Optimization of high strength concrete with construction and demolition waste

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Abstract. The development in the Infrastructure Sector has led to a revolution in the Construction Industry with fast track projects. Hence the use of prefabricated construction is gaining importance in India in the recent days. The structural elements like beams, columns and wall panels are fabricated in a factory and assembled at the site. The concrete used in the fabrication of these members are conventional concrete with density range 2400-2500 kg/m³. The transport, handling and erection of these members involve large machineries. Moreover due to the use of conventional concrete the self weight of the structure also increases leading to large column size and foundations. Hence this work is based in optimizing reactor powder with mineral admixtures, construction and demolition waste and steel fibres that can be used in precast construction. The compressive strength achieved is 63.12 Mpa, flexural strength is 6.21 and tensile strength is 6.38MPa. Rapid chloride penetration test (RCPT) was done to test the durability of the concrete and it was found to be 469 coulombs which proved it to be resistant to chloride penetration.

1. Introduction
The current trend of construction Industry is witnessing fast track projects with the use of precast structural units. But this technique has not gained popularity due to bulky structural elements resulting in difficulty in transportation and erection in the site. Also Lightweight concrete is available in construction practice but the strength attained so far is not sufficient to take up the structural loads. Reactive powder concrete (RPC) is a high strength concrete comprising powder admixtures and eliminating the coarse aggregate [1]. RPC is not conventionally used due to its high cost. RPC possess excellent strength capacities, fracture energy and can be used in any type of severe exposure conditions [2–4]. The strength development in RPC is mainly based on particle packing and the strength achieved so far is 200 to 800 MPa [5–11]. The application of RPC is mainly in bridges, nuclear power plants, tall structures and impact resistant buildings [12–14]. In spite of its many advantages RPC has not been used in the construction practices due to high cost and energy demand [12,15,16].

The components required for proportioning RPC are Portland cement, fine quartz sand, low water - binder ratio, chemical and mineral admixtures and discrete fibres [17]. The high cost of RPC is due to more cementitious binders in the matrix, fine quartz sand and steel fibres. Due to the advancement in concrete technology several mineral admixtures have been proven to perform better that ordinary Portland cement in terms of strength and durability. The mixture can be proportioned economically by the use of these mineral admixtures as replacement to cement. Also in this paper an attempt is made to
use the construction and demolition waste (C&D) as replacement to the fine quartz sand. The material is pulverized and the fraction retained in 600 micron sieve is used as fine aggregate in this concrete mix. Obviously, these expensive raw materials are responsible for the high production cost. Moreover not all structural elements require high compressive strength of 200 MPa. The maximum strength that is required in high rise buildings range from 60 to 80MPa. As the strength of the concrete increases it becomes more brittle. Hence a balance in the strength and flexural toughness is needed for concrete used in structural members to prevent the cracking in concrete due to excessive load.

RPC is a good choice in casting precast structural elements as the size of the member can be reduced due to high compressive strength which reduces the dead weight of the member also facilitating ease in transportation and handling these structural members. The flexural toughness is increased as steel fibres are included in the matrix. Accelerated curing methods like autoclaving or steam curing are generally adopted for producing RPC which normally results in high energy consumption and as a result the cost of production of RPC gets increased [18,19]. Also accelerated curing methods facilitate the structural components to be ready in 24 hours which will facilitate fast track construction of the projects.

2. Materials and methodology
Portland Pozzolano cement of 53 grade was used in this work. There are several components involved in the making of reactive powder concrete like fly ash, steel fibres, silica fume and fine quartz sand. In this work fly ash F has been used as cement replacement upto 20%. And to reduce the usage of quartz sand pulverized construction and demolition (C&D) waste has been used as replacement to quartz sand upto 20%. The mixture proportion was done as follows: 60% of the binding material was Portland cement in which the replacement with flyash was varied from 0 to 20% of cement, 10% was silica fume, 10% was metakaolin and 20% was ground granulated blast furnace slag (GGBS). The other modification made in this project is the use of CNC waste steel fibres instead of commercial available steel fibres. These fibres were available as fine coiled springs. They were cut to a length of 10 mm. The W/C ratio was maintained as 0.35%. Superplasticiser (commercially available Glenium-53) was used as 1% by weight of cement. The individual components are dry mixed in Hobart mixer for 3 min. Then water and superplasticiser are added to the mix and mixed for 5 minutes approximately. The mixture is then poured in moulds for the appropriate testing. Since many components are involved in the making of reactive powder concrete (RPC), the traditional methods of experimentation will lead to number of trials.

