A Comparative Study of Reactive Powder Concrete (RPC) and Ordinary Portland Cement (OPC) by Ultra High Strength Technology

B.S.Sahani[1], N.H.S.Ray[2]

Abstract:

Reactive powder concrete (RPC) is a new cement based material developed through micro structural engineering. RPC is composed of very fine powders of sand, crushed quartz, rice husk ash and silica fume, with the particle sizes comprised between 300µm and 0.02µm and low water content ratio (w/c < 0.20). A very dense matrix is achieved by optimizing the granular packing of these powders. The densificication of the mixture results from the optimization of the grain size distribution, the improvement of the microstructure is achieved by post set heat treatment and finally a high ductility is obtained by the incorporation of steel fibers. Mechanical properties of RPC compared to Ordinary Portland Cement (OPC) is high, which is generated as a result of the use of combination of fine powder materials (maximum grain size of 600 microns), selected for their relative grain size and chemical activity.

Keywords:

RPC, OPC, Autoclave Testing, Compressive strength, Flexural strength, Rheometer, Pycnometer.

[1] *(Faculty, Dept. of Civil Engg. CEB, Bhubaneswar, Odisha) Email Id- bhabaniabc@yahoo.co.in*

[2] *(Faculty, Dept. of Mech. Engg. CEB, Bhubaneswar, Odisha) Email Id- nhs.ray@gmail.com*

I.INTRODUCTION

The RPC was developed in France in early 1990s and the world's first RPC structure in 1997. RPC is an ultra strength and high ductility cementitious composite with a advanced mechanical and physical properties. The concept of RPC was first developed by P.RICHARD and M.CHEYREZY and RPC was first produced in early 1990s by researchers a BOUGUES laboratory in France.RPC has been successfully for isolation and containment of nuclear waste in Europe due to its excellent impermeability. RPC is a high strength ductile material formulated from a special combination of constituent materials. These materials include Portland cement, silica fume, quartz flour, fine silica sand, high range water reducer, water and steel organic powders. The technology of the materials is covered by one of many patterns in a range known as Ultra-High-performance concretes, all under the trade mark.

The requirements for RPC used for the waste containment structure of Indian nuclear power plant are moderate compressive strength, moderate E value, uniform density and high durability. There is a need to evaluate RPC regarding its strength, durability permeability chemical resistance and corrosion resistance as compared to OPC and to suggest its use for nuclear waste containment structures in the Indian context. The RPC research program is to be conducted with the application of the following basic principles.

1. Enhancement of homogeneity by elimination of coarse aggregates.

2. Enhancement of compacted density by optimization of granular mixture and application of pressure before and during setting.

3. Enhancement of microstructure by post-set heat-treating.

4. Enhancement of ductility by incorporating small sized steel fibers.

5. The utilization of the pozzolanic properties of silica fume and rice husk ash.

6. Optimal usage of super plasticizer to reduce w/c & improve workability.

II.METHODOLOGY

2.1Property analysis of RPC and OPC

2.1.1Mechanical properties

The RPC family includes two types of concrete, designated RPC 200 and RPC 800, which offers interesting implicational possibilities in different areas. Mechanical for the two types of RPC are given in the table. The high flexural strength of RPC is due to addition steel fibers.

Table-1 Mechanical properties of RPC according to composition

RPC Properties	Curing at 20^0c	Curing at 90^0c
Compressive strength(MPa)	180	230
3-points flexural strength(MPa)	40 to 50	50 to 60
Young's Modulus(GPa)	55 to 60	55 to 60

Table-2 Mechanical properties of RPC compared to OPC

	OPC	RPC
Compressive strength(MPa)	20-50	180-230
Flexural strength (MPa)	4-8	40-60

The mechanical behavior of RPC has been characterized for compression and bending. It has extremely high compactness as a result of the rational use of silica fumes, silica powders& super plasticizers, makes it possible to obtain a compressive strength of 200 MPa in the case of RPC 200 with Young's modulus which can reach 66 GPa and a linear elastic limit in the range of 60% of ultimate strength.

