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A State Of Art- On Development Of Reactive Powder Concrete

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Abstract:

Low flexural tensile strength has number of undesirable consequences for its performance as an effective building material. These include necessity of auxiliary steel reinforcement and thick sectioned members that are both aesthetically unappealing and consume significant quantities of aggregates. An emerging technology with the potential to overcome these limitations is reactive powder concrete (RPC) RPC is a cold cast cementitious material in which the mechanical properties of the matrix are improved by suppression of the weak interfacial transition zone normally developed around the aggregate through improved particle packing and by refinement of the hydrated paste microstructure by extensive use pozzolanic silica and elevated temperature curing. Tensile capacity is provided by steel micro fibres rather than conventional reinforcement the low and non connected porosity of RPC also render extremely durable. RPC offers the possibility building with concrete with slender member with improved seismic response.

Keywords*: RPC, high strength concrete, durability.*

1.Introduction

Interest in the production of very high-strength concrete has been increasing over the past several years, particularly in the precast and pre-stressed concrete industries, builders of high rise concrete structures also could benefit from higher strength concrete by large reduction in dead load. Although the very high strength concrete to be used for most cast in place construction could not be applicable. Reasoning behind, it requires special care of each aspect of strength development and preventative measures.

Reactive Powder Concretes (RPCs) are ultra-high strength cementitious materials composed of very fine powders with a maximum particle size of approximately 800μm. In addition to the absence of the traditional coarse aggregates used to produce normal and high strength concrete, RPCs are characterized by very high silica fume content and very low water-cement (w/c) ratios (Cheyrezy et al, 1995)[1]. The low w/c ratios are achieved through the use of new generation super plasticizers in large doses to have a workable mix. Although very little in the way of concrete mix design was used in this investigation (trial mixes were made, and then adjusted by observation).

Papers by Cheyrezy[1] and Manu Santhanam[2] were helpful to start with the trial by using material available in Indian conditions.

2.Historical Background Of Rpc

'Reactive powder concrete' (RPC) is the generic name for a class of cementitious composite materials developed by the technical division of Bouygues, S.A. France in the early 1990s and the world's first RPC structure, the Sherbrooke Bridge in Canada, was constructed in July 1997. It is characterized by extremely good physical properties, particularly strength and ductility. Reactive powder concrete (RPC) is a developing composite material that will allow the concrete industry to optimize material use, generate economic benefits, and build structures that are strong, durable, and sensitive to environment.

Since Reactive Powder Concrete (RPC) first appeared on the world research stage in 1994, it has received considerable attention. The original development of RPC came from the Scientific Division of Bouyges, France. Since then further development of the material has continued throughout the world (for example Australia, Canada, Japan, Korea and the United States of America) at a frenetic pace. Superior mechanical properties and durability characteristics promise that the material will have a wide and significant impact on the concrete industry.

To date, the greater part of research into RPC has focused on what the material is and its properties, micromechanical analysis, potential applications and preliminary work into the structural behaviour. However in India investigations in RPC, using locally sources and materials, developing composition, mechanical properties and durability parameter are still in their infancy. This information is required to assist with the increased use of RPC in practice and to further develop analytical techniques and design standards.

3.Composition Of Reactive Powder Concrete

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. These Reactive Powder Concretes have compressive strengths ranging from 160 MPa to 800 MPa.

4.Basic Principles For The Composition Of Rpc

Elimination of coarse aggregates for enhancement of homogeneity.
Optimization of the granular mixture for the enhancement of compacted density.
Utilization of the pozzolanic properties of silica fume.
The optimal usage of super plasticizer to reduce w/c ratio and to improve compaction.
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.

4.1. Homogeneity Enhancement

Conventional concrete is a heterogeneous material, in which the aggregates (sand and Gravel) form a skeleton of contiguous granular elements in the cementitious paste (cement, additives and water). Heterogeneity-related problems are substantially reduced with RPC for the following reasons:
Elimination of coarse aggregates, replaced by fine sand, (600µm maximum);
Improved mechanical properties of the paste;
Reduction in the aggregate/matrix ratio.

4.2.Effect Of Aggregate Size

For RPC, with a reduction in the size of the coarsest aggregate by a factor of about 50 (e.g., 400µm instead of 20mm), a major reduction is obtained in the size of micro cracks of the following origins:

Mechanical (external loads);

Chemical (autogenous shrinkage);

Thermo-mechanical (differential expansion between paste and aggregate under the effects of heat-treatment).

