

REACTIVE POWDER CONCRETE - A REPLACEMENT OF COARSE AGGREGATE

¹Subhashree Mohanty, ²Arpita Samal, ³Sruttakirti Biswal

¹Assistant Professor, ²Lecturer, ³Student

¹Department of Civil Engineering

¹Templecity Institute of Technology & Engineering, Bhubaneswar, India

Abstract : This dummy run was performed to study the functioning of Reactive Powder Concrete (RPC) with different materials . The constituents of reactive powder concrete used in this analysis are cement (ordinary Portland cement), crushed quartz sand powder, fine aggregate (sand), silica fume , steel fiber and super plasticizer with low water to cement ratio with no coarse aggregates. Experiments were carried out to analyze the productive substitution of coarse aggregate by steel fibre to attain ultra- high strength concrete. The impact of quartz powder, silica fume and other admixtures to enhance the rupture properties of the RPC mix, is studied in addition to the normal water and hot water curing method to achieve higher compressive and flexural strength.

Index Terms - Reactive Powder Concrete, micro silica, steel fiber, pozzolana

I. INTRODUCTION

Reactive Powder Concrete (RPC) is a advance composite material that will allow the concrete industry to optimize material use to gain economic benefits and build structures that are strong, durable and sensitive to the environment .

High-Performance Concrete (HPC) is a simple mixture of cement, water, and aggregates. It contains mineral components and chemical admixtures having very specific characteristics, which give specific properties to concrete. HPC has achieved the maximum compressive strength in its existing form of microstructure. 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, the coarse aggregate is removed. This philosophy has been employed in Reactive Powder Concrete .

Reactive Powder Concrete (RPC) was developed in France in 1990s and the world's first Reactive Powder Concrete structure, the Sherbrook Bridge in Canada was erected in July 1997[16]. It is an ultra high strength and high ductility cementitious composite with advanced mechanical and physical properties. In this concrete the microstructure is optimized by a specified gradation of all particles in the mix to yield maximum density.

Reactive powder concrete (RPC) is a generic name for the class of cementitious composite materials developed by the technical division of Bouygues, S.A. in 1990s. It is characterized as excellent physical properties, more strength and high ductility. Table 1 gives the properties of RPC with those typically associated with conventional high performance concrete. While RPC is considerably more expensive to produce than regular concrete, more isotropic in nature and greater ductility make it competitive with steel, over which it has a significant cost advantage for many structural applications.

II. OBJECTIVE

The main objective is to study the compressive and flexural strength behavior of RPC with varying compositions of materials in our environment and to achieve the maximum possible strength This included demonstrating that a quality product could be obtained with local constituent materials and establishing an independent benchmark of the performance levels achievable.

III. COMPOSITION OF REACTIVE POWDER CONCRETE:

It consist of fine particles to achieve excellent mechanical behavior, higher strength & greater durability. The mix include high amorphous micro silica to escalate the hydration of cement and initiate a strong pozzolanic reaction effect. Super plasticizers and superfine silica fume and quartz are added to attain low water/binder ratio to reduce porosity and increased strength. Steel fiber is introduced to enhance ductility of composites. Coarse aggregates are replaced to gain homogeneity of concrete mix.

Table 1: Properties of RPC

Property of RPC	Descriptions	Recommended Values	Types of failure eliminated
	Coarse aggregates are	Max. size of fine sand is	
Reduction in size of aggregates	replaced by fine sand with a reduction in the size of the coarse aggregate by a factor of about 50	600 µm	Mechanical, Chemical & Thermo-mechanical
Increase in mechanical properties	Mechanical properties improved by the addition of silica fume	Elasticity modulus ranges between 50 GPa – 75 Gpa	Disturbances of the mechanical stress field

Table 2: Specifications for material selection :

Materials	Parameters	Functions	Particle Size	Types
Sand	Good hardness locally available and economical.	strength	150 μm to 600 μm	Naturally Crushed
Cement	C ₃ S -60% C ₂ S -22% C ₃ A -3.8% C ₄ AF -7.4%	Binding material, hydration process	1 μm to 100 μm	OPC medium fine
Quartz Powder	Fineness	Max. reactivity during heat treating	5 μm to 25 μm	Crystalline
Silica fume	Very less quantity of impurities	Filling the voids, Enhance rheology ,	0.10 μm to 1.0 μm	Manufactured from Ferrosilicon industry (in refined form)
Steel fibers	Good aspect ratio	Improves ductility	L : 13 – 25 mm \varnothing : 0.15 – 0.2 mm	Straight
Super plasticizer	Less retardedness	Reduce w/c	–	Polyacrylate based

The high ductility property of RPC mix can replace the steel in some cases which is economic. The fine matters of the mix makes the concrete void proof and leakage proof. RPC structures have higher shear capacity and great resistance to withstand seismic forces[21].

