International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 3.45 (SJIF-2015), e-ISSN: 2455-2584
Volume 3, Issue 5, May-2017

FRESH AND STRENGTH PROPERTIES OF GREEN REACTIVE POWDER CONCRETE

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***Abstract*— Reactive Powder Concrete (RPC) is a high strength, new generation concrete, formed from a special combination of constituent materials. The composition of reactive powder concrete includes cement (ordinary Portland cement), fine sand, silica fume, quartz powder, and high tensile steel fibers. Reactive powder concrete is grouped under ultra high performance concrete. Reactive Powder Concrete (RPC) is differs significantly from traditional concretes, in RPC no aggregate used and contains small steel Fibers that gives additional strength. A very dense matrix is achieved, and this compactness gives RPC ultra-high strength and durability properties.**

In the present study, a new type of green reactive powder concrete (GRPC) with ultra high compressive strength is prepared by totally replacing ultra fine quartz sand by the least costly and easily obtained natural river sand and Performance of green reactive powder concrete containing fly ash and GGBS as a replacement for cement at the percentage of 5% (M1), 10% (M2) and 15% (M3) by each is investigated. To compare the results of cement replaced mixture, specimen without cement replacement Standard GRPC mix (M) are also casted.

Performance of the various mixes is tested by the compressive strength, split tensile strength and flexure strength. A cube specimen of size 150mmX150mm X150mm, cylindrical specimen of size 100 mm dia X 200 high mm and beam specimen of size 150mm × 150 mm × 700mm were cast and demoulded after 24 hours then they allowed for normal water curing. The results show improvement in compressive strength in cement replaced mixes. The compressive strength varied in the range of 90 Mpa to 110 Mpa. The maximum compressive strength value that can be achieved in this study is 110 MPa for the GRPC with the Fly ash and GGBS as a replacement for cement at the percentage of 5% by each.

Keywords*— Green reactive powder concrete (GRPC), Ultra-high performance concrete (UHPC), Ultra high strength, Self-compactability, Fibers reinforced concrete (FRC), Fly Ash (FA), Ground granulated blast furnace slag (GGBS).

I. INTRODUCTION

As more skyscrapers are being built, the demand for high strength concrete with compressive strength over 100 N/mm2 has been increasing year by year. Demands for materials with much higher strength will be far larger in the future[1]. In the history of the compressive strength of cement based materials, the record of 600 N/mm^2 established by Roy, et al. in 1972, had not been broken until 1992 when Lu and Young marked 800 N/mm^2 based on the densest compaction theory[2,3]. In 1994 Richard et al. invented an 800 N/mm^2-class cement-based material with increased toughness, by mixing steel fiber. This new material born from an innovative concept of ultra high strength combined with high toughness was named RPC (reactive powder concrete) for the reactive powder they used[4]. Since RPC of the 800 N/mm^2 class (RPC800) requires heating and pressing curing which is unpractical for commercial production, some proposed RPC of the 200 N/mm^2 class (RPC200) which can be obtained by steam-curing. Strength of the RPC is almost one digit higher than that of normal high strength concrete[5]. 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[6].

Reactive powder concrete (RPC), also known as Ultra-high performance concrete (UHPC), is relatively new generation of concrete produced as a ultra-dense mixture of water, Portland cement, silica fume, fine quartz sand, quartz powder, super-plasticizer and steel fibers. The RPC mixtures are optimized at the nano and microscale to provide superior mechanical and durability properties compared to conventional and high performance concretes[7].

From the point of view of chemical composition, cements with low C3A content (for reducing the water demand) give better results. Use of cements with a high fineness should be avoided due to its high water demand. Silica fume is one of the main constituents of RPC. Silica fume in RPC has the three main functions, which greatly improve the properties of RPC.