2.1.2 Elastic properties

RPC differs significantly from traditional concretes. It has no large aggregates and contains small steel fibers that provides additional strength and in some cases can replace traditional mild steel reinforcement. Due to its high density and lack of aggregates, ultrasonic inspection at frequencies ten to twenty times that of traditional concrete inspections are possible. These properties make it possible to evaluate anisotropy in the material using ultrasonic waves, and there by measure quantitatively the elastic properties of the material. The research reported in this paper examines elastic properties of this new material as modeled as an orthotropic elastic solid and discusses ultrasonic methods for evaluating young's modulus nondestructively. Calculation of shear moduli and Poisson's ratio based on ultrasonic velocity measurements are also reported. Ultrasonic results are compared with traditional destructive methods.

A new material has recently become available in the United states that demonstrates greatly improved strength and durability characteristics compared with traditional or even high- performance concrete classified as ultra-high performance concrete(UHPC) or Reactive powder concrete(RPC).The material consists of a concrete using sand as its large aggregate and fine steel fibers distributed within the concrete .Compressive strengths of 200 to 800 MPa have been achieved with RPC,compared with maximum compressive strength of 50 to 100 MPa for high performance concretes. Young's modulus of 50 to 60 GPa are common for RPC, as compared with values of 14 to 42 GPa of normal weight concrete (Mindness and Young 1981).Additionally, the material has tensile strength of between 6-13 MPa that is maintained after first cracking, where as traditional concrete has tensile strengths on the order of 2 to 4 MPa that is lost when cracking occurs.

2.1.3 Durability

RPC has ultra-high durability characteristic resulting from its extremely low porosity, low permeability, limited shrinkage and increasing corrosion resistance. In comparison to OPC, there is no RPC its use in chemically aggressive environments and where physical wear greatly limits the life of other concretes RPC is a high strength ductility and low porosity cementious material.RPC properties are improved by fresh RPC samples, which can increase its specific weight as high as 3000kg/m^3.The high content silica fumes increase the compressive strength and decrease the density. The silica fumes produced high strength RPC with a specific weight as low as 1900kg/m^3.The light weight reactive powder concrete could be used in area where substantial weight saving can be realized and where remarkable characteristics of the material can be fully utilized.

2.2 Experimental Programme

To obtain a good workability and minimal secondary effects the synthetic polymer dosage can be optimized with a rheometer which is specially designed for RPC.This new family materials has compressive strengths of (170 to 230MPa), Young's modulus (55 GPa to 60 GPa)and flexural strengths (30 to 50 MPa) depending on the type of fibers used. The ductile behavior of this material is a first for concrete. The materials, has a capacity to deform and supports flexural and tensile load even after initial cracking. These performances are result of improved micro- structural properties of the mineral matrix especially and toughness and control of bond between matrix and fiber. The durability properties are those of impermeable materials. There is almost no carbonation or penetration of chlorides and sulfates, and high resistance to acid attack. Resistance to abrasion is similar to that of rock

1. To determine the guide lines for the production of RPC i.e. selection of material of mix proportion and curing.

2. To investigation to the compressive strength and tensile strength of concrete to determine its suitability for use in multistoried building.

3. The aim of project is to produce to the RPC of the following properties.

Compressive strength -180 MPa to 230 MPa

Flexural strength - 40 MPa to 60 MPa

Young's modulus - 55 GPa to 60 GPa

4. Also to compare the results of RPC with similar OPC Under same laboratory condition.

2.3 Experimental Procedures

1. The size of cube taken is 70mmx70mmx70mm.

2.6 Kg cement, 1.5kg silica fumes, 1.86 kg quartz powder, 6.54 kg Ennur sand, 45mmsize 0.18 kg steel fiber, 0.09 liters super plasticizers &2.1 liters waters are used to make the cube.

