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Review Paper on Reactive Powder Concrete (RPC)

Pawan Khandare[1], Rudra Gawas[2], Prathamesh Patil[3], Gaurav Niwalkar[4] Hari Chavan[5] and Assist Prof. Bhagoji Ranvir[6]

[1, 2,3,4,5] Student, Department of Civil Engineering, Zeal Education Society, Narhe, Pune-411041, Maharashtra, India

[6]Associate Professor, Department of Civil Engineering, Zeal Education Society, Narhe, Pune-411041, Maharashtra, India

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ABSTRACT: The development of new generation concrete by eliminating the coarser particles such as coarse aggregate and utilization of micro-particles like silica fume, quartz powder and sand thereby introducing reactive powder concrete (RPC) is presented in the present work. This study investigates mechanical properties of specimens with the addition of the RPC with micro-fibre reinforcement, thereby investigating the compressive strength, modulus of elasticity, flexural strength, ductility, and energy absorption under different curing conditions.

KEYWORDS: RPC, HPC, Silica fume, Steel fibers, Quartz.

I. INTRODUCTION

i. Reactive Powder Concrete

Reactive powder concrete (RPC) is the ultra-high strength concrete prepared by replacing the ordinary aggregate of normal concrete with quartz powder, silica fume, steel fibers etc. RPC not only has high strength but also has high ductility. Its compressive strength ranges from 200 MPa to 800 MPa.

Reactive powder concrete (RPC) is ultra-high strength and high ductile composite material with advanced mechanical properties. Reactive powder concrete is a concrete without coarse aggregate, but contains cement, silica fume, sand, quartz powder, super plasticizer and steel fiber with very low water binder ratio. The absence of coarse aggregate was considered by inventors to be key aspect for the microstructure and performance of RPC in order to reduce the heterogeneity between cement matrix and aggregate. Compressive strength of RPC ranges from 200 to 800 MPa, flexural strength between 30MPa and 50 MPa and Young's modulus up to 50-60 GPA. RPC structural elements can resist chemical attack, impact loading from vehicles and vessels and sudden kinetic loading due to earthquake. Ultra-high performance is the most important characteristic of RPC. There is a growing use of RPC owing to the outstanding mechanical properties and durability.

Reactive powder concrete contains Very fine powders like cement, fine sand, quartz powder of size less than 300 micron, silica fume, 1 cm length steel fibers of size 180 microns and super plasticizer. Typical Composition of ingredients in Reactive powder concrete of 200 MPa and 800 MPa the requirements for HPC used for the nuclear waste containment structures of Indian Nuclear Power Plants are normal compressive strength, moderate E value, uniform density, good workability, and high durability. There is a need to evaluate RPC regarding its strength and durability to suggest its use for nuclear waste containment structures in Indian context.

ii. High Performance Concrete

Engineers are constantly looking for new materials to provide answers to complex problems. As construction and material costs escalate, demand has increased for stronger materials. One of the first breakthroughs was the development of High Performance Concrete (HPC) characterized by a compressive strength of 100-120 MPa and high level durability which lead to interesting realizations in civil engineering The concrete that was known as high-strength concrete in the late 1970s is now referred to as high-performance concrete because it has been found to be much more than simply stronger discussed some significant differences between convene- tonal and high-performance concrete as below:

- Size and composition of constituents
- Water to cementations material ratio (w/cm)
- The use of steel fibers (sometimes micro-fibers) to improve ductility and toughness
- The amount of mixing energy employed
- Curing procedures. Other improvements have been obtained by adding polymer components to macro-defect-free (MDF) con- creates or by controlling the proportions and the me-

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chemical behaviour of components in the case of dense- field with small particles (DSP) concretes.