Table 3: Materials and its properties

Sl. No.	MATERIALS	Specific Gravity	Particle size ranges
I	Cement, OPC of 53-grade [IS. 12269 – 1987]	3.16	31 μm – 7.5 μm
II	Silica fume [ASTM C1240 – 97b]	2.20	5.30 μm – 1.80 μm
III	Quartz Powder	2.75	5.31 μm – 1.31 μm
IV	Standard sand grade-2 [IS. 650 – 1991]	2.65	0.60 mm – 0.30mm
V	Standard sand grade-3 [IS. 650 – 1991]	2.65	0.50mm – 0.150mm
VI	Steel fibers (30 mm) [ASTM A 820 – 96]	7.10	Length : 30 mm & diameter : 0.40mm

Table 4: Mix Proportions for RPC

Materials	Non-Fibered	Fibered
Cement	1.00	1.00
Silica fume	0.25	0.25
Quartz powder	0.31	0.31
Standard sand grade 2	1.09	1.09
Standard sand grade 3	0.580	0.580
30mm steel fiber	-	0.200
Admixtures (Polyacrylate based)	0.030	0.030
Water	0.25	0.25

Compressive strength:

To identify the mechanical performance of RPC, the compressive strength evaluated by different curing methods and different material proportions. Fig. 1. shows that the Compressive strength is almost very at early stages reactive powder concrete and goes up further. It shows that the RPC is very durable and can be used for heavy construction works.

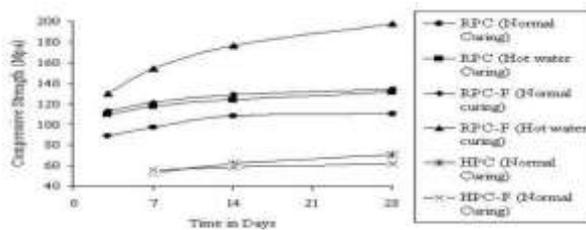


Fig .1: Compressive strength comparison of RPC and HPC

The maximum compressive strength of RPC obtained from this study is as high as 200 MPa, while the maximum strength obtained for HPC is 75 MPa. The incorporation of fibers and use of heat curing was seen to enhance the compressive strength of RPC by 30% – 50%[18].

Flexural strength :

Non fibered RPC was found to possess a higher flexural strength than HPC. Table 5 shows the variations in flexural strength of RPC and HPC with the addition of steel fibers. The increase of flexural strength of RPC with the addition of fibers is higher than HPC.

Table 5: Flexural strength (as per IS 516) at 28 days (MPa)

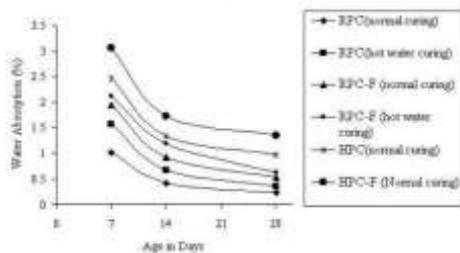
HPC		RPC	
Normal curing	Hot water curing	Normal curing	Hot water curing
11	12	18	22

As per literature, RPC 200 should have an approximate flexural strength of 40 MPa. The reason for low flexural strength obtained in this study could be that the fibers used (30 mm) were long. Fiber reinforced RPC (with appropriate fibers) has the potential to be used in structures without any additional steel reinforcement. This cost reduction in reinforcement can compensate the increase in the cost by the elimination of coarse aggregates in RPC to a little extent.

Water absorption

Fig. 2 represents a variation graph of water absorption between RPC and HPC. The percentage of water absorption of RPC is very low as compared to that of HPC.

Fig. 2: Water absorption of RPC and HPC



The consolidation of strands and the utilization of warmth relieving is seen to imperceptibly build the water retention. The nearness of strands perhaps prompts the formation of channels at the interface between the fiber and mixture that advance the take-up of water. Warmth restoring (hot curing), then again, prompts the improvement of an increasingly open microstructure (contrasted with ordinary relieving) that could bring about an expanded ingestion.

IV. METHODOLOGY:

Preparation of mix:

For Non-Fibered mix: The required amount of sand is taken as obtained from the mix design passing through 600 micron sieve and retaining in 150 micron sieve. Then required quantity of Portland cement added to the sand . The required amount of silica fume is added to the above sand and cement mix and thoroughly blend it in mixer at low speed till a uniform mixture is obtained . Required amount of super plasticizer added to the required amount of water. Then water added to the above dry mix and mix it thoroughly in a high speed mixer for about 10 minutes. The slump value of the wet mix taken .

