CHARACTERIZATION OF REACTIVE POWDER CONCRETE FOR ITS MECHANICAL PROPERTIES

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ABSTRACT

There has been a continuous demand for development of materials with higher performance for various civil engineering applications that will be long lasting and have very low maintenance requirements. Reactive Powder Concrete (RPC) is one such material which is categorized as high performance concrete with compressive strength in the range of 100-200 MPa. Developed from a special combination of constituent materials such as Portland cement (c), silica fume (sf), quartz sand (qs), high-range water-reducer, water and steel fibers (optional), RPC is devoid of coarse aggregates, resulting in strong mortar with a requirement of very low water cement ratio. This paper presents the results of an experimental programme wherein mix proportions for RPC were developed. The effects of variation of silica fume/cement ratio (sf/c) on the mechanical properties in terms of compressive strength, flexural strength, shear strength and bond strength with normal concrete and steel is studied. The results highlighted the enhanced performance in the mechanical properties of RPC in direct application of its use in structural members requiring high standards of strength coupled with superior performance and durability.

Key words: Reactive powder concrete, high strength, silica fume, mechanical properties.


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1. INTRODUCTION

Concrete is the most widely used construction material in the world today. In the modern age, a highly developed infrastructure is essential for economic growth and prosperity. Reactive powder concrete (RPC) is a material that demonstrates great improved strength and durability
characteristics as compared with traditional or even high-performance concrete. RPC is the generic name for a class of cementitious composite materials developed by the technical division of Bouygues, S.A. France in early 1990s. The material consists of a concrete using quartz sand as its largest aggregate along with silica fume as one of the main ingredients. Compressive strengths of 200 to 800 MPa have been achieved with RPC by Pierre Richard [1]. Development of RPC was made possible by the application of a certain number of basic principles relating to the composition, mixing and post-set heat curing of the concrete. N. P. Lee & D. H. Chisholm et al. [2], examined the effect of a number of process variables including water-to-binder (w/b) ratio, super-plasticizer dosage, curing regime and the choice of silica pozzolana, on the compressive and tensile strength of the hardened material. Mechanical strength was observed to directly correlate with the spatial efficiency that the dry powders’ constituents could be packed together. Consequently, it is necessary for these powders to exist in distinct size classes with a wide separation between mean particle size diameters. Halit Yazici et al. [3] worked on the mechanical properties of reactive powder concrete produced with class-C fly ash (FA) and ground granulated blast furnace slag (GGBFS) under different curing conditions (standard, autoclave and steam curing). Increasing the GGBFS and or FA content improved the toughness of RPC under all curing regimes considerably. Yin-Wen Chan et al. [4] have studied the effect of silica fume on steel fiber bond characteristics in reactive powder concrete consisting of micro steel fibers.

Thus through the previous studies, it is seen that RPC displays excellent compressive as well as flexural strength. Its specific use in any special structures along with normal concrete demands study of its bond characteristics with other concrete as well as with steel. Major earlier work focusses on special curing condition. Hence the properties of RPC in normal curing condition need to be investigated when used directly for in-situ conditions. The experimental program carried out will help to characterize some mechanical properties of RPC under normal curing condition and will help to remove some of the barriers related to the adoption of RPC technology in India.

2. MATERIAL SPECIFICATIONS

The RPC considered here is prepared by mixing Ordinary Portland Cement (OPC) of 53 grade confirming to the specification of IS 12269 (1987) [5], quartz sand with maximum particle size limited to 600 μm and silica fume with particle size less than 1μm in diameter, the average being about 0.15 μm. Particle sizes below 150 μm in quartz sand are avoided, in order to prevent interface with the largest cement particles (80 - 100 μm). The very low water cement ratios are used in RPC and it necessitates the fluidizing power of high-quality third generation super-plasticizing agents. Some important specifications of the material used are:

The quartz sand has SiO₂ of 99.9% with specific gravity of 2.6-2.7 and pH neutral. Silica fume of Silica Grade 920-D is used having minimum 90% SiO₂ and with coarse particles greater than 45 micron limited to maximum 1 %. The specific surface is minimum 18 m²/g with bulk density of 500 – 700/m³. The super plasticiser is polycarboxylate based with minimum pH 6.0 and volumetric mass @ 20° C equal to 1.09 Kg/Litre.

3. MIX PROPORTIONS

Trial studies were initially conducted on RPC specimens of different proportions of ingredients based on previous studies carried out by researchers [1, 2, 6]. Results of these trial studies are used to found the optimum proportions of ingredients. Based on the results of these tests, a constant quartz sand/cement ratio (qs/c) of 1.5 and water/cement ratio (w/c) of 0.3 is maintained for all mixes in the experimental programme presented in this paper. Focussing the use of silica fume in RPC, silica fume/cement ratio (sf/c) has been varied as
0.15, 0.20, 0.25 and 0.30 of 1 part of cement to study the effect of proportion of silica fume on mechanical properties of RPC. For the experimental study on bond strength with normal concrete, M30 grade of concrete is designed as per IS 10262: 2009 [7]. The mix proportions for different tests conducted are given in Table 1.

