15 mm was used in these circumstances. 20 Microns Ltd provided the quartz sand under the brand name "Micron Silica 2080." The properties are given in table 2.

TABLE 2: PROPERTIES OF "MICRON SILICA 2080"

Sr. No.	Properties	Units	Specification Limit
1	Brightness	%	83-89
2	Bulk Density	gm/lit	400-500
3	Oil Absorption	gm/100gm	28-34
4	Particle Size Analysis (a) D(97)- 97% particles below (b) D(50)- 50% particles below	 µ µ	 22-28 4-6
5	Moisture (ex. Work)	%	Max. 0.2
6	pH (10% Aq. Slurry)	-	8.5-9.5

5) **Steel Fibers**: The nature of plain concrete is that it is brittle. It has a low tensile strength

and a low degree of ductility. However, while RPC is superior than ordinary concrete in terms of tensile strength, its uses are severely constrained. To improve RPC ductility, micro-fibers of corrugated carbon steel wire, 12.5 mm in length and 0.45 mm in diameter, with a minimum wire tensile strength of 2000 MPa, were included in various mixtures. Steel fibres material has a specific gravity of 7.1.

6) **Super plasticizer**: The fluidizing power of high-quality third generation super-plasticizing chemicals allows RPC to achieve such low w/b (cement + silica fume) ratios. To ensure adequate workability of the RPC mix, a polycarboxylate-based new generation plasticizer was utilised. Polycarboxylitic Ether (PCE) superplasticizers are a big development in concrete technology since they can save up to 40% on water and provide incredible workability without the negative consequences of retardation and segregation. As a result of PCE super plasticizers, there is less need for redusing with extra admixtures or retempering with water, especially with low w/c ratio mixes, lengthy haulages, and hot weather conditions. BASF Chemicals (India) Pvt. Ltd. has supplied the super plasticizer. Table 3 lists the characteristics of Glenium-51 (Polycarboxylic ether base)

Table 3: Properties of "Glenium -51(Polycarboxylic ether based)"

Sr. No.	Properties	Units	Specification Limit
1.	Specific Gravity	--	1.095
2.	Chloride	%	≤ 0.10
3.	pH	--	7.2
4.	Alkali	%	≤ 4

TABLE 4: SELECTION PARAMETERS FOR RPC COMPONENTS

Components	Selection Parameters	Function	Particle Size	types
Sand	Good hardness, readily available, low cost	Give strength	150-600μm	Natural, Crushed
Cement	C_3S: 60% C_2S:22% C_3A:3.8% C_4AF:7.4%	Binding material, production of primary hydrates	1-100 μm	OPC Medium fineness
Quartz Sand	Fineness	Maximum reactivity during heat treating	5-25 μm	Crystalline
Silica Fume	Nature and quantity of impurities	Filling the voids, Enhance rheology, Production of secondary hydrates	22m2/g μm	procured from Elkem India (P) Ltd.
Steel Fibers	Good aspect ratio	Improve ductility	L:12.5 mm d:0.45mm	Corrugated
Super plasticizers	Less retarding characteristic	Reduce W/C ratio		polycarboxylate

TABLE 5: SPECIFICATION OF MATERIALS USED FOR RPC

Sample	Specific Gravity	Particle Size Range
Cement (IS 12269 : 1987)	3.15	31 μm – 7.5 μm
Silica fume (ASTM C1240 – 97B)	2.2	5.3 μm – 1.8 μm
Quartz sand	2.7	5.3 μm – 1.3 μm
Steel fiber – 6mm (ASTM A 820 – 96)	7.1	Length 6 mm and dia.0.10 mm
Sand (IS 383: 1970)	2.61	0.6 mm – 0.15 mm

► **MIX PROPORTION:**

There were two fundamental types of RPC produced: a low temperature mix designed to be cured in ambient settings, as is standard site practice, and a high temperature mix suitable for production activities such as pre-cast plants with steam curing facilities. In the experimental technique, the optimization of granular mix is performed by a series of experiments for various mixtures.