These are as follows: filling the voids in the next larger granular class, namely cement; enhancing lubrication of the mixture due to the perfect sphericity of the basic particles; and production of secondary hydrates by the pozzolanic reaction with the $Ca(OH)_2$ from primary hydration of cement. For enhancing the homogeneity of RPC, coarse aggregate is replaced by fine quartz sand. The maximum size of sand is recommended to be 1.18 mm for use in RPC[8].

Obviously, these expensive raw materials are responsible for the high production cost. Therefore, how to increase the ratio of performance to cost is a key problem for the application of RPC in practical engineering. The use of RPC in reinforced applications has been limited mainly due to view held that the relatively high cost of materials, to reduce cost of RPC in current study we examined the strength and fresh properties of the Green reactive powder concrete (GRPC) experimentally in which, The ultra fine Quartz sand with the maximal diameter of 600 µm is totally replaced by the least costly and easily obtained natural river sand with the maximal diameter of 1.18 mm, and 10–30% of Portland cement is replaced by the cheap composite mineral admixtures that consist of two types of components such as Fly Ash (FA), Ground Granulated Blast-furnace Slag (GGBS) in this study[9,10].

II. MATERIALS USED AND THEIR PROPERTIES

In this paper, ingredients used in preparing GRPC mixtures are different from conventional concrete. The materials include Cement, Silica fume (SF), Quartz Powder (QP), sand, Super plasticizer and Water. Details of each constituent are as follows. Table 1 shows the properties of Super Plasticizer.

A. **Cement:** Ordinary Portland cement of grade 53 make from a single lot is used for the study. The physical properties of cement as obtained from various tests are listed in Table 4.1. All the tests are carried out in accordance with procedure laid down in IS 1489 (Part 1):1991, valid for ordinary portland cements.

B. **Silica fume:** The silica fume was used in this experiment conforms to IS 15388:2003. The specific gravity 2.63, The silica fume is extremely fine particle size of 0.5µm-1µm.

C. **Sand (Fine Aggregates):** Locally available sand is used as fine aggregates in the preparation of the concrete mix. Grade 1 (particles size ranges from 600µm- 1.18 mm) and grade 2 (particle size ranges from 300µm-600µ) which conforms to IS 383:1970.

D. **Quartz Powder:** The specific gravity 2.6 and it is in White colour powder form and has particles size ranging from 20µm-45µm.

E. **Fly Ash:** Fly ash with various fineness conforming to IS 3812-Part 1- 2003 is used for the study.

F. **Ground granulated blast-furnace slag:** Ground granulated blast-furnace slag conforming to IS 12089 is used for the study.

G. **Water:** The water, which is used for making concrete and for curing, is clean and free from harmful impurities such as oil, alkali, acid, etc, in general, the water, which is fit for drinking is used for making concrete.

H. **Super plasticizer:** Master Glenium sky 8276 which is poly-carboxylic ether based hyper super plasticizer procured from BASF India Ltd construction chemicals- Ahmedabad.

Table 1 Properties of Super plasticizer

Sr. No.	Properties	Glenium 8276
1	Type of SP	Polycarboxylic ether
2	Appearance	Light brown
3	PH value	≥6
4	Specific gravity	1.08
5	Solid content	less than 30% by weight
6	Chloride content	<0.2%

III. EXPERIMENTAL PROGRAMME

A. Mix proportion

The mix design of RPC based on the reference mixes available in the literature and various trail and errors had done at the laboratory.

Table 2 Standard Mix Design

Sr. No.	MATERIAL	QUANTITY (per cu.m)
1.	Portland Cement	955 kg/m3
2.	Fine sand	1051 kg/m3
3.	Silica Fume	229 kg/m3
4.	Quartz Powder	10 kg/m3
5.	Superplasticizer	13 L/m3
6.	Steel Fibers	153 kg/m3
7.	Total Water	191 L/m3
8.	W/B Ratio	0.20

Table 3 Percentage of Fly Ash and GGBS Replaced

Sr. No.	Mix	Percentage of Fly Ash Replaced	Percentage of GGBS Replaced
1	Standard Mix (M)	0%	0%
2	Mix 1 (M1)	5%	5%
3	Mix 2 (M2)	10%	10%
4	Mix 3 (M3)	15%	15%

Where, M, M1, M2, M3 are Composition of Standard Mix, Mix 1, Mix 2, and Mix 3 respectively.

