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# Reactive Powder Concrete Properties with Cement Replacement Using Waste Material

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**Abstract**— Reactive Powder Concrete (RPC) is composed of very fine powders (cement, sand, quartz powder and silica fume), steel fibres (optional) and superplasticizer. A very dense matrix is achieved, and this compactness gives RPC ultra-high strength and durability properties. In the present study, performance of reactive powder concrete without quartz powder and containing fly ash and GGBS as a replacement for cement at the percentage of 5% (RPC1), 10% (RPC2) and 15% (RPC3) by each is investigated. To compare the results of cement replaced mixture, specimen without cement replacement (RPC)are also casted. Performance of the various mixes is tested by the compressive strength, flexure strength and modulus of elasticity. The results show improvement in compressive strength, flexural strength and modulus of elasticity in cement replaced mixes.

**Index Terms**— compressive strength, flexure strength, fly ash, ggbs, modulus of elasticity, RPC, silica fume, steel fiber.

## 1 INTRODUCTION

REACTIVE Powder Concretes (RPC) constitute a particular type of cementitious materials developed in the early 1990s [Richard et al., 1995] and characterized by ultra-high mechanical performances. As compared to ordinary cement-based materials, the primary improvements of RPC include the particle size homogeneity, porosity, and microstructures. The mechanical properties that can be achieved include the compressive strength of the range between 200 and 800 MPa, fracture energy of the range between 1200 and 40,000 J/m2, flexural strength range between 30 and 60 MPa and very high ductility. Its ductility is about 250 times higher than that of conventional concrete [Richard and Cheyrezy,1995]. This is generally achieved by micro-structural engineering approach, including elimination of the coarse aggregates, reducing the water-to-cementitious material ratio, lowering the CaO to SiO2 ratio by introducing the silica components, and incorporation of steel micro-fibers. 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 [chen et al., 2003]. As more skyscrapers are being built, the demand for high strength concrete with compressive strength over $100N/mm^2$ has been increasing year by year. Demands for materials with much higher strength will be far larger in the future. Many successful applications of RPC have been reported such as the 60m span Sherbrooke footbridge in Canada [1997]; the 25 meter span Futur Bridge in USA [2005] and many others. This paper focuses on the effect of fly ash and GGBS on properties of compressive strength, flexural strength and stress-strain behaviour of RPC mixes.

## 2 LITERATURE REVIEW

Many researchers have carried out studies on RPC in the past years to assess the properties and its behavior. Some of the works carried out re discussed below:

Richard and Cheyrezy [1995] developed an ultrahigh strength ductile concrete with the basic principles of enhancing the homogeneity by eliminating the coarse aggregate, enhancing the microstructure by post-set heat treatment and the tensile strength of concrete was increased by incorporating small, straight, high tensile microfibre. Two types of concretes were developed and designated as RPC200 and RPC800, which had exceptional mechanical properties. The mean compressive stress obtained for RPC200 was 218MPa and for RPC800 was exceeding 600MPa. For RPC800, a value of 810MPa has been obtained with a mixture incorporating steel aggregate. The concrete finds its applications in industrial and nuclear waste storage silos.

Chan and Chu, [2002] has studied the effect of silica fume on the bond characteristics of steel fiber in matrix of reactive powder concrete (RPC) by bond strength, pullout energy, etc. Various silica fume contents ranging from 0% to 40% are used in the mix proportions. Results of them show that the incorporation of silica fume can effectively enhance the fiber–matrix interfacial properties, especially in fiber pullout energy.

Yang et. al., [2007] has carried out direct uniaxial tension tests on '8-shaped' RPC200 specimens. The bond-slip process, mesoscopic structural variation and mechanical characteristics of a fiber pullout of the matrix have been investigated using the real-time SEM loading system and CCD observation techniques. Results of them show that there exists an optimal threshold of fiber volume $\rho v$, opt =1.5% at which the bond performance of a fiber pullout of RPC behaves best.

Yunsheng et. al., [2008] prepared (C200 GRPC) by utilizing composite mineral admixtures, natural fine aggregates, short and fine steel fibers. They investigated mechanical properties under three different type of curing (standard curing, steam curing and autoclave curing) condition. Their experimental results show that the mechanical properties of the C200 GRPC made with the cementitious materials consisting of 40% of Portland cement, 25% of ultra fine slag, 25% of ultra fine fly ash and 10% of silica fume, 4% volume fraction of steel fiber are higher than the others. The corresponding compressive strength, flexural strength, fracture energy and fiber–matrix interfacial bonding strength are more than 200MPa, 60MPa, $30,000J/m^2$ and 14MPa, respectively.

