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A Study on Properties of Reactive Powder Concrete

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***Abstract* - The term reactive powder concrete (RPC) has been used to describe a fibre reinforced , superplasticized, silica fume-cement mixture with very low water-cement ratio, characterized by the presence of very fine aggregates instead of ordinary aggregate. It is having compressive strength about 150MPa. Fibres are incorporated in RPC in order to enhance the fracture properties of the composite material. Reactive powder concrete, is recognised as a revolutionary material that provides a combination of ultra-high strength and excellent durability. However, production of reactive powder concrete is not yet available with the limited research in this area. This paper investigates mechanical and fresh concrete properties of reactive powder concrete.**

Keywords – Reactive Powder Concrete, Compressive strength, Workability.

I. INTRODUCTION

The demand for high strength construction materials is the force behind the development of Reactive Powder Concrete. The pre-stressed hybrid pedestrian bridge at Sherbrooke in Canada, shown in fig 1, completed in 1997 was the first engineering structure application of RPC. In 1997 and 1998, RPCs were cast in beams of Cattenom and Civaux power plants as the first industrial application. The first UHPC road bridge was designed and constructed at Bourg-les-Valence in France in 2001 [2]. The preparation and performance of UHPC have been investigated in other literatures [3-5].

Ultra high performance concrete is characterized primarily with high strength(>150MPa), and when it is reinforced with steel fibers, exhibits high ductility.

Original Reactive Powder Concrete (RPC), otherwise known as ultra high performance concrete (UHPC), was developed through microstructural enhancement techniques for cementitious materials. RPC term has been used to describe a fibre- reinforced, superplasticized, silica fume-cement mixture with very low water-cement ratio, characterized by the presence of very fine aggregates instead of ordinary aggregate. In fact, it is not a concrete because there is no coarse aggregate in the cement mixture. Fibres are incorporated in RPC in order to enhance the fracture properties of the composite material. The advantages of Reactive Powder Concrete (RPC) include higher durability, ductility and strength in comparison with normal concrete and fibre reinforced concrete due to its extremely low porosity, dense matrix, high tensile/compressive strength, and ductile tensile behavior. In comparison with normal steel reinforced concrete, the application of RPC is expected to improve the resistance of buildings and infrastructures under extreme mechanical and environmental loads.

Reactive Powder Concrete (RPC), which is UHPC, lies at the front in terms of innovation, aesthetics and structural efficiency. This new concrete type has compressive strengths of 150-230 MPa depending on the type and amount of fibres used. RPC has an ultra-dense microstructure as ultra high strength concrete. RPC based on the densest packing theory with heat curing is investigated and it is observed that it exhibits compressive strength of more than 200 MPa with great ductility. Reactive Powder Concretes are characterized by a high silica fume content and very low water to cement ratio. Very fine granulometry sand and heat treatment are optimized to obtain excellent mechanical and durability properties. In order to increase concrete ductility and flexural strength, metallic fibers can be added.

Currently, to achieve excellent mechanical behaviour, some special techniques and raw materials must be adopted in the preparation of RPC, which include:

(a) Coarse aggregate is removed to enhance the homogeneity of concrete.

(b) Metal fibre or steel tube is introduced to improve ductility of composites.

(c) High quality superplasticizer and large quantities of superfine silica fume and quartz are added, to achieve a low water/binder ratio to reduce porosity and improve strength.

(d) Pressure may be applied before and during the setting to increase the compactness of the concrete.

(e) High activity micro-silica and/or precipitated silica may be mixed into cementitious materials to accelerate the hydration of cement and catalyze a strong pozzolanic reaction effect.

(f) Steam curing may be supplied to gain higher strength.

In short, to gain the desired strength of a UHPC, well-chosen raw materials and sophisticated technical procedures are conventionally required.[2]

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The RPC offers superior technical characteristics including ductility, strength, and durability while providing highly moldable products with a high quality surface aspect. This innovative, unique combination of properties enables designers to create thinner sections and longer spans that are lighter, more graceful and innovative in geometry and form while providing improved durability and impermeability against corrosion, abrasion and impact. The material technology permits it to be used without passive reinforcing (rebar) and reductions in formwork, labor and maintenance further add to economy. The elimination of rebar improves safety, the reduction of weight speeds construction, and the improved durability reduces maintenance and extends the usage-life. Many researches were conducted on Reactive Powder concrete, and in most of them, material characterization only is done. The main purpose of the present study is to find how effectively RPC can be used for structural applications.

Fig. 1. Sherbrooke Bridge

II. LITERATURE REVIEW

Mohammed Mansour et al. (2014) [3] conducted studies on the performance of Reactive Powder Concrete (RPC) under two different curing conditions, water curing at 25°C and heat treatment at 90°C and 95% relative humidity. They studied the influence of using steel fiber and heat treatment on RPC slab specimen. Slabs, simply supported along four edges were loaded concentrically by a square plate of dimension (70x70x25mm). It was found that the use of steel fibers and heat treatment showed adequate improvement on the compressive strength, indirect tensile strength, modulus of elasticity and flexural strength. The experimental results showed that the presence of ultra fine steel fibers gives improved stiffness, reduced crack width and propagation of cracks. The steel fibers provide sufficient tensile strength and ductility. This allows the reduction of reinforcement needed for resisting tension for many structural applications and thus there can be a reduction in self weight and cost. This enables the designer to create thinner sections, longer spans and taller structures.