Table 6: RPC mix proportions literatures

Materials	P. Richard, M. Cheyrezy	S.A. Bouygues	A. S. Dilli, M. Santhanam	
	Fiber (6mm)	Fiber (6mm)	Without Fiber	Fiber (6mm)
Cement	1	1	1	1
Sand	1.1	1.423	1.6	1.6
Silica fume	0.23	0.324	0.25	0.25
Steel fibers (Optional)	0.175	0.268	---	0.20
Water	0.30	0.282	0.25	0.25
Super platicizer	0.019	0.027	0.03	0.03

The water demand of the combination is the most important factor that determines its quality (quantity of water for minimum flow of concrete). In reality, the mixture's voids index is proportional to the total of water demand and imprisoned air. Cubes were cast and compressive strength was assessed at 7 and 28 days after selecting a mixture design based on minimum water consumption. On the basis of the foregoing compositions, a number of trials for various mixes for various compositions are conducted to optimise the granular mixture. Initially, studies to achieve an acceptable RPC flow were carried out with the lowest water-cement ratio and the highest superplasticizer doses.

Table 7: Optimized RPC mixture (parts by mass) used for experimental work

Material	Without Fiber	With Fiber
Cement	1	1
Silica fume	0.23	0.23
Quartz sand	1.1	1.1
Steel Fibers	----	1%
Super plasticizer	0.019	0.019

► CASTING OF SPECIMEN:

The liquid gradients were measured in a measuring flask and all ingredients were carefully weighed with a weighing machine. The liquid-to-cement ratio was set at 0.019. According to Euro code, the initial batch of concrete had a W/C ratio of 0.3 with 0% fibres. Steel fibres were used as 1% of the volume in the second batch of concrete mix. Steel fibre accounted for 2% of the cement volume in the third batch of concrete Fibers and water in the proper quantities were mixed separately for each batch and added to the dry mix. Each batch of concrete was crushed evenly with a tamping rod until no bubbles were visible at the surface. The corner zone received special attention in order to achieve optimum compaction at the corners. After 24 hours of casting, all of the specimens were demoulded.

► CURING OF SPECIMENS:

The specimens are held in the mould for 24 hours after casting and polishing the surface. The specimens are numbered when they have been removed from the mould. The specimens are then placed in the curing tank for a usual curing period of 28 days. For hot water curing, the specimen is placed in a hot water curing tank for the first 48 hours and then placed in a standard water curing tank for the remainder duration up to 28 days. The specimens are taken from the curing tank after 28 days and white washed before being tested.

► TESTING OF SPECIMENS:

The compressive strength of a cubical specimen of 50 mm x 50 mm x 50 mm was cast and tested according to the IS 516-1959 specification. Compressive strength was measured on 50 mm cubes that were cured in a water tank totally immersed at constant temperature 27^{o} C for 7 and 28 days, with 3 specimens in each case.The test is conducted on CTM.

RESULTS

Table 2.1 Compressive Strength Test on Concrete for 28 days of size 50X50X50 mm in Normal Curing Condition

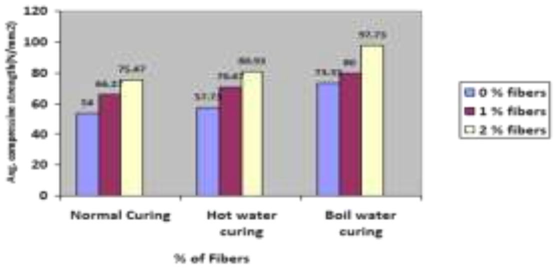
% of steel fibers	Load in KN			Compressive Strength in N/mm²			28 days Average Compressive Strength in N/mm²
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	
0%	132	135	138	52.8	54	55.2	54
1%	164	170	163	65.6	68	65.2	66.27
2%	197	184	185	78.8	73.6	74	75.47

Table 2.2 Compressive Strength Test on Concrete for 28 days of size 50X50X50 mm3 in warm water curing condition

% of steel fibers	Load in KN			Compressive Strength in N/mm²			28 days Average Compressive Strength in N/mm²
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	
0%	145	140	148	58	56	59.2	57.73
1%	170	187	173	68	74.8	69.2	70.67
2%	210	200	197	84	80	78.8	80.93

Table 2.3 Compressive Strength Test on Concrete for 28 days of size 50X50X50 mm3 in Boil water curing condition

% of steel fibers	Load in KN			Compressive Strength in N/mm²			28 days Average Compressive Strength in N/mm²
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	
0%	175	190	185	70	76	74	73.33
1%	190	195	215	76	78	86	80
2%	243	257	248	97.2	102.8	99.2	97.73



CONCLUSION

When the test findings were compared to the results of normal concrete, it was discovered that the Reactive Powder Concrete had a higher strength than the usual concrete. However, Reactive Powder Concrete is more expensive, it can be employed in situations when high strength is necessary. RPC has a great strength, frost resistance, and impermeability. RPC is a material with a lot of potential that has yet to be discovered. As a result, it has a lot of potential in the future for big structures like bridges, dams and high-rise buildings.

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