For Fibered mix: The required amount of sand is taken as obtained from the mix design passing through 600 micron sieve and retaining in 150 micron sieve .Then required quantity of Portland cement added to the sand . The required amount of silica fume, quartz powder , fly ash and admixture added to the above sand and cement mix and thoroughly blend it in mixer at low speed till a uniform mixture is obtained . Required amount of super plasticizer added to the required amount of water. Then water added to the above dry mix and mix it thoroughly in a high speed mixer for about 10 minutes. Required amount of steel fiber added to the above mixture and mix thoroughly for about 2 minutes. And the slump value is taken .

Casting: The wet mix poured in cubes of size 150mm x 150mm x 150mm size for compressive strength and (70x15x15)cm beam mould , (15x30)cm cylindrical mould for flexural strength determination. The mould were compacted by hand tamping in two layers. The specimens were permitted to harden over 24hrs in their moulds. About 21 Celsius and 95% relative humidity.

Curing: Normal Curing: At atmospheric temperature in water upto the date of casting.

Steam Curing: The cubes are steam cured for approximately 2 hours at about 100°C[23].

Testing:

The compressive strength of cured RPC cube specimens weir determined by compressive testing machine .The test is carried out at 7 days , 14days and at 28 days as specified by the test specimen prepared as follows:

Specimen-1:

Material	Proportion in Kg per m ³ of concrete	Wt. taken in Kg for 1-set of cubes based on wt. of materials
CEMENT	850	10
SILICA FUME	212.5	2.5
SAND	1105	11
SUPERPLASTICIZER	25	0.16
WATER	195.5	1.97
STEEL FIBER	-	-

Specimen-2:

Material	Proportion in Kg per m ³ of concrete	Wt. taken in Kg for 1-set of cubes based on wt. of materials
CEMENT	850	10
SILICA FUME	212.5	2.5
SAND	1105	11
SUPERPLASTICIZER	17	0.16
WATER	150.5	3.8
STEEL FIBER	149.5	1.7
FLYASH	166	1.68
QUARTZ POWDER	184	1.86

V. RESULTS AND DISCUSSION

Reactive Powder Concrete (RPC) is an emerging modern composite matter which aims in achieving high strength and greater durability as compared to conventional high performance concrete. The advancement of RPC depends on the utilization of some essential standards to accomplish upgraded homogeneity, great functionality, high compaction, improved microstructure, and high flexibility. RPC has a ultra-thick microstructure by giving beneficial waterproofing and strength to the structures. The compressive and flexural strength results are summarised in table below for sample 1 for non fibered concrete mix and sample 2 for fibered RPC mix.

sample no.	curing in days	Avg. compressive strength (mpa)	flexural strength(mpa)
1	7	53	5.2
	14	84	
	28	100	

sample no.	curing in days	Avg. compressive strength (mpa)	flexural strength(mpa)
2	7	151.3	27.7
	14	209.6	
	28	215.3	

VI. CONCLUSIONS

Result shows that ultra high strength RPC mixes gives compressive strength exceeding 200 MPa and third-point Flexural strength approaching 20 MPa can be readily produced using mixing, casting and curing techniques familiar to the pre-stressed concrete industry and unremarkable constituent materials. In addition to a sufficiently reactive pozzolona silica source, staging of RPC mainly depends on the optimization of packing of the powder constituents. Commercial production of RPC would therefore require the importation of silica fume, which is comparatively expensive because of demand and the difficulty of handling a low density powder. The high content of fine granular powder, combined with heavy super plasticizer dosage, results in fresh RPC mixes possessing an almost tar-like consistency. They are far more cohesive than conventional mortars or concrete and often show marked thixotropy properties, making workability evaluations by standard flow/slump techniques unfeasible except for the simplest and most idealized of compositions. Its tensile strength much more closely approaches its compressive capacity, While the flexural strengths measured for the samples produced in this study are comparatively high for cementitious materials. The ultimate flexural loads were typically about 10% of the compressive value, a fairly characteristic ratio for normal concrete. The proponents of the Multi-Scale Concept of fiber reinforcement hold that fiber with relatively large length diameter ratio, as employed here, mostly assist in stitching together macro cracks, which primarily increases the capacity of the concrete post-ultimate load (i.e. its ductility) Significant improvements in tensile strength require a high proportion of short fiber in the matrix, which serve to bridge micro-cracks at the point of initiation and prevent them coalescing to form said macro-cracks.

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