A Study on Properties of Reactive Powder Concrete Using Industrial Wastes

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Abstract: In this paper, we are hoping to prepare a Reactive Powder Concrete using locally available Industrial Waste materials like Fly Ash, Silica Fume and Quarry Dust. Reactive Powder Concrete (RPC) is an Ultra High Performance concrete which has very low water per cement ratio and has no coarse aggregate. Steel Fibers are incorporated in RPC to enhance the tensile properties of the concrete. Reactive Powder Concrete is a revolutionary material that provides a combination of ultra- high strength and excellent durability. The usage of Industrial Wastes helps to reduce the impact on the environment due to waste materials.

Index Terms **- Reactive Powder Concrete, Silica Fume, Fly Ash, Quarry Dust, Ultra-High Strength, durability.**

I. INTRODUCTION

Reactive powder concrete is a high performance concrete, a new generation concrete, formed from a special combination of constituent materials. The composition of reactive powder concrete includes pozzolanic Portland cement, manufactured sand, silica fume, quartz powder, quartz sand and high tensile steel fibers with very low water cement ratio. This concrete does not contain coarse aggregate. Reactive powder concrete is grouped under Ultra High Performance Concrete. This type of concrete has enhanced mechanical and durability properties. This concrete has a very high compressive strength of 200 MPa which can be improved further by introducing steel pellets up to 800MPa. This new family of concrete has improved ductile behavior with a flexural strength of 25MPa to 40MPa. These performances are due to the improved microstructure properties and highly discontinuous pore structure. Also, the toughness index of this concrete is high when compared with the ordinary confined concrete. There is almost no carbonation and chloride ion penetration and near zero sulphate attack. Moreover the resistance to abrasion is near to rock. The net effect is a maximum compactness and highly disconnected pore structure. There is also no shrinkage or creep, which makes the material very suitable for application in prestressed and prefabricated structures. Many researchers around the world have developed RPC that could be classified, as Ultra High Performance Concrete (UHPC). This material has a capacity to take high load, deform and support flexural and tensile load, even after initial cracking. The concept of Reactive Powder Concrete was first developed by P. Richard and M. Cheyrezy. RPC was first produced in the early 1990s by researchers at BOUYGUE's laboratory in France**.** The first footbridge made of RPC in the world is located at Sherbrooke, Québec Province, Canada. It adopts truss structure of RPC steel tube in 60 m width. Stainless steel tube loaded with RPC200 is used to make the web member of the truss structure. The lower chord is RPC twin beams. Each of the prefabricated sections is 10 m long and 3 m high and they are assembled together through post- tensioned pre-stressing after being transported to the site. The use of RPC not only mitigates weight greatly but also improves the structure's durability to resist the frequent corrosion from the de-icing salt and damage due to the freezing and thawing cycle under environments with high humidity.

II. LITERATURE REVIEW

1. Journal Name: A Study on Properties of Reactive Powder Concrete

Author Names: Dr. Elson John and Sarika S

Journal Publication: International Journal Of Engineering Research And Technology (IJERT) | Volume 4 - Issue 11 | Published Online: Nov 2015.

Studies were conducted on the performance of Reactive Powder Concrete (RPC) using quartz sand of maximum size 2.36 mm and found the compressive strength and work ability of Reactive Powder Concrete. They found that it is possible to produce RPC even under normal curing conditions. They produced concrete of compressive strength 130MPa after 28 days of normal curing and having a spread diameter of 260 mm which was tested using slump flow test. The paper suggests that by the use of temperature curing the mechanical properties of the reactive powder concrete can be further improved.

2. Journal Name: Composition of Reactive Powder Concrete.

Author Names: Richard .P and Cheyrezy .M

Journal Publication: Cement And Concrete Research |Volume 25 | Pages 1501-1511 | Published Online: Feb 1995

Ultra- high strength ductile concrete was developed with the basic principles of enhancing the homogeneity by eliminating the coarse aggregate and enhancing the microstructure by post-set heat treatment. In addition, the ductility and tensile strength of concrete is increased by incorporating small, straight, high tensile microfibers. Two types of concretes are developed and designated as RPC 200 and RPC 800. These concretes had exceptional mechanical properties, which resulted in elimination of reinforcement, and reduction of materials resulting in reduction of self-weight resulting in cost savings. The concrete finds its applications in industrial and nuclear waste storage silos.

