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ISSN 0974-5904, Volume 08, No. 02

International Journal of Earth Sciences and Engineering

April 2015, P.P.307-312

Study on Fracture Energy of Reactive Powder Concrete Beams

D AMBIKA[1] AND M SHIVARAJA[2]
[1]*Department of Civil Engineering, Kongu Engineering College-638 052 Tamilnadu, India*
[2]*NSN College of Engineering and Technology, Karur- 639 003, Tamilnadu, India*
***Email:** ambikaceg@gmail.com, m.shivaraj2006@gmail.com*

Abstract: 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. RPC is a better alternative to high strength concrete and high performance concrete. The main objective of this paper is to study the mechanical properties of properties of reactive powder concrete with crimpled steel fiber of Ø <0.5mm, to understand the fracture energy absorption of RPC beams so as to assess its strength performance and to evaluate the flexural performance of RPC beams.

***Keywords:** Admixtures, Durability, Crimpled, Fracture energy*

1. Introduction

Reactive powder concrete is an ultra-high strength, ultra high performance and high ductility composite material with advanced mechanical and durability properties. The original concepts of Reactive powder concrete (RPC) was developed in the year of 1990s, by P. Richards and M. Cheyrezy at Bouges laboratory in France. It uses extensively the pozzolanic properties of highly refined silica fume and optimization of the Portland cement chemistry to produce the highest strength hydrates. The mechanical properties that can be achieved include the compressive strength in excess of 200 MPa range. By introducing fine steel fibers, RPC can achieve remarkable flexural strength up to 50 MPa. 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 SiO_2 ratio by introducing the silica components, and incorporation of micro steel fibers. Hence the study is carried out to study the mechanical properties of reactive powder concrete with crimpled steel fiber of Ø <0.5mm and to understand the fracture energy absorption of RPC beams so as to assess its strength performance.

Reactive Powder Concrete (RPC) or Ultrahigh Performance Concrete has been used to describe a fiber-reinforced, super-plasticized, silica fume-cement mixture with very low water-cement ratio (w/c) characterized by the presence of very fine quartz sand (0.15-0.40mm) instead of ordinary aggregate.[1]

2. Influence of Mineral Admixtures

The ingredients like fly ash, silica fume, quartz powder, ground granulated blast slag plays a vital role in RPC to increase its mechanical properties. Increasing the GGBFS and fly ash content improved the toughness of reactive powder concrete Silica fume lowers the total porosity and increases compressive strength

Under the consideration of environmental protection, direct disposal of coal ash is not acceptable. It is required to solidify fly ash before ocean disposal or land disposal. The objective of this study is to investigate the properties and the possible applications of the solid blocks produced from fly ash. Thirty-six mixes have been proportioned using different cementing materials such as Portland cement, lime, sludge treatment compound, and industrial silica slag. Extensive laboratory studies have been conducted to evaluate the block properties such as compressive strength, tensile strength, abrasion resistance, and soundness. In addition, the possible engineering application is also evaluated.

Fiber pullout tests are conducted to measure the bond characteristics of steel fiber from RPC matrix. It is found that the incorporation of silica fume can effectively enhance the fiber–matrix interfacial properties, especially in fiber pullout energy. It is also concluded that in terms of the bond characteristics, the optimal silica fume content is between 20% and 30%, given the conditions of the experimental program. The micro structural observation confirms the findings on the interfacial-toughening mechanism drawn from the fiber pullout test results.

2.2. Fracture Energy

It is found that the method for determination of fracture energy from beam tests can be significantly affected if the load line measurements are not accurate.

The effects of the volume fraction of steel fiber and curing conditions on the fracture mechanical properties of ECOLOGICAL RPC were studied. The results showed that the fracture energy and fracture toughness of ECOLOGICAL RPC increased with the increasing of fiber. Under the standard curing conditions the ductility index of ECOLOGICAL RPC reached a maximum when the fiber volume fraction is 2%. With the rising of curing temperature the maximum fracture strength of ECOLOGICAL RPC and its brittleness were improved.The effects of curing conditions on fracture energy, fracture toughness and ductility index are different from each other.