In this work, the experimental trials were designed using design of experiment software in order to minimize the trial runs and also to get meaningful conclusions from the experimental results. The range of factors that were varied was entered in the software and combination for each trial was designed by the software. Specimens for testing the compressive strength (15 cm cube), flexural strength (beam of size 10 cm x 10 cm x 500 cm) and split tensile strength (cylinders of 10 cm diameter and 20 cm height) were casted in the laboratory based on the designed trial mixes. The specimen were subjected to steam curing at 90°C for 24 hours and tested on the next day. The test results which are the responses were entered in the software. The significance of the test results were analyzed by the software. Thus the advantage of using design expert software is that, apart from minimizing the trials it also facilitates to verify the reliability of experimental results by statistical analysis (ANOVA). The interaction effect between the individual factors can also be inferred from the response surface graphs [20]. The major factor and the range of the factor can be identified by using this tool and based on the results the reasons for decrease or increase in the responses can be evaluated from the available literature and reactions of the components.

Durability of concrete was tested using Rapid Chloride Penetration Test (RCPT). The test set up is as shown in figures1-2. The quality of concrete can be assessed based on the coulombs passed. The lesser the charge passed, concrete is durable.
3. Results and discussions

The concrete specimens are to be tested for compressive, tensile and flexural strength. The results of the response surface graph are given in the graphs. Fig. 3 shows that compressive strength increases as the fly ash and C&D waste content increased. Similarly as the steel fibres content increased there was increase in strength (Figure 4). The same trend was observed with respect to flexural strength and tensile strength also as given in graphs (5 to 8). The improvement in strength parameters is mainly attributed to the use of 60% mineral admixtures (fly ash, silica fume, metakaolin and GGBS) which enhances the filler effect and improves the particle packing of the matrix resulting in dense microstructure. The density of the concrete varied from 1680 to 1852 kg/m$^3$, which is less when compared to the density of conventional concrete (2400 kg/m$^3$).

![Figure 1. Details of the test.](image1)

![Figure 2. Test set up in the laboratory.](image2)

![Figure 3. Response surface with fly ash and C&D waste for compressive strength.](image3)

![Figure 4. Response graph with C&D waste and steel fibres for compressive strength.](image4)
Figure 5. Response surface with fly ash and C&D waste for flexural strength.

Figure 6. Response surface with C&D waste and steel fibres for flexural strength.

Figure 7. Response surface graph with fly ash and C&D waste for tensile strength.

Figure 8. Response surface graph with C&D waste and steel fibres for tensile strength.

Figure 9. Response surface with fly ash and C&D waste for RCPT.

Figure 10. Response surface with C&D waste and steel fibres for RCPT.

The RCPT results given in fig 8 and 9 shows that the value decreases with increase in fly ash and C&D waste which implies that the concrete is durable. The range of RCPT is from 500 to 650 coulombs.
The Optimization was done for high strength within the range of the parameters used. The optimized mix was casted and tested to check the predicted values as given in Table 1 and 2. The observed values were closer to the predicted values.

**Table 1.** Optimized Values.

| Fly ash (%) | C & D waste (%) | Steel fibres (%) |
|-------------|-----------------|------------------|
| 17.87       | 18.92           | 5                |

**Table 2.** Confirmatory tests.

| Compressive strength (MPa) | Flexural strength (MPa) | Tensile strength (MPa) | RCPT (Coulombs) |
|----------------------------|-------------------------|------------------------|-----------------|
| Predicted                  | 62.90                   | 6.10                   | 6.28            | 458.92          |
| Observed                   | 60.6                    | 5.89                   | 6.12            | 478.32          |

**4. Conclusions**

Based on the experimental results the following conclusions were derived:

- Construction and demolition waste (C&D waste) finds a potential use as replacement for sand in the production of reactive powder concrete which could reduce the cost of this concrete.
- The addition of supplementary cementitious materials and admixtures contributed to the strength enhancement of the RPC thereby making it a suitable material that can be used in construction of structural elements.

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