B. Mixing sequence

Since RPC is composed of very fine constituents the conventional mixing is not appropriate, so the mixing method can't be the same. The following sequence in mixing RPC is based on the previous studies.

1) A pan mixer of 100 kg capacity was used to mix RPC, having RPM of 300
2) Mixing all dry powders includes cement, silica fume, quartz powder and river sand for about 5min
3) Addition of half the volume of water containing of SP, mixing it for about 3 min
4) Addition of remaining water and super plasticizer; mixing is continued for until uniform mixture was achieved which has flow able self compacting consistency.
5) Finally steel fibers were added when the flow able consistency was achieved.

Table 4 Fresh Properties of Green Reactive Ponder Concrete

Mix	Slump Flow (mm)
M	820
M1	830
M2	835
M3	845

Where, M, M1, M2, M3 are Composition of Standard Mix, Mix 1, Mix 2, and Mix 3 respectively.

Figure 1 Flow Table Test

C. Specimen preparation and curing

Casting and testing of specimen was carried out as per IS codes IS:516-1959 for compression strength, split tensile and flexural strength. Materials are weigh batched, mixed in a mixer, cast into steel moulds and specimens were stored in room temperature for 24 hours, then removed from the moulds, and cured in normal water until tested.

D. Testing

Cubes of size 150 mm × 150 mm × 150 mm were tested to compute compressive strength, cylinders of size 100 mm dia × 200 mm high were tested to compute split tensile strength and beam of size 150mm × 150 mm × 700mm were tested to compute flexural strength of concrete. Specimens were tested under the Compression testing machine of 3000 KN capacity. Average of 3cubes compressive strength, 3 cylinders split tensile strength and 3 beams flexural strength are tabulated.

E. Theoretical modulus of elasticity

Theoretical Modulus of elasticity of UHSC is calculated using the empirical formula which is given by ACI 363R-929.99

$$\mathbf{Ec = 3.65 \times f_c^{0.5}} \text{ ---------------- (1)}$$

Where, Ec= Theoretical modulus of elasticity in GPa

Fc= Compressive strength in MPa. Substituting the compressive strength values in the above equation 1 the modulus of elasticity is calculated.

IV. RESULTS AND DISCUSSION

A. Production process

By physical observation during concrete mixing, a long time is required for GRPC mixes to ensure that self flow able self-compacting consistency. The total mixing time is 15 min; the long time mixing is necessary for dispersing silica fume and quartz powder in well manner.

B. Mechanical properties

The test results of compressive strength, and split tensile strength, flexural strength and theoretical modulus of elasticity for corresponding mixes are tabulated.

1) Compressive strength

Cube specimens of size 150mmX150mm X150mm were cast for compressive strength as per Indian standard specifications BIS: 516-1959. Compressive strength test results are shown in table 5 and fig no 2. The compressive strength result shows that there is an increase in compressive strength at 28 days by replacing Fly ash + GGBS content up to 5+5% by weight of cement (M1) compared to the Standard GRPC mix (M). The highest compressive strength of 110 MPa is obtained at 28 days for M1 mix containing 5% of Fly ash and GGBS each. The main reason for the increase in compressive strength is due to the physical effect of Fly ash + GGBS powder grains that allows denser packing within the cement particle and Fly ash also acts as pozzolanic materials and improves the micro structure which leads to increase in compressive strength. Compressive strength of M2 and M3 was less compared to the Standard GRPC mix(M). From the figure-2 we can conclude that the variation in compressive strength is not linear.