3. Materials and Methods

The methodology involves literature collection, collection of materials, study on properties of the materials, preparation of concrete specimens after arrived mix proportion, testing of fracture energy by three tests (compressive strength, split tensile strength, flexural strength).

3.1. Ingredients used in RPC

- **Cement :** Ordinary Portland cement 53 grade (OPC)
- **Fine aggregate :** Natural river sand (fine sand less than600µm)
- **Water:** Ordinary portable water
- **Self-compacting admixtures:** Super plasticizer-Conplast SP 530, SP 430.
- **Fibres:** Steel fibre (crimpled fibre of aspect ratio 25)
- **Mineral admixtures:** Fly ash, Micro silica, Ground granulated blast furnace slag.

3.1.1. Fly ash

The term fly ash is often used to describe any fine paniculate material precipitated from the stack gases of industrial furnaces burning solid fuels. Two classes of fly ash defined by Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned.

***Figure 1** Flyash*

3.1.2. Class F flyash

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 10% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds.

3.1.3. Class C fly ash

Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate (SO_4) contents are generally higher in Class C fly ashes (Table 1).

***Table 1:** Chemical composition and classification of fly ash*

Component	Bituminous	Sub Bituminous	Lignite
$Sio_{2\,(\%)}$	20-60	40-60	15-45
$Al_2O_{3\,(\%)}$	5-35	20-30	20-25
$Fe_2O_{3\,(\%)}$	10-40	4-10	4-15
Cao (%)	1-12	5-30	15-40
LOI	0-15	0-3	0-5

3.1.4. Ground Granulated Blast Furnace Slag (GGBFS)

Blast Furnace Slag is a by-product obtained in the manufacturing of Pig iron in the Blast furnace and is formed by the combination of earthy constituents of iron ore with lime stone flux. Quenching process of molten slag his granulated slag when finely ground and combined with OPC has been found to exhibit excellent cementitious properties. Glass particles of GGBFS are the active part and consist of Mono-silicate, like those in OPC clinker, which dissolve on activation by any medium. Glass content in GGBFS is normally more than 85% of total volume. Specific gravity of GGBFS is approximately 2.7-2.90, which is lower than of OPC. Bulk density of GGBFS is varying from 1200-1300 kg/m^3.

***Figure 2** Ground granulated blast slag*

3.1.5. Steel Fibre

Fibres are playing an increasing role as the reinforcing medium of choice for concrete construction. Steel fibre reinforced used now expanding beyond pavement applications, into areas where the reinforcing specification has historically been bars or fabric. With development in steel fibre technology steel fibre reinforced concrete performance characteristics include significant ductile behaviour and enhanced tensile, flexural, shear and comprehensive strengths.

Steel fibre is a primary and secondary reinforcing medium and is most suited to thin section and plates where stresses are highly variable. These typically occur in pavement, short Crete, bored piers and pre cast elements

Figure 3 *Crimpled steel fibre*

3.1.6. Super plasticizer

A study of four commercially available super plasticizer used in type I Portland cement concrete mixes was done by Whiting (1979). They represented both melamine- and naphthalene based formaldehyde condensation products.

Hardened concrete specimens were prepared and tested for compressive strength development, drying shrinkage, freeze-thaw resistance, and resistance to de-icing scaling. From his research, Whiting found out that high range water reducers were capable of lowering the net water content of concrete mixtures from 10% to 20% when used in dosages recommended by the manufacturers. Also it was found out that one- and three-day compressive strengths could be substantially increased through use of high range water reducers. Workability of concrete was measured by slump flow test and in situ tests were undertaken to find out the pumping ability of super plasticized concrete. The coarse aggregate was crushed stone with the maximum size of 25 mm. By using this chemical admixture, which was a little bit different from the conventional ones, the ability of water reduction was increased along with the retention of high workability for a longer time. For mixtures with water-cement ratios between 0.3 and 0.45, the slump diameters were between 500 mm and 740 mm and the compressive strength varied between 53 MPa and 68 MPa at 28 days of age (Table 2).