R.Yu et al. (2014) [5] presents the mix design and properties assessment of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC). The design of the concrete mixtures is done to get a densely compacted cementitious matrix. The workability, porosity, air content, compressive and flexural strengths of the designed UHPFRC are measured and analyzed. The results supports the design UHPFRC with a relatively low binder amount, by utilizing the improved packing model. The cement hydration degree of UHPFRC is calculated. And the results show that, after 28 day of curing, there is still a large amount of unhydrated cement in the UHPFRC matrix, which could be further replaced by fillers to improve the workability and cost efficiency of UHPFRC. This study supports the use of admixtures in UHPFRC.

H.M.Al -Hassani et al. (2014) [1] investigated some mechanical properties of Reactive Powder Concrete (RPC). These properties include compressive strength, static modulus of elasticity, tensile strength (direct, splitting and flexural), load-deflection capacity and flexural toughness. The variable parameters in the study where the silica fume content (SF) as a partial replacement by weight of cement, steel fiber volume fraction and superplasticizer type. The effect of these variables on the properties of RPC were carefully studied. The experimental results showed the increase in silica fume content (SF) from 0% to 30% lead to a significant increase in compressive strength, while the increase in tensile strength is relatively lower. The inclusion of steel fibers leads to a considerable increase in tensile strength, and only a slight increase in compressive strength of RPC, as fiber volume fraction increases from 0% to 3%. The increase in the steel fiber volume fraction and silica fume content improved the load-deflection behavior and resulted in larger ductility and fracture toughness of RPC.

C.M.Tam et al. (2010) [2] investigated mechanical and fresh concrete properties of reactive powder concrete, aiming to achieve the optimal conditions for producing reactive powder concrete using local materials by investigating the material composition, curing and heating regimes and the microstructure of reactive powder concrete. Based on the experimental results, it is found that reactive powder concrete with a water-to-binder ratio of 0.2, superplasticizer dosage of 2.5%, 150–600 micron quartz sand cured at 27°C in water condition provides the best results in terms of mechanical and composite properties as well as for practical and economical reasons, although heat treatment of the reactive powder concrete can result in a significant increase in compressive strength.

K.M.Ng et al. (2010) [4] attempt to produce reactive powder concrete 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.

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III. Material Properties

1) Cement:

Ordinary Portland Cement of 53 grade was used for the study. The physical properties of cement used are given in table I.

TABLE I. PHYSICAL PROPERTIES OF CEMENT

Specific Gravity	3.14
Standard Consistency	35%
Initial setting time	76
Final setting time	380

2) Silicafume:

A highly reactive silica pozzolan is an essential component of reactive powder concrete.

In the study Microsilica 920D have been used. It conforms to the mandatory requirements of the relevant standards from American Society of Testing and Materials (ASTM) and European Committee for Standardisation. The chemical composition of the material is given in table II

TABLE II. CHEMICAL COMPOSITION OF MICROSILICA 920D

Mandatory chemical and physical requirements	ASTM C1240 - 03		prEN 13263	
	Spec.	Frequency	Spec.	Frequency
SiO_2 (%)	> 85,0	400 MT	> 85	weekly
SO_3 (%)			< 2,0	weekly
Cl (%)			< 0,3	weekly
Free CaO (%)			< 1,0	weekly
Free Si (%)			< 0,4	monthly
Alkalies (as equivalent Na_2O, %)	Report	400 MT		
Moisture (%)	< 3,0	400 MT		
Loss on Ignition, LOI (%)	< 6,0	400 MT	< 4,0	weekly
Specific surface (BET - m^2/gram)	> 15	3200 MT/3 months	> 15 & <35	monthly
Bulk density (kg/m^3)	Report	400 MT		
Pozz. Activity Index (%) - 7 days accelerated curing	> 105	3200 MT/3 months		
Pozz. Activity Index (%) - 28 days normal curing			> 100	monthly
Retained on 45 micron sieve (%)	< 10	400 MT		
Variation from avg. retained on 45 micron (%-points)	< 5	avg. of last 10 tests		
Density (kg/m^3)	Report	400 MT		

3) Water:

Potable water was used for mixing.

4) Superplasticizers (SP):

Polycarboxylates ether condensate (PCE) based superplasticizer was used in the study. Table III shows the data sheet of superplasticizer.

TABLE III. PERFORMANCE DATA SHEET OF SUPERPLASTICIZER.

Aspect	Light brown liquid
Relative Density	1.08 ± 0.01 at 25°C
pH	≥ 6
Chloride ion content	< 0.2%

5) Quartz Powder

For RPC mixes designed to be temperature cured, including autoclaving at elevated pressures, additional silica is necessary to modify the CaO/SiO ratio of the binder. In these cases powdered quartz flour with a mean particle size of 10 – 15 µm was employed.