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Maroliya and Modhera, [2010] compared the mechanical properties of plain RPC with Recron-3s fibre (RSFRPC) and corrugated steel fiber (SFRPC). Their results shows that compressive strength of SFRPC was 30% increased while in RSFRPC strength reduced by 19%. Flexural strength of SFRPC and RSFRPC in comparison to plain RPC was found that 60% and 40% higher.

Prabha et. al., [2010] conducted a study on complete stress-strain curves from uniaxial compression tests. The effect of material composition on the stress strain behaviour and the toughness index were studied. The highest cylinder compressive strength of 171.3 MPa and elastic modulus of 44.8 GPa were recorded for 2% 13 mm length fibres. The optimum fibre content was found to be 3% of 6mm length or 2% of 13mm length fibres. A new measure of compression toughness known as MTI (modified toughness index) was proposed by them and it is found to range from 2.64 to 4.65 for RPC mixes.

Yang et. al., [2010] studied dynamic mechanical properties of reactive powder concrete subjected to compressive impacts with high strain by means of SHPB (Split-Hopkinson-Pressure-Bar) tests of the cylindrical specimens with five different steel fiber volumetric fractions. The dynamic stress-strain relationships of RPC were modeled based on the experimental data. The investigations indicate that for the plain RPC the stress response is greater than the strain response, showing strong brittle performance. The RPC with a certain volume of fibers sustains higher strain rate impact and exhibits better deformability as compared with the plain RPC. With a constant fiber fraction, the peak compressive strength, corresponding peak strain and the residual strain of the fiber-reinforced RPC rise by varying amounts when the impact strain rate increases, with the residual strain demonstrating the greatest increment.

## 3 Experimental Program

### 3.1 Mix composition

The material used in this study includes cement(53 grade), silica fume, fly ash, GGBS, sand (2.36mm below size), steel fiber having 0.2mm diameter and 10mm length, and water binder ratio of 0.2. The mix propotions used are based on Yunsheng et al., (2008). A control mix CRPC without cement replacement is tested. Fly ash and GGBS are used to replace cement content at 5% (RPC1), 10% (RPC2) and 15% (RPC3) in the mixes. All mixes contains same amount of silica fume of 0.1%. Two mix compositions tested by Yunsheng et al., (2008) containing 2% (M3–2%) and 3% (M3–3%)of steel fibres is used for comparison with control RPC, RPC1, RPC2 and RPC3. The various mix proportions are as tabulated in Table1.

### 3.2 Specimen casting and testing

Casting and testing of specimen was carried out as per IS codes IS:516-1959 for compression strength, flexural strength, modulus of elasticity.

### 3.21.Specimen preparation

Materials are weigh batched, mixed in a mixer, cast into steel moulds and compacted using a vibrating machine to consolidate the specimens. The specimens were stored in room temperature for 24 hours, then removed from the moulds, and cured in normal water until tested.

TABLE 1
MIX PROPOTIONS OF VARIOUS RPC MIX

| Ingredients | Mix type (percentage) | | | | | |
|---|---|---|---|---|---|---|
| | RPC | RPC1 | RPC2 | RPC3 | M3 - 2% | M3 - 3% |
| Cement | 90 | 80 | 70 | 60 | 40 | 40 |
| Silica fume | 10 | 10 | 10 | 10 | 10 | 10 |
| Fly ash | - | 5 | 10 | 15 | 25 | 25 |
| GGBS | - | 5 | 10 | 15 | 25 | 25 |
| Sand | 83.3 | 83.3 | 83.3 | 83.3 | 83.3 | 83.3 |
| Water/binder | 0.2 | 0.2 | 0.2 | 0.2 | 0.15 | 0.15 |
| Steel fiber | 1.5 | 1.5 | 1.5 | 1.5 | 2* | 3* |
| Super plasticizer | 0.04 | 0.035 | 0.034 | 0.033 | | |

*Steel fibre of length 13mm, diameter 0.175mm

### 3.2.2.Testing

Specimens are tested for compressive strength, flexure strength and modulus of elasticity as per IS standards.