3. Journal Name: Investigations On Reactive Powder Concrete: A Developing Ultra High Strength Technology

Author Names: Dili and Manu Santhanam

Journal Publication: Indian Concrete Journal |Volume 78 –Issue 4 | Published Online: April 2005.

Two RPC mixes of 200MPa and 800MPa strength were developed, which could be suitable for nuclear waste containment structures. The workability and durability properties were studied for the designed RPC mix. Also characterization of mechanical properties was carried out. The durability test carried out for the RPC mixes showed that the flow table test as per ASTM C 109 was in the range of 120%-140% and the water and chloride ion Permeability is extremely low. These test results indicates the suitability of the designed RPC mix for nuclear waste containment structures. However, the suitability of RPC mix for use in nuclear waste containment structures with respect to resistance then penetration of heavy metals and other toxic wastes emanating from nuclear plants has to study.

4. Journal Name: Assessing Drying Shrinkage And Water Permeability Of Reactive Powder Concrete Produced In Hong Kong.

Author Names: C. M. Tam, V. W. Y. Tam, and K. M. Ng

Journal Publication: Construction And Building Materials |Volume 26 – Issue 1 | Pages 79-89 | Published Online: 2012.

Reactive powder concrete was attempted to produce using local materials under laboratory conditions. Concrete designed from reactive powder concrete and high-performance concrete is experimentally conducted and compared. The results show that the compressive strength, splitting tensile strength and static modulus of elasticity are found to be significantly higher than that of high-performance concrete using the same water-to-binder ratio. It is noted that the rate of strength development of the reactive powder concrete samples is greater than that of high-performance concrete. The difference in strength at a later age is even bigger. Compressive strength of about 200 MPa could even be achieved in 3 days for the reactive powder concrete samples when the samples were heat-treated at a temperature of about 250°C for 16 h, which can be explained by the formation of xonotlite under scanning electron microscopy investigation.

III. MATERIAL PROPERTIES

1. Cement

In this paper, we are using OPC-53 grade cement which is confining to IS 12269-2013. The physical properties of cement are as follows.

Table 1: Physical Properties of Cement

S.No	Description	Values obtained
1	Consistency	31%
2	Initial setting time	40 minutes
3	Final setting time	560 minutes
4	Specific gravity	3.15

2. Fly Ash

In this paper, we are using fly ash as 25% replacement of cement which is confining to ASTM C618. Fly ash is also known as flue-ash, it is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases.

Figure 1: Fly Ash

3. Silica Fume

Silica fume also called as micro silica is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. In this paper, we are using silica fume of 25% by weight of binder or powder content confining to ASTM C 1240.

Figure 2: Silica Fume

4. Fine aggregate

Fine aggregate is the portion of the aggregate that is less than the size of 4.75 mm in size. Fine aggregates are one of the important constituents of concrete. In this paper, we are using Quarry Dust of maximum size 600 micron which is confining to IS 383-1970.

Table 2: Physical Properties of Quarry Dust

S.No	Description	Values obtained
1	Bulk density	1.85
2	Specific gravity	2.57
3	Voids	42%
4	Water absorption	1%
5	Fineness modulus	2.41

5. Steel fibers

Steel fibers are used to enhance the durability and flexural property of reactive powder concrete. In this paper, we are using steel fibers of diameter 0.5 mm and length 30 mm with a tensile strength greater than 1100 MPa. The physical properties of steel fibers are as follows.

Table 3: Physical Properties of Steel Fibers

S.No	Description	Values
1	Length	30 mm
2	Diameter	0.5 mm
3	Aspect ratio	60
4	Tensile strength	>1100 MPa
5	Density	7850 kg/m^3

6. Mixing water

Potable mixing water was used for preparing the concrete.