Table 2: *Mix proportion trials*

Materials	Trail-1	Trail-2
	Amount	Amount
Portland Cement	995	995
Fine sand	1051	1051
Micro ilica (20%Flyash)	229	229
Steel fibre	297	297
Super plasticizer	24	24
Water	303	303

4. Results and Discussion

4.1. Compressive strength

Compressive strength is one of the important properties of concrete. Concrete cubes of size 150x150x150mm were cast with and without of fly ash. After 24 hours the specimen were remoulded and subjected to water curing. After 3 days, 7 days and 28 days of curing three cubes were taken and allowed to dry and tested in compressive strength testing machine. The specimens were tested according to the IS 516-1964 the rate of loading was about 14 N/mm² per minute and the ultimate load was noted. Compressive strength of fly ash and GGBS for 3 days,7 days and 28 days are illustrated in the tables 3 and 4 respectively.

Table 3: *Compressive strength of RPC (20% of Flyash)*

Specimen	Compressive strength		
	3 days	7 days	28 days
1	15.24	32.6	60.06
2	16.08	33.7	62.32
3	16.78	35	62.27
Average	16.03	33.76	61.21

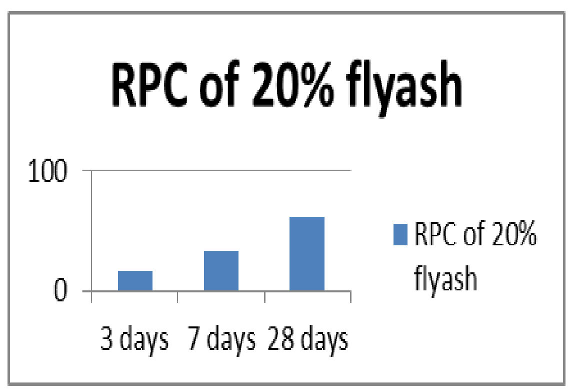


Figure 4 *Compressive strength of RPC (flyash)*

Table 4: *Compressive strength of RPC (20% of GGBS)*

Specimen	**Compressive strength**		
	3 days	**7 days**	**28 days**
1	14.38	27.6	51.23
2	14.45	29.2	52.16
3	15.1	31.4	49.45
Average	14.64	29.55	50.94

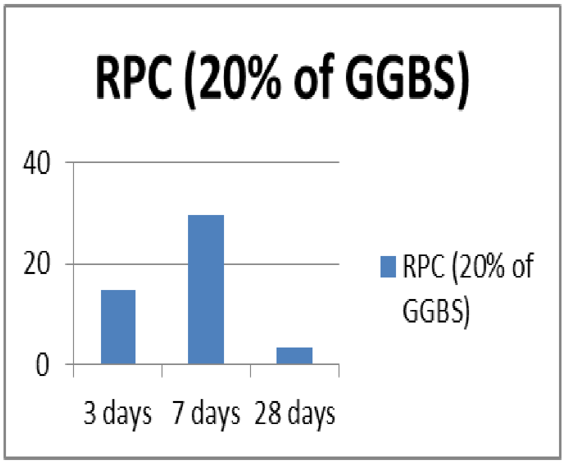


Figure 5*Compressive strength of RPC (GGBS)*

4.2. Split Tensile strength

Split tensile strength is indirect way of finding the tensile strength of concrete by subjecting the cylinder to a compressive to a compressive force. Cylinders of size 150mm diameter and 300mm long were cast with and without fly ash. After 24 hours the specimen were demoulded and subjected to water curing. After 3 days, 7 days and 28 days of curing of two cylinders were taken and allowed to dry and tested in universal testing machine by placing the specimen horizontal. The ultimate loads of the specimen were noted. The testing of the specimens were done as per IS 5816: 1999.Tensile strength of flyash and GGBS for 3 days,7 days and 28 days are illustrated in the tables 5 and 6 respectively.