II. DEFINATION OF RPC

Reactive powder concrete (RPC) is the ultra-high strength concrete prepared by replacing the ordinary aggregate of normal concrete with quartz powder, silica fume, steel fibers etc. Fibers are incorporated in RPC in order to enhance the fracture properties of the composite material. RPC not only has high strength but also has high ductility.

i. Advantages of RPC

- Used in areas where weight savings is required.
- Low porosity
- Impermeable
- Replace steel in compression members
- Limited shrinkage
- Increased corrosion resistance
- No penetration of liquid or gas
- Improved seismic performance

ii. Limitations of RPC

- Least costly components of conventional concrete are eliminated by more expensive elements.
- RPC is still in the initial stages, So long term properties are not yet known.
- In RPC mixture design, the least costly components of conventional concrete are basically eliminated or replaced by more expensive elements.

iii. Principles for developing RPC

- Elimination of coarse aggregates for enhancement of homogeneity
- Utilization of the pozzolanic properties of silica fume
- Optimization of the granular mixture for the enhancement of compacted density
- The optimal usage of super plasticizer to reduce w/c and improve workability
- Application of pressure (before and during setting) to improve compaction
- Post-set heat-treatment for the enhancement of the microstructure
- Addition of small-sized steel fibers to improve ductility

III. PROPERTIES OF RPC

i. Mechanical properties

RPC has compressive strength between 200~800 MPa, modulus of rupture between 25~150 MPa, fracture energies of about 30,000 J/m2 and volume weights of 2500~3000 kg/m3.RPCs in-variably have Young's modulus values exceeding 50 GPA, which can go as high as 75 GPA. In the latter case we observe that the global modulus for the paste and aggregate is slightly higher than that for the silica aggregate. Thus the effect of mechanical heterogeneity has been totally removed, and even reversed.

ii. Homogeneity

The homogeneity of the concrete material can be improved by eliminating all coarse aggregates and making as much of the dry component materials the same particle size as possible. All the dry components for use in RPC are less than 600m.

iii. Compactness

The compactness can be enhanced by optimization of the granular mixture and the application of pressure before and during the concrete setting period

iv. Microstructure

The microstructure of the cement hydrate can be changed by applying heat treatment during the curing of concrete

v. Material ductility

RPC matrix can reach very high compressive strength by application of heat treatment and pressure, but its material ductility isn't better than that of a conventional matrix. The material ductility can be improved through the addition of short steel fibers.

IV. COMPOSITION OF RPC

RPC is composed of very fine powders (cement, sand, quartz powder and silica fume), steel fibers (optional) and super plasticizer. The super plasticizer, used at its optimal dosage, decreases the water to cement ratio (w/c) while improving the workability of the concrete. A very dense matrix is achieved by optimizing the granular packing of the dry fine powders. This compactness gives RPC ultra-high strength and durability6. Reactive Powder Concretes have compressive strengths ranging from 200 MPa to 800 MPa.

Mix Design for Reactive Powder Concrete Block (M20)

Cement Sand Ratio = 1:1.5
Size of Cube = 150mm × 150mm × 150mm
Volume of Cube = 0.003375m3

i. Cement

Volume of Cement Required
= (1/2.5) × Size of Cube
= (1/2.5) × 0.003375 = 0.00135m3
Weight of Cement Required
= Volume of Cement × Density
= 0.00135 × 1426 = 1.9251 = 2kg

- **Selection Parameter:**

C_3S (tricalcium silicate): 60%,
C_2S (dicalcium silicate): 22%,
C_3A (tricalcium aluminate): 3.8%,
C_4AF (calcium alumino ferrite): 7.4%.
(Optimum)

- **Function:** Binding material, Production of primary hydrates
- **Particle Size:** 1µm to 100µm
- **Type:** OPC, Medium fineness

ii. Sand

Volume of Sand Required
= (1.5/2.5) × Size of Cube
= (1.5/2.5) × 0.003375 = 0.002025m3
Weight of Sand Required
= Volume of Sand × Density
= 0.002025 × 1540 = 3.118kg