3. The w/c is 0.35% for the 1st set of test and 0.3 for the 2nd set of testing.

4. All the materials are hand mixed then water and super plasticizers are added. After attaining a homogeneous mix, the concrete is placed in 70mmx70mmx70mm cube in 3 layers as per IS code 456-2000.

5. Compaction of concrete is done in 3 layers using vibrating table as per the IS code.

6. After 24 hours, the curing of concrete started for the 1st set of 3 cubes. The next set of the cubes are placed in the auto clave for 8 hours under 90^{0}c temperature before curing is started.

7. The curing is done up to 28 days.

8. The cubes are tested for 7 days and 28 days compressive strength.

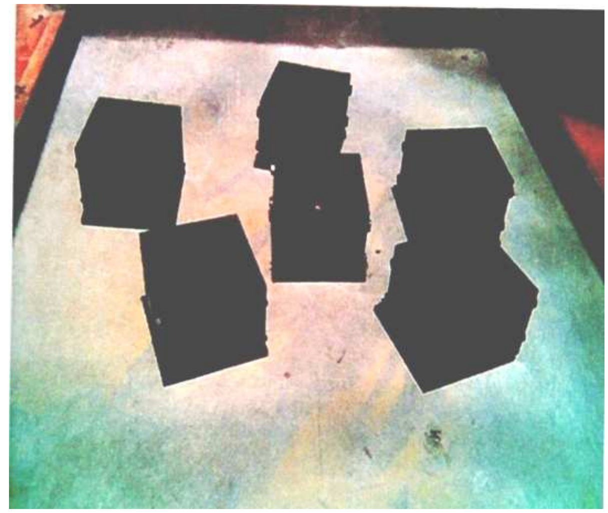

Figure-1 RPC Test Specimen 70X70X70mm

Figure-2 Compression Testing Machine

2.4 Material and mix proportion

Table-3, R.P.C-1

Sl. no.	MATERIALS	MIX PROPERTION
1	CEMENT	6Kg
2	SILICA FUMES	1.5 Kg
3	QUARTZPOWDER	1.86Kg
4	ENNUR SAND	6.54Kg
5	45mm STEEL FIBER	0.18Kg
6	SUPERPLASTICIZER	0.09 Lts
7	WATER	2.1Lts
8	W/C	0.35%

Table-4, R.P.C-1

Sl. no.	MATERIALS	MIX PROPERTION
1	CEMENT	10Kg
2	SILICA FUMES	2.5 Kg
3	QUARTZPOWDER	2.1Kg
4	ENNUR SAND	8.3Kg
5	45mm STEEL FIBER	0.8Kg
6	SUPERPLASTICIZER	0.015Lts
7	WATER	3.1Lts
8	W/C	0.3%

2.5 Particle size distribution (Ennur Sand)

Table-5

Sieve size In mm	Wt. of sample retained in gm	% of soil retain ed	Cumu lative % retain ed	% of passing
4.75	0	0	0	100
2.36	0	0	0	100
1.18	0	0	0	100
600µ	0	0	0	100
4.25µ	120	12	12	88
300µ	80	8	20	80
150µ	50	5	25	75
pan	0	0	0	0

2.6 Particle size distribution (Quartz Powder)

Table-6

Sieve size in mm	Wt.of sample retain ed in gm	%of soil retain ed	Cumu lative % retain ed	% of passing
4.75	0	0	0	100
2.36	0	0	0	100
1.18	0	0	0	100
600µ	0	0	0	100
4.25µ	120	12	12	88
300µ	80	8	20	80
150µ	50	5	25	75
PAN	0	0	0	0

2.7 Specific Gravity of Ennur Sand

Table-7

Sl. no	**Observation & calculation**	**Determination No.**		
		1	2	3
	Observation			
1	Pycnometer	401	402	403
2	Room temp	26^0 C		
3	Mass of empty pycnometer (M_1)	705gm		
4	Mass of empty pycnometer and dry soil (M_2)	1200 gm		
5	Mass of pycnometer,soil,and water (M_3)	1800 gm		
6	Mass of pycnometer and water (M_4)	1500 gm		
7	Calculation M_2-M_1	495		
8	M_3-M_4	300		
9	G=(7)/(7)-(8)	2.65		