Split tensile strength, $f_{sp} = 2P/\pi bd$

Where,

P = Load applied to the specimen in N
b = Breadth of the specimen in mm
d = Depth of the specimen in mm

Table 5: *Split tensile strength of RPC (20% of Flyash)*

Specimen	**Split Tensile Strength**		
	3 days	**7 days**	**28 days**
1	1.21	3.04	6.02
2	1.08	3.2	6.23
3	1.5	3.27	6.38
Average	1.26	3.17	6.21

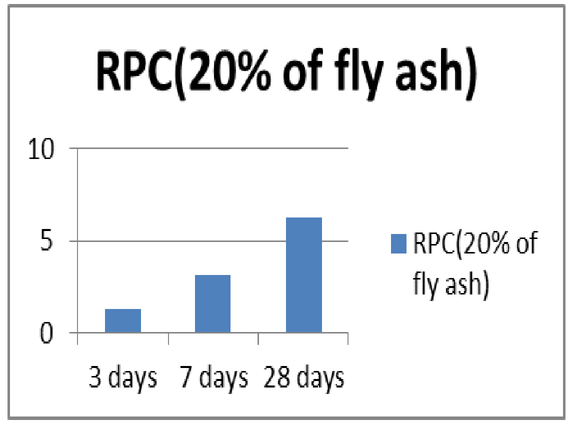
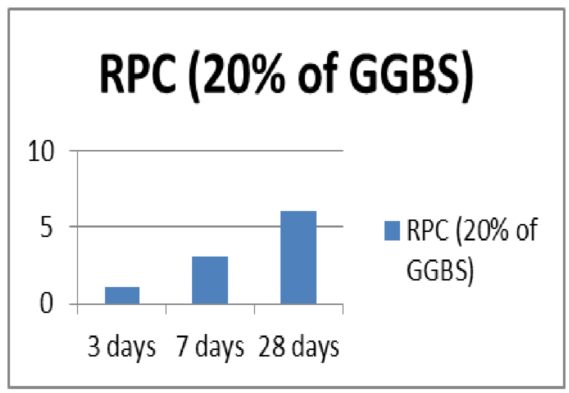


Figure 6 *Split tensile strength of RPC (flyash)*

Table 6: *Split tensile strength of RPC (20% of GGBS)*

Specimen	**Split tensile Strength**		
	3 days	**7 days**	**28 days**
1	1.12	2.96	5.83
2	1.05	3.11	6.17
3	1.22	3.19	6.28
Average	1.13	3.08	6.09



4.3. Flexural Strength

The extreme fiber stress calculated at the failure of specimen is called Modulus of rupture. It is also an indirect measure to predict the tensile strength of concrete. Flexural strength test was conducted as per recommendation IS: 516 – 1959. For flexural strength test beams of size 50 x 50 x 500 mm were casted. Flexural strength of flyash and GGBS for 3 days,7 days and 28 days are illustrated in the tables 7 and 8 respectively.

Table 7: *Flexural strength of RPC (20% of flyash)*

Specimen	**Flexural strength**		
	3 days	**7 days**	**28 days**
1	4.1	8.3	17.3
2	3.97	8.12	14.26
3	1.14	4.14	14.38
Average	4.07	8.22	15.31

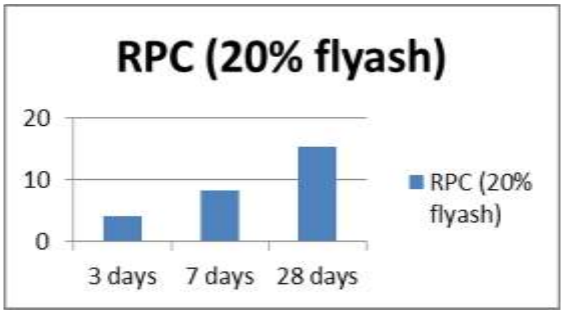


Figure 8 *Flexural strength of RPC (20% flyash)*

Table 8: *Flexural strength of RPC (20% of GGBS)*

Specimen	Flexural strength		
	3 days	7 days	28 days
1	3.92	7.86	14.2
2	3.86	8.04	11.31
3	4.02	8.09	12.18
Average	3.93	7.99	12.56