7. Super-plasticizers

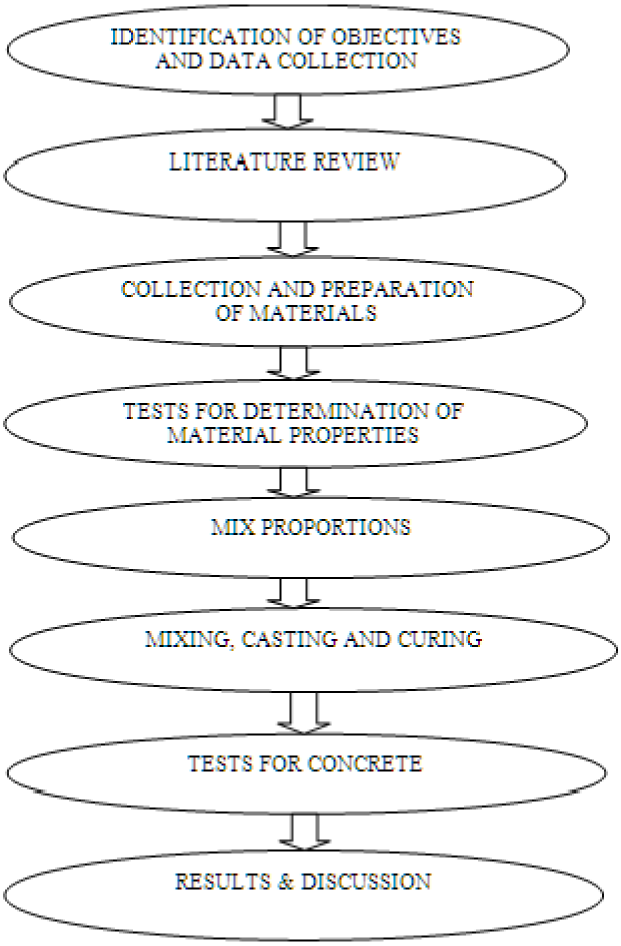
Super plasticizers are known as high range water reducers and are chemical admixtures which are used where well dispersed particle suspension is required. In this paper, we are using Conplast SP430 (HRWR) of 3.3% of powder content. The performance data sheet of Conplast SP430 is given below.

Table 4: Performance Data Sheet of Conplast SP430

S.NO	Description	values
1	Aspect	Light brown liquid
2	Relative density	1.08
3	PH	>=6
4	Chloride ion content	<0.2%

Figure 3: Conplast SP430

IV. METHODOLOGY



V. DESIGN CONCEPTS USED

1. **Post- Peak Behaviour**:

The post- peak behavior is the behavior or characteristic exhibited by concrete after the ultimate load is reached. This behavior of concrete is very important because it helps to prevent sudden failure of concrete, which is more common in high strength concrete. The post-peak behavior can be enhanced by the addition of fibers to the concrete. It is also known as post-crack property. The graph shows the behavior of various grades of concrete after the ultimate load is reached. It is found that higher grades of concrete have poor post-peak behavior than lower grades of concrete. To enhance this property fibers are added to concrete which in turn increases the tensile property of concrete.

2. **Densification And Homogeneity**:

Densification is the process of filling the voids in concrete. The general idea of concrete is that the fine aggregate fills the voids of the coarse aggregate, the cement content fills the voids of the fine aggregate, and finally the voids in the cement are filled by various cementitious materials like fly ash, silica fume, Metakaolin etc. In RPC, this concept is used to attain high performance and impermeability. The omission of coarse aggregate is done to prevent the interfacial bond failure in concrete. By achieving a homogeneous mix of various fine powders by mixing and compaction during placing, a uniform cement matrix paste is obtained which gives the concrete very high strength.

VI. MIX PROPORTION

The mix proportion adopted for RPC is given below.
Water/ powder ratio = 0.28

Table 5: Mix Proportion

S.No	Material	Percentage (%) used	Quantity
1	Cement	60% of total powder content	716 kg/m^3
2	Fly Ash	20% of total powder content	239 kg/m^3
3	Silica Fume	20% of total powder content	239 kg/m^3
4	Water	28% of total powder content	335 kg/m^3
5	Quarry Dust	1.467 times the weight of cement content	1050 kg/m^3
6	Steel Fibers	10% of weight of cement content	95 kg/m^3
7	Super-plasticizer	3.3% of total powder content	39 kg/m^3