RESULT: Specific gravity of inner sand at 26^0c=2.65

2.8 Specific Gravity of Quartz powder

Table-8

Sl. no	**Observation & calculation**	**Determination No.**		
		1	2	3
	Observation			
1	Pycnometer	401	402	403
2	Room temp	26^0 C		
3	Mass of empty pycnometer (M_1)	705		
4	Mass of empty pycnometer and dry soil (M_2)	857		
5	Mass of pycnometer,soil,and water (M_3)	1318		
6	Mass of pycnometer and water (M_4)	1540		
7	Calculation M_2-M_1	222		
8	M_3-M_4	152		
9	G=(7)/(7)-(8)	2.58		

Specific gravity of inner sand at 26^0 C=2.58

2.9 Specific Gravity silica fume

Table-9

Sl. no	**Observation & calculation**	**Determination No.**		
		1	2	3
	Observation			
1	Pycnometer	401	402	403
2	Room temp	26^0 C		
3	Mass of empty pycnometer(M_1)	705		
4	Mass of empty pycnometer	865		

	and dry soil (M_2)			
5	Mass of pycnometer,soil,and water (M_3)	1540		
6	Mass of pycnometer and water (M_4)	1440		
7	Calculation M_2-M_1	260		
8	M_3-M_4	100		
9	G=(7)/(7)-(8)	2.6		

Specific gravity of inner sand at 26^0c=2.6

2.10 Mix proportion of RPC and OPC

Table-10

	RPC1	RPC2	OPC
CEMENT	1	1	1
FINE AGGREGATE	NONE	NONE	2
COARSE AGGREGATE	NONE	NONE	4
SILICA FUME	0.25	0.25	NONE
QUARTZ POWDER	0.31	0.31	NONE
ENNUR SAND	1.09	1.09	NONE
45mm STEEL FIBER	0.03	0.03	NONE
SUPER PLASTICIZER	0.015	0.015	NONE
W/C	0.35	0.3	0.4

III-RESULT AND DISCUSSION

TEST RESULTS OF SAMPLES WITH ORDINARY CURING

AT 7 DAYS

FOR CUBE

Sample -1=load/area =160x1000/ (70x70) =32.65N/mm^2

Sample-2=load/area=220x10^3/(70x70) =44.89N/mm^2

AT 28 DAYS

Sample-1=load/area=290x10^3/(70x70) =59.18N/mm^2

Sample-2=load/area=240x10^3/(70x70) =49N/mm^2

TEST RESULTS OF SAMPLE WITH AUTO CLAVE CURING

Figure-3 Autoclave Cube Testing at 90^{0}C

AT 7 DAYS

FOR CUBE

Sample-1=load/area=180x10^3/(70x70) =36.73N/mm^2

Sample-2=load/area=230x10^3/(70x70) =47.93N/mm^2

AT 28 DAYS

Sample-1=load/area=240x10^3/(70x70) =50.02N/mm^2

Sample-2=load/area=270x10^3/(70x70) =57N/mm^2

TEST RESULTS OF SAMPLES WITH OPC

AT 7 DAYS

Sample-1.Stress=load/are=100x10^3/ (70x70) =22.44N/mm^2

Sample-2.Stress=load/area=100x10^3/ (70x70) =20.40N/mm^2

AT 28 DAYS

Sample 1=27.75N/mm^2

Sample 2=26.50N/mm^2

RESULTS

Table-11

Compressive strength (7/days)	**RPC 1 (Ordinary) N/mm^2**	**RPC2 (Auto clave) N/mm^2**	**OPC N/m^2**
	32.65	36.73	22.44
	44.89	47.73	20.4
	36.73		
Compressive strength (28days)	59.18	50.02	27.75
	49.0	57.0	26.50
		58.1	25.00