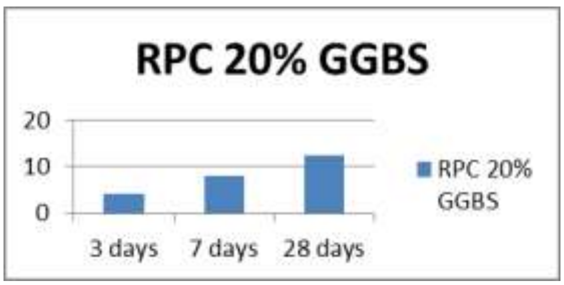


Figure 9*Flexural strength of RPC (GGBS)*

4.4. Experimental Test set up

The laboratory apparatus used for the fracture energy tests was adapted from a standard two-point loading flexural strength test setup. The load was applied to a single roller direct measurement of the beam deflection, provided that the supports do not deform in elastically by more than 0.0004 (0.01mm). The load deflection values for different mixes are illustrated in table 9 and 10 respectively.

Table 9: *Load deflection (Mix-1)*

Load/KN	Deflection (MM)
10	0.35
20	0.72
30	1.05
40	1.6
50	1.95
60	2.35
70	2.8
80	3.2
90	3.9
100	4.6
108	5.8

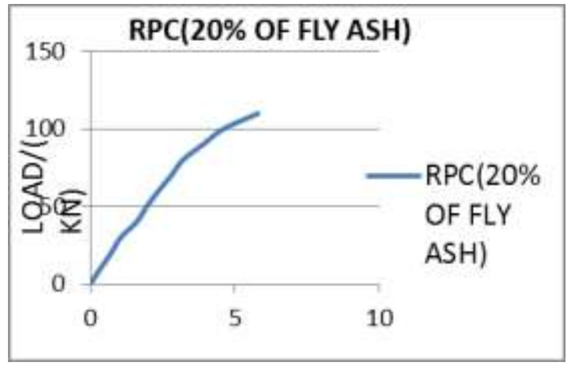


Figure 10 *Load deflections (Mix-1)*

Table 10: *Load deflection (Mix-2)*

Load/KN	Deflection (MM)
0	0
10	0.6
20	0.95
30	1.2
40	1.6
50	1.9
60	2.2
70	2.9
80	3.5
90	3.9
94	4.9

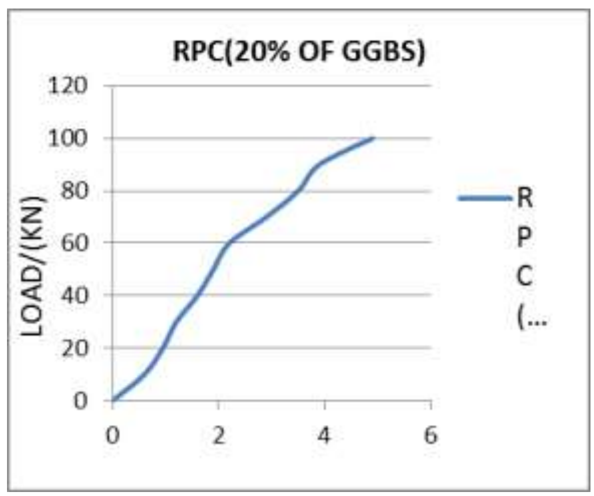


Figure 11 *Load deflections Curve for GGBS*

5. Conclusion

In experiment, all RPC beams work and fail similarly. Compared with the conventional concrete, RPC has better mechanical performance. RPC has higher ultimate flexural strength and cracking flexural strength than those of the conventional concrete.

Therefore, RPC provides high safety and high durability material for some special projects such as the long-span bridges and the important structures. In RPC (Mix-1) the maximum compressive strength, spilt tensile strength, flexural strength is 61.21Mpa, 6.21Mpa, 15.31Mpa.In RPC (Mix-2) the maximum compressive strength, spilt tensile strength, flexural strength is 50.94Mpa, 6.09 Mpa, 12.56Mpa.In RPC (Mix-1) facture test, the maximum load at failure 108 KN. In RPC (Mix-2) facture test, the maximum load at failure 94 KN. On the whole comparing the above results we find that Fly ash attain more strength than GGBS.

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