VII. MIXING, PLACING AND CURING PROCEDURE

Mixing is one of the main steps in preparation of RPC (Reactive Powder Concrete). Since it has mainly fine powders as materials it requires excellent mixing and greater time or duration of mixing. Generally machine mixing is done to obtain a very even homogeneous mix, but in our project we used hand mixing. Firstly, all the materials are weighed and placed separately. Then the cement content is mixed with fly ash until an even colour is achieved. Then this mixture is mixed with the silica fume content until the uneven white colour disappears. Secondly, the whole mixture is dry mixed with the quarry dust until a homogeneous mix is obtained. Now 75% of the mix water is added and then it is mixed rapidly with trowels by hand to prevent the formation of lumps. Thirdly, 15% of mix water and 70% of super plasticizer is added and the mixing is done for 3-4 minutes to achieve consistency. Then the remaining water and super-plasticizer content is added and it is mixed for another 4 minutes. Finally, the steel fibres are added to the mixture and the mixing is done for 2 minutes to achieve uniform distribution of steel fibres. The moulds are first cleaned and oiled before starting the mixing process, and then the concrete mixture is carefully placed into the moulds of dimension (70.6 mm*70.6 mm). They are placed in layers with compactions using tamping rod. Then, they are removed from the moulds after 23 hrs from the time of mixing of concrete. The cubes are then placed in water for normal curing of 28 days.

VIII. TEST FOR DETERMINATION OF PROPERTIES OF CONCRETE

1. Slump Flow Test

   The slump flow test is used to determine the workability of concrete. In this test, the slump cone mould is filled with RPC in layers. Then the mould is lifted vertically up in gentle manner and the spread diameter in two perpendicular directions is measured. The average value gives the spread diameter of concrete.

2. Compressive strength test

   The 70.6 mm* 70.6 mm cubes were removed from the curing tank and wiped clean of the water. Then they are tested using compression testing machine of capacity 1000 KN capacity as per IS 516: 1959 specifications.

Figure 4: Compression Test

IX. RESULTS AND DISCUSSIONS

1. Slump flow test

The results of slump flow test are shown in tabular column.

Table 6: Workability of Concrete

S.No	Parameter	Value
1.	Spread of concrete	280 mm

2. Compression test

The results of compression test are shown in tabular column below.

Table 7: Compressive Strength of RPC

Specimen Number	Compressive strength (N/mm^2)		Average compressive strength (N/mm^2)	
	7 days	28 days	7 days	28days
1	49.23	82.12	49.38	82.41
2	50.34	83.46		
3	48.57	81.63		

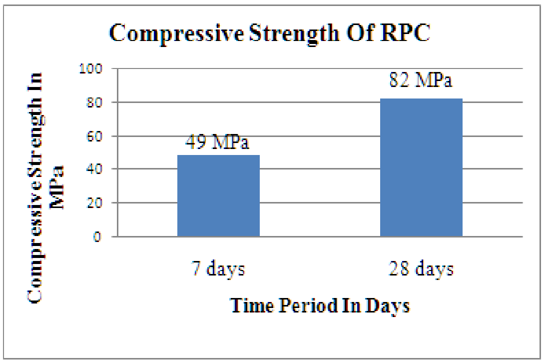


Figure 5: Compressive strength of RPC.

The test results indicate that RPC of maximum compressive strength 82 MPa can be produced. The main reasons for the low compressive strength are,

- Usage of 25% Fly Ash as cement replacement which causes late ultimate strength gain.
- Due to omission of quartz powder causes porosity and lesser densification leading to lower strength.
- Higher water/binder ratio leads to lower compressive strength due to formation of water voids.
- Usage of quarry dust as total sand replacement reduces the compressive strength.
- Hand mixing leads to lesser homogeneity of concrete mix, RPC requires machine mixing.
- Usage of normal curing can require more duration for strength gain.
- Usage of Conplast SP430 requires more water to exhibit super-plasticizer action thus requiring more water.

X.CONCLUSION

Concrete has become an indispensable part of human life, so it is necessary to improve the properties of concrete for obtaining better applications in day-to-day life. The use of waste materials in RPC helps to produce a high strength concrete which is environmental friendly and also cost efficient. This helps to meet the growing demand for raw materials and lead to sustainable future.

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