Table 5 Compressive Strength Test

Mix Type	Compressive strength(MPa)	
	7 Days	28 Days
M	86.65	106.89
M1	81.13	110.39
M2	71.61	87.22
M3	69.02	82.50

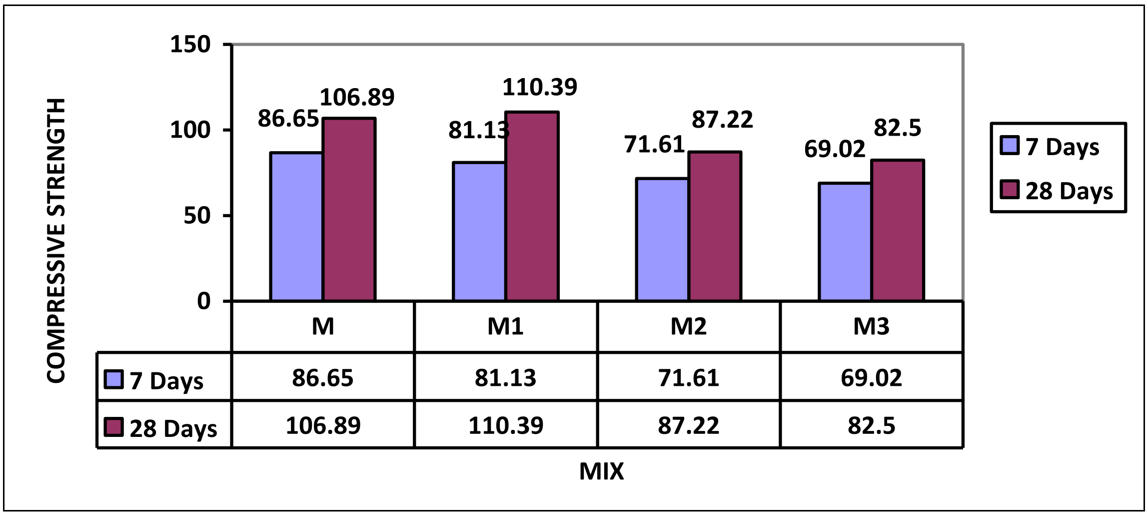

Figure 2 Compressive Strength

2) Split tensile strength

Split tensile strength results are shown in table 6 and fig no 3. The split tensile strength of GRPC is more than that of conventional concrete. It was recorded that maximum split tensile strength is 6.8 MPa for Standard mix (M). Effect of Fly ash + GGBS on Split tensile strength is very small or negligible as compared to compressive strength.

Table 6 Split tensile strength Test

Mix Type	Split tensile strength (MPa)	
	7 Days	28 Days
M	4.736	6.883
M1	4.177	6.543
M2	3.74	6.093
M3	3.353	5.556