6) Fine Aggregate

RPC is produced using manufactured sand having particle size less than 2.36mm.Three different gradations are used, having size between 2.36 mm and 1.18mm, between 1.18mm and 600 micron, and from 600- 0 micron, in different proportions.

7) Steel Fibres

To enhance the RPC ductility, mixes were produced with steel fibers of length 20 mm and diameter 0.3 mm, with a minimum on-the-wire tensile strength is greater than 1100 MPa. The details of steel fiber is shown in table IV.

TABLE IV. DETAILS OF STEEL FIBRE

Length	Diameter	Aspect Ratio	Tensile stength
20mm	0.3mm	66	>1100MPa

IV. Mix Proportion

The mix proportion adopted for the RPC mix is given in table V.

TABLE V. MIX PROPORTION

Material	**Mix Proportion (kg/m^3)**
Cement	1000
Silica fume	225
Quartz powder	252
w/b	0.2
Water	245
Steel fibre	30.6
Superplasticizer	49
Aggregate (2.36mm-1.18mm)	700
Aggregate (1.18mm-600µ)	150
Aggregate (600µ-0)	100

V. Mixing Procedure

All the materials are mixed in dry state for 2 minutes, then 80% of the mixing water is added and mixed for 3 minutes, 15% water and 70% superplasticizer is added and mixed again for 3 minutes then the mixer machine is stopped for 1 minute. Now the remaining water and super plasticizer is added and mixing is continued for 4 minutes. Steel fibres are added and mixed for 1 minute for uniform distribution. The total mixing time is 14 minutes.

VI. Curing

100mmx100mm sized cubes are casted and water cured for 28days.

VII. Properties of Concrete

A. *Fresh properties of concrete*

1) Workability of concrete

Slump flow test is conducted to measure the workability of concrete. In this test, the mould is filled with RPC and the spread diameter of the RPC is measured in two directions orthogonally, after lifting the mould vertically upwards. The average value is expressed as the spread of the concrete. The bleeding and segregation of the mix can be examined visually. The spread of concrete is shown in fig 2.

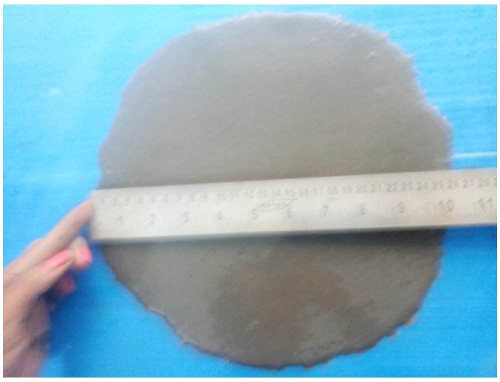

Fig. 2. Slump flow test

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B. Mechanical properties of hardened concrete

1) Compressive strength of hardened concrete

The compressive strength test was carried out on cubical specimen of size 100mm in a compression testing machine of capacity 2000kN, as per IS 516:1959 specification. The setup of compression test is shown in fig 3.

Fig. 3. Compression test

VIII. RESULTS AND DISCUSSIONS

A. Workability of concrete

TABLE VI. WORKABILITY OF CONCRETE

Spread of concrete	260mm

B. Compressive strength of hardened concrete

TABLE VII. COMPRESSIVE STRENGTH

Compressive strength (N/mm^2)	
7 day	28day
92	130

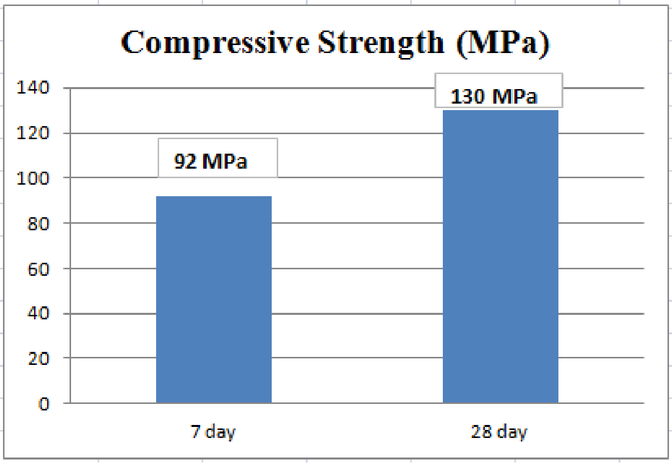

Fig. 4. Variation of compressive strength

The 28 day strength of the mix is 130MPa. 70% of the 28th day strength is attained on the 7th day.

IX. CONCLUSIONS

Test results indicate that production of RPC is possible under standard water curing.

From the literatures it is clear that with temperature curing, mechanical properties can be improved.

Concrete having a strength of 130 MPa was achieved.

The 28 day strength of the mix is 130MPa. 70% of the 28th day strength is attained on the 7th day.

Spread of concrete obtained from slump flow test is 260mm.

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