4.3.Effect Of Enhanced Mechanical Properties Of The Paste

In the case of an RPC, the volume of the paste is at least 20% greater than the voids index of non-compacted sand. Thus the aggregates used in RPC do not form a rigid skeleton, but a set of inclusions trapped in a continuous matrix. Paste shrinkage is blocked locally round each aggregate particle whereas global shrinkage is not blocked by the rigid skeleton. Each grain can be transported by the paste, and can migrate with respect to its neighbors. This advantage only concerns structures where global shrinkage is unrestricted by any external source.

5.Selection Parameters

From the above descriptions and the literature survey carried out some basis have been finalized for the selection of different components of RPC.

The optimization of granular mix can be achieved by a number of trials for the different mixes in the experimental method. These are based on the following principles:

Pozzolanic silica is added in the stoichiometric quantity necessary to react with all the calcium hydroxide that would be produced assuming complete cement hydration. Using cement chemists notation, the simplified hydration reaction is:

$2C_3S + 6H \quad C_3S_2H_3 + 3CH \qquad \rightarrow$

$2C_2S + 4H \quad C_3S_2H_3 + CH \qquad \rightarrow$

[Where C = CaO; S = SiO_2; H = H_2O]

The calcium hydroxide [CH] produced by hydration occupies 20 - 25% of the cement paste by volume and makes no contribution to strength and durability. Addition of amorphous silica forms further desirable C-S-H at the expense of calcium hydroxide, according to the 'pozzolanic reaction':

$CH + S + H \quad C\text{-}S\text{-}H \qquad \rightarrow$

For mixes cured at 90°C or higher, the CaO/SiO2 ratio in the binder is reduced by the addition of further silica. This modifies the hydration sequence further, resulting in a lower-lime C-S-H that ultimately converts to crystalline tobermorite [C5S6H5], and conferring higher strength to the hardened concrete:

$$(C_3S + C_2S) + S + H \rightarrow C_3S_2H_3 + CH + S \rightarrow C\text{-}S\text{-}H \rightarrow C_5S_6H_5$$

At these elevated temperatures, finely divided crystalline forms of silica are sufficiently reactive to act pozzolanically, so ground quartz flour is normally employed and highly siliceous aggregate can also contribute to this reaction.

The volume of the binder (cement + silica fume + water) in the composite RPC matrix should exceed the void volume of the aggregate by at least 50% (i.e. each aggregate particle should 'float' in the matrix, rather than touch together as in a conventional concrete). This improves the probability of plastic deformation as a response to stresses such as autogenous shrinkage, rather than accommodation of strain via the formation of micro-cracks.

Components	Selection Parameters	Function	Particle Size	Types
Sand	Good hardness readily available and low cost	Give strength, Aggregate	150 µm – 600 µm	Natural, Crushed
Cement	C3S : 60%; C2S : 22%; C3A : 3.8%; C4AF : 7.4%	Binding material, Production of Primary hydrates	1 µm - 100 µm	OPC Medium fineness
Quartz Powder	Fineness	Max. reactivity during heat treating	5 µm - 25 µm	Crystalline
Silica Fume	Nature and quantity of impurities	Filling the voids, Enhance rheology, Production of secondary hydrates	22m2/g (Fineness)	Procured from the zirconium industry (highly refined)
Steel Fibers	Good aspect ratio	Improve Ductility	L :13-25mm, Dia:0.15-0.5mm	Corrugated
Super-plasticizer	Less retarding characteristic	Reduce water to cement ratios	--	Poly acrylate-based (or) poly carboxylate based

Table 1: Selection parameters for RPC components

Materials	**P. Richard, M. Cheyrezy**	**S. A. Bouygues**	**A. S. Dili, M. Santhanam**	
	Fibered (12mm)	**Fibred (25mm)**	**Without Fiber**	**Fiber (25mm)**
Cement	1	1	1	1
Sand	1.1	1.423	1.6	1.6
Silica fume *or*	0.23	0.324	0.25	0.25
Powdered quartz flour	0.39	0.296	0.31	0.31
Steel fibers [optional]	0.175	0.268	-	0.20
Water	0.19	0.282	0.25	0.25
Super plasticizer	0.019	0.027	0.03	0.03

Table 2: RPC mixture design from literatures (parts by mass)

The major parameter that decides the quality of the mixture is its water demand (quantity of water for minimum flow of concrete). In fact, the voids index of the mixture is related to the sum of water demand and entrapped air.