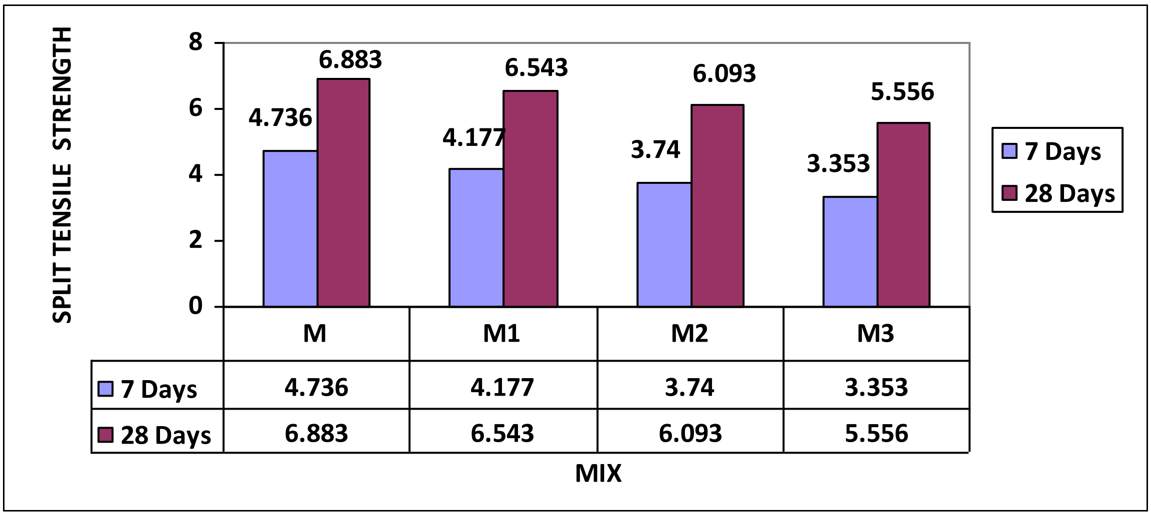

Figure 3 Split tensile strength

3) Flexural Strength

Flexural strength results are shown in table 7 and fig no 4. The Flexural Strength of GRPC is more than that of conventional concrete. It was recorded that maximum split tensile strength is 19.85 MPa for Standard mix (M). Effect of Fly ash + GGBS on flexural strength is very small or negligible as compared to compressive strength.

Table 7 Flexural strength test

Mix Type	Split tensile strength (MPa)	
	7 Days	28 Days
M	13.58	19.853
M1	13.12	19.586
M2	11.55	18.066
M3	10.60	16.066

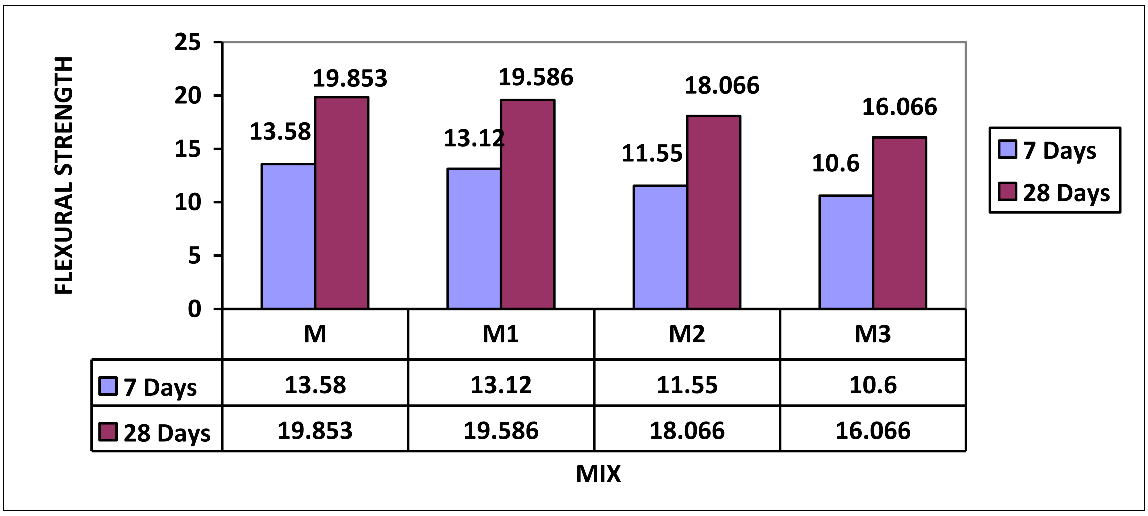

Figure 4 Flexural strength

4) Theoretical Modulus of Elasticity

The Theoretical Modulus of Elasticity results are shown in table 8 and fig 5. The maximum elasticity was calculated 39.97 GPa for Standard GRPC mix (M) samples.