- **Selection Parameters:** Good hardness readily available and low cost.
- **Function:** Give strength,
- Aggregate
- **Particle Size:** 150µm to 600µm
- The material having the largest particle size in RPC is the sand.
- **Type:** Natural, Crushed

iii. Quartz

Volume of Quartz Required
= (36/100) × Volume of Sand
= (36/100) × 0.002025 = 0.000729m3
Weight of Quartz Required
= Volume of Quartz Sand × Density
= 0.000729 × 1676 = 1.22kg

- **Selection Parameters:** fineness.
- **Function:** Maximum reactivity during heat treating. It fills grade between sand and cement particles making the matrix denser.
- **Particle Size:** 5µm to 25µm
- **Type:** Crystalline

iv. Silica Fume

Volume of Silica Fume Required
= (15/100) × volume of cement
= (15/100) × 0.00135 = 0.0002025m3
Weight of Silica Fume Required
= Volume of Silica Fume Required × Density
= 0.0002025 × 670 = 0.1356kg

- The main quality of a silica fume is the absence of aggregates.
- Function of silica fume is Filling the voids

v. Fly Ash

Volume of Fly Ash required
= (15/100) × volume of cement
= (15/100) × 0.00135 = 0.0002025m3
Weight of Fly Ash Required
= Volume of Fly Ash Required × Density
= 0.0002025 × 860 = 0.1741kg

- **Selection Parameters:** Very less quantity of impurities.
- **Function:** Filling the voids,

Enhance theology,
Production of secondary hydrates

- **Particle Size:** 0.1 µm to 1 µm
- **Type:** Procured from Ferrosilicon industry

(highly refined)

vi. Steel Fiber

Weight of Steel Fiber Required
= Volume of Steel Fiber Required × Density
= (1.5/100) × 3.422 = 0.051kg = 50g

- **Selection Parameters:** Good aspect ratio
- **Function:** Improve ductility
- **Particle Size:** L : 13 – 25 mm

Ø : 0.15 – 0.2 mm
Type: Straight

vii. Water

Amount of Water required
= water cement ratio × weight of cement
= 0.25 × 1.9251 = 0.48 = 500ml

viii. Super Plasticizer

Amount of Super Plasticizer required
= 1% to weight of cement
= (1/100) × 3.422 = 1711ml

- It is used at its optimal dosage.
- Decreases the water to cement (w/c) ratio.
- Increases the workability of the concrete.

V. LITERATURE SURVEY

i. An Investigation on Reactive Powder Concrete containing Steel Fibers and Fly-Ash.

Journal and Author: International Journal of Emerging Technology and Advanced Engineering (Volume 2, Issue 9, September 2012) M K Maroliya.

Conclusion: The flexural strength of the RPC obtained by using circular steel fibers has increased by 50% compared to plain RPC when hot water curing is adopted and 18% higher than plain RPC when normal curing is adopted.

ii. Effect of silica fume on steel fiber bond characteristics in reactive powder concrete.

Journal and Author: Cement and concrete research (34)2004 Yin-Wen Chan, Shu-Hsien Chu

Conclusion: The incorporation of silica fume in RPC matrix remarkably enhances the steel fiber–matrix bond characteristics due to the interfacial-toughening effect upon fiber slip.

iii. Studies on Relationship between Water/Binder Ratio and Compressive Strength of High Volume Fly Ash Concrete.

Journal and Author: American Journal of Engineering Research (AJER) Issue-2(2013) Dr Sravana1 Sarika.P, Dr.Srinivasa Rao, Dr.Seshadri Sekhar T, Apparao.G

Conclusion: The fly ash used in these investigations exhibits good Pozzolanic properties and can be used in the production of high strength high volume fly ash concrete. High volumes of fly ash up to 50% can be used as additional material without sacrificing strength at lower w/b ratios.

iv. Micro structural behaviour of reactive powder concrete under different heating condition.

Journal and Author: Magazine of Concrete Research Volume 64 Issue 3(2012) Chi-ming Tam Vivian Wing-yan Tam

Conclusion:

- The duration of the heat treatment influences the form of the structure and quality of crystal formation.
- Increased heat-treatment temperature leads to the development of longer C–S–H chain.
- When the heat-treatment temperature increases, the compressive strength increases owing to C–S–H crystal formation, thereby improving the microstructure behaviour.

v. Factors affecting the strength of Reactive Powder Concrete (RPC).