Table 1 Mix Proportions in RPC

<table>
<thead>
<tr>
<th>Mix</th>
<th>Cement</th>
<th>Water/ Cement ratio</th>
<th>Silica fume/ Cement ratio</th>
<th>Quartz sand/ Cement ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.3</td>
<td>0.15</td>
<td>1.5</td>
</tr>
<tr>
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<td>1</td>
<td>0.3</td>
<td>0.2</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.3</td>
<td>0.25</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0.3</td>
<td>0.3</td>
<td>1.5</td>
</tr>
</tbody>
</table>

4. PREPARATION OF MOULDS AND SPECIMENS

The moulds for compression test, flexure test is as per IS 516 (1959) [8], of size (70.6 x 70.6 x 70.6) mm and (100 x 100 x 500) mm respectively. The mould of size (150 x 150 x 150) mm is used for bond test and pure shear test, and for pull-out test (100 x 100 x 100) mm cube embedded with 10 mm or 12 mm diameter bars is used. The specimen for bond test is based on Bi-Surface shear test given by A Momayeza et al. [9] as shown in Fig.1. The specimen is consisting of three parts; wherein the middle 1/3 rd consist of RPC and the outer 1/3 rd portions are cast with M30 grade concrete.

Figure 1 Specimen for bond test

The mix procedure as given by Pierre Richard [1] is followed. For each mixture proportions of RPC, dry ingredients were first mixed for about 3 minutes at low speed in bucket mixer, water and superplasticiser were added and remixed for about 7-10 minutes a high speed. Subsequently flow was measured for workability and specimen for various tests were casted. The specimens were kept in moulds for 24±1/2 hrs at room temperature. After that specimens were removed from steel moulds and were cured in potable water for 28 days.

5. TESTING

Compression and flexure test is carried out as per IS 516 (1959) [8], the casting and testing of specimen for pull out test was done as per IS 2770 (1967) [10]. For conducting the pure shear and bond test, double shear failure arrangement based on Bi-Surface shear test given by A
Momayeza et. al. [9] is adopted in testing setup. Three metal plates of size 50 mm x 150 mm x 25 mm are prepared. The test sample is placed in the compression testing machine and the two metal plates are placed at bottom of the specimen and one on the top of the specimen as shown in the Fig. 2. The compressive load is applied gradually till the specimen fails. After each test, the specimens were carefully observed to identify the failure mode.

(a) Test set up  (b) Shear test specimen after failure  (c) Bond test specimen after failure.

Figure 2 Shear and bond Test

6. RESULTS AND DISCUSSIONS

The results of compression and flexure test is shown in Fig. 3 and 4 respectively. Results of pull out test carried for 10 mm and 12 mm bar is shown in Fig. 5. The results of bond test of RPC with M30 grade concrete and pure shear test is represented in Fig. 6. Each data represented here is the average test results of four specimens.

Figure 3 Compressive strength  Figure 4 Flexural strength
It is seen from the results that with addition of silica fume in RPC, the strength increases. This is because the pore structure becomes dense as silica fume fits in the pores of cement particles and density increases due to packing of material. This quality of silica fume in the absence of aggregates is in making good quality DSP (densified systems containing homogeneously arranged ultrafine particles materials). In addition, the silica fume particles fill micro and sub micro level pores in the paste and limit the particle size of hydrates thereby showing the space filling effect.

Experimentally the optimum fume/cement ratio for RPC is found to be 0.25. This ratio corresponds to optimum filling performance and it is close to the dosage required for complete consumption of the lime resulting from total hydration of the cement. However, cement hydration is incomplete in an RPC, and the available quantity of silica fume is more than required by the pozzolanic reaction.

In cementitious compounds, silica fume being a pozzolanic material, works on the pozzolanic reaction where the hydration of OPC produces many compounds. This includes calcium silicate hydrates (CSH) and calcium hydroxide (CH). The CHS gel is responsible for the strength development in RPC. When silica fume is added to fresh concrete it chemically reacts with the CH to produces additional CHS gel. The benefit of this reaction is it increases the strength and chemical resistance. Bond strength between the concrete paste and the quartz sand, in the crucial interfacial zone, is greatly increased.

7. CONCLUSIONS

Based on the experimental results obtained, following conclusions are made.

- It is seen that compressive strength and flexure strength is directly proportional to increase in silica fume/cement ratio. The flexural strength of RPC is about 25% of the compressive strength which is much higher than conventional concrete.
- From the results of bisurface shear test and pull out test, it is observed that increase in content of silica fume increases the bond strength, the optimum value of silica fume/cement ratio being 0.25.
- The shear strength of RPC increases with the increase in the silica fume/cement ratio, the optimum value being 0.25 corresponding to the optimum filling performance.

From the above experimental work, it is concluded that the proportion 1: 1.5: 0.25 (c: qs: sf) and 0.3 water cement ratio gives optimum result for various mechanical tests carried out on RPC.
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