## 4 Discussion of results

The test results are discussed and compared with the two mixes from Yunsheng et al., [2008].

### 4.1 Compressive strength:

The results of compressive test are tabulated in the table 2 and figure 1 shows the variation of compressive strength for various mixes considered. It is observed that there is an increase in compressive strength at 28 days in RPC1 and RPC2 compared to the RPC mix. The highest compressive strength of 128MPa is obtained at 28 days for RPC1 mix containing 5% of fly ash and GGBS each. Compressive strength of RPC3 was less compared to the RPC. The mix M3-2% and M3-3% tested by Yunsheng et al., (2008) gives compressive strengths of 153.57MPa and 167.85MPa respectively at 28 days, which may be because of high percentage of steel fibre and low water cement ratio. Comparison of 28 days compressive strength of mixes with RPC, RPC1, RPC2, RPC3, M3-2% and M3-3% for are shown in figure 2.

TABLE 2
COMPRESSIVE STRENGTH TEST

| Mix type | Compressive strength (MPa) | | |
|---|---|---|---|
| | 7 days | 14 days | 28 days |
| RPC | 109.5 | 122.5 | 126.33 |
| RPC 1 | 106.5 | 121 | 128 |
| RPC 2 | 102.5 | 117 | 126.67 |
| RPC 3 | 93.33 | 99.67 | 110 |
| M3-2% | - | - | 153.57 |
| M3-3% | - | - | 167.85 |

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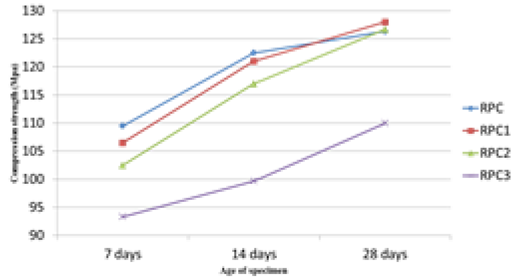


Fig 1. Variation in compressive strength

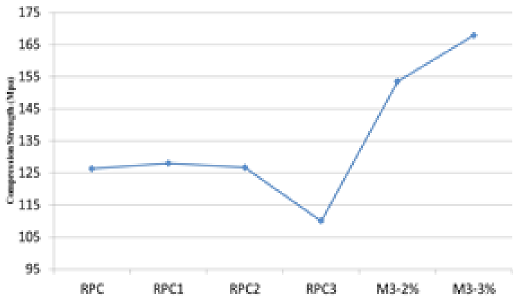


Fig 2. Varation in comprssive strength of 28 days

## 4.2 Flexural strength

The results of flexural test are tabulated in the table 3 and figure 3 shows the variation of flexural strength for various mixes considered.

TABLE 3
FLEXURAL STRENGTH

| Mix type | Flexural strength test (MPa) | | |
|---|---|---|---|
| | 7 days | 14 days | 28 days |
| RPC | 17.658 | 22.90 | 25.585 |
| RPC 1 | 16.677 | 19.62 | 23.073 |
| RPC 2 | 17.167 | 21.601 | 25.604 |
| RPC 3 | 19.737 | 23.54 | 28.525 |
| M3-2% | - | - | 23.33 |
| M3-3% | - | - | 28.33 |

It is observed that there is an increase in flexural strength at 7, 14 and 28 days in RPC3 compared to the RPC mix. Highest flexure strength of 28.525MPa is obtained at 28 days for RPC3 mix containing 15% of fly ash and GGBS each. Flexural strength of RPC1 was less compared to the RPC. The mix M3-2% and M3-3% tested by Yunsheng et al., (2008) gives flexural strengths of 23.33MPa and 28.33MPa respectively at 28 days, which may be because of change in aspect ratio of steel fibre. Comparison of 28 days flexural strength of these mixes with RPC, RPC1, RPC2 and RPC3 for are shown in figure 4.