Journal and Author: International Journal of Civil Engineering and Technology (IJCIET), Volume 3, Issue 2, July- December (2012) Khadiranaikar R.B. and Muranal S. M.

Conclusion:

- The maximum compressive strength of RPC obtained in the present study is 146 MPa at w/b ratio of 0.2 with accelerated curing.
- In the production of RPC the optimum percentage addition of silica fume is found to be 15% (by weight of cement) with available super plasticizer.
- The addition of quartz powder increases the compressive strength of RPC up to 20%
- The high temperature curing is essential for RPC to achieve higher strength. It increases the compressive strength up to 10% when compared with normal curing.

vi. Compressive strength of cementations concrete containing used foundry sand.

Journal and Author: National Conference on Recent Advances in Civil and Structural Engineering (RACSE-'14) April-2014 Smit M. Kacha1, Ankur C. Bhogayata2, Abhay V. Nakum

Conclusion: Replacement of natural sand by UFS provided an excellent improvement in basic strength property of concrete up to the replacement of 40%, the compressive strength was increased by 15%

VI. BENEFITS

- RPC is a better alternative to high performance concrete and has the potential to structurally compete with steel.
- Its superior strength combined with higher shear capacity results in significant dead load reduction and less limited shapes of structural members.
- With its ductile tension failure mechanism, RPC can be used to resist all but direct primary tensile stresses. This eliminates the need for supplemental shear and other auxiliary reinforcing steel.
- RPC provides improved seismic performance by reducing inertia loads with lighter members, allowing larger elastic deflections by reducing cross sections, providing higher energy absorption and improved confinement.
- Its low and non-interconnected porosity diminishes mass transfer making penetration of liquid/gas
- Radioactive elements nearly non-existent. Cesium diffusion is non-existent and Tritium diffusion is 45 times lower than conventional containment materials

VII. UTILIZATION

RPC is a natural extension of existing high performance concrete and has the potential to structurally compete with steel. RPC is significantly more expensive than normal strength concrete or even high performance concrete, but less expensive than steel on a volumetric basis, since steel has a compressive strength similar to RPC. Based on the properties and cost of RPC, RPC will have potential in the construction industry in a number of markets where it may compete with steel.

VIII. APPLICATIONS

- Impact-resistant structures
- Nuclear structures
- Used in areas where weight savings is required.
- **Low** porosity
- Impermeable
- Replace steel in compression members
- Limited shrinkage Z
- Increased corrosion resistance
- No penetration of liquid or gas
- Skyscrapers
- Corrosion-proof structures
- Pavements
- Barrier to nuclear radiation.

- Security for banks, computer centers
- Pedestrian Bridge 197m span, 3.3m wide, 3.0m deep, 30mm thick slab, in the city of Sherbrook, Quebec, Canada.
- Seonyu foot Bridge 120m span, 4.4m wide, 1.3m deep, 30mm thick slab, in Seoul, Korea
- Sakata Mirai footbridge, in Japan
- Sewer, Culvert and pressure pipes in Army engineer waterways experiment station, Vicksburg, MS.
- Isolation and containment of nuclear waste of several projects in Europe.
- Half-canopy in steel form of Shawnessy Light Rail Transit Station, Calgary, Canada

IX. CONCLUSION

RPC is an emerging technology that lends a new dimension to the term high performance concrete. It has immense potential in construction due to superior mechanical and durability properties than conventional high performance concrete, and could even replace steel in some applications. The development of RPC is based on the application of some basic principles to achieve enhanced homogeneity, very good workability, high compaction, improved microstructure and high ductility. RPC has an ultra-dense microstructure, giving advantageous waterproofing and durability characteristics. It could, therefore be a suitable choice for industrial and nuclear waste storage facilities.

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