6.Sample Production For Rpc

The required quantities of the ingredients are taken according to the mix proportion adopted for different trials on the basis of literature survey. The RPC mixes were produced for the required volume in batches using an epicyclic mixer compliant with the requirements of ASTM C 305 The weighed quantities of all the dry ingredients are taken and are lightly grind to break-up the agglomerates (if any) in the dry mixture. After adding all the dry ingredients in the mixing mould they were mixed for a while before adding water in to it.

Mixing protocol	**Elapsed time(Minutes)**
Lightly grind cement and silica fume to break-up agglomerates	-
Add all dry powders and aggregate	0
Start mixing	½
Add 75% of water required	3
Add steel micro-fibers (if used)	5
Add remainder of water and super-plasticizer	8
Stop mixing and cast test specimens	30

Table 3: Procedure for production of RPC mixes

The extended mixing time is necessary both to fully disperse the silica fume, breaking up any agglomerated particles, and to allow the super-plasticizing agent to develop its full potential. The mixing is unusual in that a distinct conversion point is observed several minutes after the final aliquot of water is added, during which the dry-balled ingredients suddenly coalesce to plastic flowing mix. At the conclusion of the mixing period, the workability of the mix was assessed according to the ASTM C 1437 'flow table' test by means of ASTM C 185. The Fig. 1.0 shows the dry mixture of RPC. All the dry ingredients of RPC are mixed well manually so that there should be no agglomerates present in the mixture. Figure 2.0 shows the paste formed after complete mixing of all the ingredients needed.The flow of RPC mixture is found out with flow table and the test is known as flow table test. The flow of the mixture is calculated by measuring the flow of mixture after giving blows in six direction and taking the average of the flow. For RPC, flow between 105mm to 120mm is suitable for achieving good strength. Figure 3.0 shows the RPC mixture after flow test. The flow of the mixture was obtained as 112mm including the bottom dimension of mould.

Figure1:Dry Mixture Of RPC (Without Fibers)

Figure2 :Paste After Proper Mixing (Without Fibers)

Figure 3:Flow Test Of RPC Mixture

7.Suggestions And Recommendations

Workability of RPC measured by flow table test, flow for RPC is increases with the increase in silica fume content up to certain limit (0.2 parts by mass of cement) and then after workability is decreased. Such a higher silica fume content and low water cement ratio. Third generation super plasticizer. (Polycarboxylic ether base) only can give good workability, and normal plasticizer like SNF & SMF does not help in getting good workable RPC,As it for the ordinary concrete, effect of W/c ratio on workability and compressive strength observed but with help of PCE super plasticizer it could possible to reduce w/c ratio as low as 0.22

Circular cross section and corrugated steel fibres give beneficial effect in development of compressive strength compared to flat and corrugated steel fibres however, circular fibre gives 10 to 15 % increased compressive strength compared to plain RPC with steel fibres (as more nos. of fibres are available per unit volume) compared to flat fibres While flat corrugated steel fibres gives 5 to 10 % increased in compressive strength confining concrete.

As the all ingredients are fine in RPC so longer fibres does not help to get good workability and strength, hence, short fibres and smaller diameter is advantageous.

Flexure strength obtained by flat fibres is less than flexural strength obtained by using circular corrugated steel fibres.

Duration of hot water curing contribute significantly in compressive strength it also enhance the micro structure of because crushed quartz will he reactive at higher temp and consume further $CAOH_2$ hence forth more dense micro structure is obtained which lids higher strength however it is observed the hot water curing for initial 48 hours after final setting and then remaining days normal water curing found to be optimum and economically option among all type of curing condition.

Replacement of cement by metakaolin does not benefit in to have more strength though metakaolin is highly reactive demands more water which indirectly reduces the strength.

Replacement of steel fibres by Recron is not benefitting in strength development higher the Recron-3s content in RPC compressive strength id reducing contrary to steel fibres which increased the strength it is also observed that the Recron-3s having low density and modulus of Elasticity, could not confine the matrix However, for the given weight of Recron-3s, volume of fibres are large hence workability is severely affected.

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