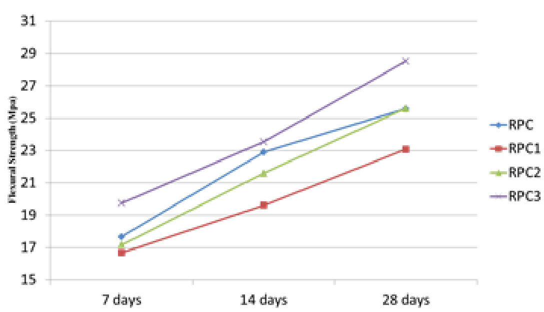


Fig 3. Variation of flexural strength

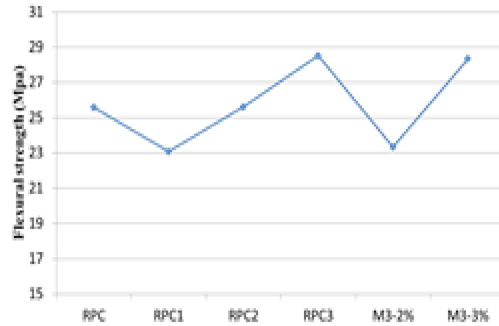


Fig 4.Variation in 28 days flexural strength

## 4.3 Modulus of elasticity

The test results corresponding to modulus of elasticity are tabulated in table 4 and figure 5 shows the variation in stress strain curve of RPC mixes.

TABLE 4
MODULUS OF ELASTICITY

| Mix type | Modulus of elasticity (GPa) |
|---|---|
| RPC | 39.169 |
| RPC1 | 46.290 |
| RPC2 | 42.433 |
| RPC3 | 36.371 |

It is observed that there is an increase in modulus of elasticity at 28 days in RPC1 and RPC2 compared to the control RPC. The highest modulus of elasticity of 46.29MPa is obtained at 28 days for RPC1 mix containing 5% of fly ash and GGBS each. Modulus of elasticity of RPC3 was less compared to the control mix RPC.

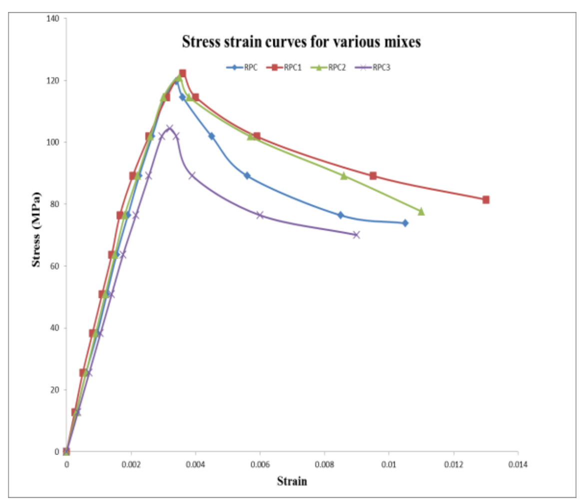


Fig 5. Stress strain curve for various RPC mixes

# 5 Conclusion

1) The 28 days compressive strength increased for 5% (RPC1) and 10% (RPC2) replacement of cement by flyash and GGBS each.

For 15% replacement (RPC3) the results were lower than the control mix (RPC).

2) RPC1 with 5% cement replacement gave highest 28 days compressive strength of 128MPa as compared to RPC having 28 days strength of 126.33MPa.

3) The 7 days and 14 days compressive strength values were lower than RPC for all mixes with cement replacement, which is because of slow hydration of cementitious matter at initial days.

4) Flexural strength of RPC with 10% and 15% replacement of cement by flyash and GGBS each (RPC2 and RPC3) were higher than that of control mix (RPC). For RPC with 5% replacement of cement (RPC1), the flexure strength was lower than the strength of control mix (RPC).

5) RPC with 15% replacement of cement by fly ash and GGBS each (RPC3) gave higher 28 days flexural strength of 28.525MPa.

6) As the finer material increases flexural strength also increased for each RPC mix with cement replacement (RPC1, RPC2 and RPC3).

7) Modulus of elasticity of RPC with 5% and 10% replacement of cement by flyash and GGBS each (RPC2 and RPC3) was higher than that of control mix (RPC). For RPC with 15% replacement of cement (RPC1), the modulus of elasticity was lower than the, that of control mix (RPC).

8) RPC2 mix with 10% replacement of cement gave increase in compressive strength, flexural strength and modulus of elasticity of 126.67MPa, 25.604MPa and 42.433GPa respectively, when compared to the strengths of control mix (RPC).

9) The various mix considered RPC2 mix with 10% replacement of cement gave better results.

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