Table 8 Theoretical Modulus of Elasticity

Mix Type	Theoretical Modulus of Elasticity (GPa)	
	7 Days	28 Days
M	33.97	37.73
M1	33.87	38.34
M2	30.88	34.08
M3	30.32	33.15

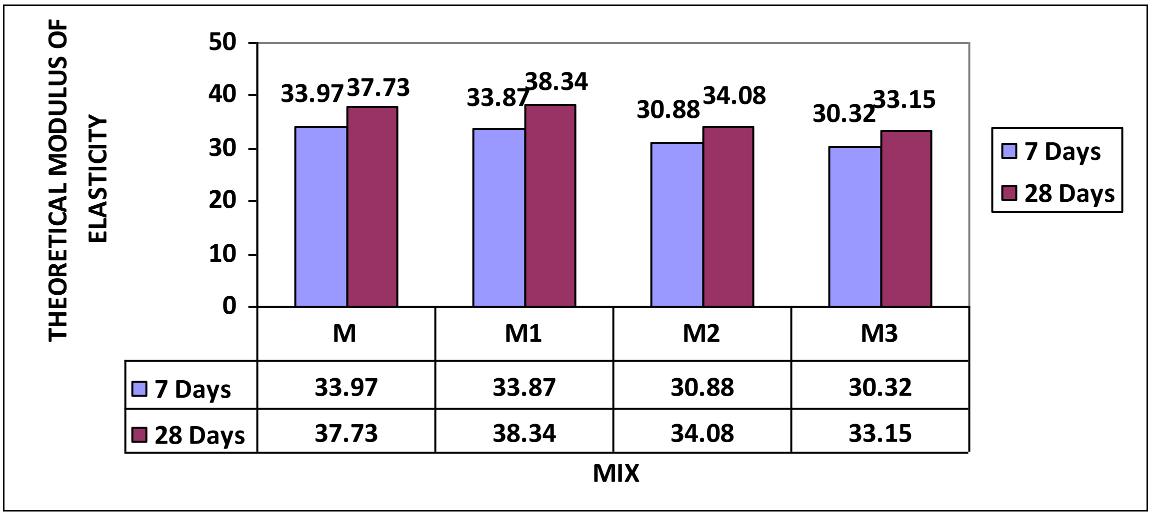

Figure 5 Theoretical Modulus of Elasticity

V. CONCLUSIONS

RPC has ultra-dense micro structure, giving advantages water proofing and durability characteristics. With increase percentage of Fly Ash + GGBS in RPC the heat of hydration is decreases and also cost is decrease. Strength is decrease as the percentage of Fly Ash + GGBS increase, but it is negligible as compared to other benefit. The research shows that use of Fly ash + GGBS replacing to cement achieves economy.

1) The 28 days compressive strength increased for 5% (M1) replacement of cement by Fly ash and GGBS each. For 10 and 15% replacement (M2 & M3) the results were lower than the control GRPC mix (M).
2) M1 with 5% cement replacement gave highest 28 days compressive strength of 110.39 MPa as compared to Standard mix (M) having 28 days strength of 106.89 MPa.
3) The 7 days and 14 days compressive strength values were lower than Standard mix (M) for all mixes with cement replacement, which is because of slow hydration of cementitious matter (Fly ash + GGBS) at initial days.
4) The various mix considered M1 mix with 10% (5% fly ash + 5% GGBS) replacement of cement gave better results.
5) Effect of Fly ash + GGBS on split tensile strength and flexural strength is very small or negligible as compared to compressive strength.
6) The split tensile strength of Standard mix (M) is more than that of other Mix (M1, M2, M3). It was recorded that maximum split tensile strength is 6.8 MPa for Standard mix (M). Strength is decrease as the percentage of Fly Ash + GGBS increase, but it is negligible
7) The Flexural Strength of Standard mix (M) is more than that of other Mix (M1, M2, M3). It was recorded that maximum split tensile strength is 19.85 MPa for Standard mix (M). Strength is decrease as the percentage of Fly Ash + GGBS increase, but it is negligible

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