Table-12

	Compressive strength	**Size**	**weight**
RPC	180MPa to 230 MPa	70x70 mm	0.745 kg
OPC	50 MPa to 60 MPa	150x150 mm	1.96 kg

The compressive strength of RPC can be recorded accurately if;

1. Curing is done under pressure of about 20psi.

2. Mixing is done in high speed mixture machine.

3. If high tensile fibers of aspect ratio 1 in 5 is added to increase the tensile strength.

IV-CONCLUSION

The project is carried out under ordinary atmosphere has yielded the following results. It is able to produce a RPC of compressive strength of 44.89N/mm^2 in 7 days and 59.18N/mm^2 in 28 days.

Under the same laboratory conditions the OPC cubes of mix proportion 1:2:4 is tested. The compressive strength at 7 days and 28 days are recorded, Compressive strength of 22.44N/mm^2 in 7 days and Compressive strength of 26.5N/mm^2 in 28 days.

The researches as shown with the locally available material under ordinary laboratory condition that we produce the RPC of 60 MPa strength. If we can improve the mixing, curing and post heating setting methods, we can improve the compressive strength up to 200MPa.If low alkali cement is used with w/c of 0.2 .we can also improve the compressive strength. The elimination of coarse aggregate combine to optimization granular mix allows obtaining and homogeneous and dense of cementious matrix, that exhibits high mechanical properties. Application conforming to the fresh concrete combine to excess removal of water furthers improves its density. Induced micro cracking does not impede compressive strength enhancement. Addition of small size of steel fibers of ratio 2 to 2.5% of volume gives RPC ductile behavior.

REFERENCES

[1] A.Feylssoufi, M.Cresein, P.Dion, H.VanDamme, Laboratoire des Materiaux, Groupe Bouybues," Controlled rate thermal treatment of reactive powder concrete" Cnrs &University, Oraleans, France.

[2] Aitcin P.C, "Cements of yesterday and today concrete of tomorrow", Cement and Concrete Research, Vol. 30, (2000), pp 1349 - 1359.

[3] Blais P. Y, and Couture M, "Precast, Prestressed Pedestrian Bridge - World's first reactive powder concrete structure", PCI Journal, Vol. 44, (1999), pp. 60 - 71.

[4] Basu P.C, "Performance Requirements of HPC for Indian NPP Structures", The Indian Concrete Journal, Sep. 1999, pp. 539 – 546.

[5] Bonneau O, Vernet C, Moranville M, and Aitcin P. C, "Characterization of the granular packing and percolation threshold of reactive powder concrete", Cement and Concrete Research, Vol. 30 (2000) pp. 1861 – 1867.

[6] Dauriac C, "Special Concrete may give steel stiff competition, Building with Concrete", The Seattle Daily Journal of Commerce, May 9, 1997.

[7] Lee N.P. & Chisholm D.H. (2005), “Reactive Powder Concrete” Study Report SR 146BRANZ Ltd, Judge Ford, New Zealand.

[8] Mohamed lachemi, Sherbrook, “The shear broke reactive powder concrete foot bridge”, Univ. Canada.

[9] Matte V and Moranville M, “Durability of Reactive Powder Composites: Influence of Silica Fume on the leaching properties of very low water/binder pastes”, Cement and Concrete Composites, 21 (1999) pp. 1 - 9.

[10] Richard P, and Cheyrezy M, “Composition of Reactive Powder Concrete”, Cement and Concrete Research, Vol. 25, No.7, (1995), pp. 1501 – 1511.

[11] Staquet S, and Espion B, “Influence of Cement and Silica Fume Type on Compressive Strength of Reactive Powder Concrete”, 6th International Symposium on HPC, University of Brussels, Belgium, (2000), pp. 1 – 14.

[12] Indian Standard Designation IS 516-1959, “Methods of Test for Strength of Concrete,” BIS, New Delhi, 2002.

[13] ASTM Standard Designation C109-99, “Standard Test Method for Compressive Strength of Hydraulic Cement Mortars,” ASTM, Pennsylvania, 2001.