Concrete using Silica Fume and Fly Ash

MD MUSHIRUDDIN
STUDENT
RAMA UNIVERSITY

Abstract— Usage of substitute minerals in concrete helps the conservation of raw materials, reduces CO2 emissions and ultimately helps to a cleaner environment. Increased use of supplementary cementing materials in place of cement in concrete structures worldwide contributes to sustainability in construction. SF, a by-product of silicon metal, and FA, a by-product of coal-fired thermal power stations are the two globally available supplementary cementitious materials which possess pozzolanic properties. SF like all other pozzolanic materials is capable of reacting with the calcium hydroxide, Ca(OH)2 liberated during cement hydration to produce hydrated calcium silicate (C–S–H), which is accountable for the strength of hardened concrete. The high content of very fine amorphous spherical (100 nm average diameter) silicon dioxide particles (present more than 80%) is the main reason for high pozzolanic activity of SF. The SF can improve both chemical and physical properties of concrete. Similarly, FA can react with Ca(OH)2 and yield calcium silicate hydrate (C-S-H) gel and calcium aluminate hydrate (CAH) which are active in creating denser matrix leading to higher strength and better durability.

Key words: CO2 emissions, Cementing materials, Sustainability, Cementitious, Amorphous, Durability.

1.0 INTRODUCTION

An extensive literature review revealed that majority of the published literatures, if not all, present studies on ordinary Portland cement. However, production of Portland cement in the recent times is almost stopped and the present construction industry depends mostly on slag cement. This fact calls for a detailed study on the concrete made with PSC partially replaced by SF/FA.

Most of the previous studies on SF concrete consider the partial replacement of cement keeping the total weight of cementitious material, fine and coarse aggregate constant. The main purpose of these studies was to evaluate the effect of SF on the behaviour of concrete. However, in practical constructions, SF concrete is prepared as per relevant codes and standards. Many international design codes (IS: 10262-1982, ACI234R-96) advices an extra cement of 10% while mineral admixture is used as partial replacement of cement. Also, due to the differential specific gravity of cement and SF, the mix design results varying weights of aggregates as the percentage replacement of SF varies. Therefore, the concrete behaviour changes due to the combined effect of additional amount of cement, SF and reduced amount of aggregates.

Also, all the previous studies on SF concrete are concentrated in high-strength concrete. No attempt has been carried out using SF as a replacement of cement for low/medium grade concretes (viz. M20, M25).

This Chapter presents experimental investigations on the behaviour of medium grade concrete designed as per industry practice using PSC partially replaced by SF/FA.

2.0 Materials and Test Specimens

This chapter presents the experimental results of concrete made of PSC partially replaced with SF and FA. This section presents a brief description of ingredient materials used in the present study and the details of different test specimens.

SF of grade 920-D having specific surface area of about 19.5 m2/g obtained from Elkem Private Ltd. is used to replace the cement partially in the present study. Chemical composition of SF is analysed according to ASTM C 1240 and presented in. The cement and SF used in the experiment are tested to check the conformity with the relevant Indian Standards.

FA used in the experiment is tested to check the conformity with the relevant Indian Standards and presented in PSC conforming to IS: 455-1989; having 28-day compressive strength of 48 MPa is used in this study. The chemical components and physical properties of cement are presented.

Natural river sand (zone-II) conforming to IS: 383-1970 is used as fine aggregate. The specific gravity and water absorption values are obtained as 2.65 and 0.8%, respectively. Crushed, angular graded coarse aggregate obtained from local quarry having nominal maximum size of 20 mm is used. The specific gravity and the water absorption of the coarse aggregates are 2.75 and 0.6% respectively. Water reducing superplasticizer (Sikaplast 301 I, Polycarboxylic based) having a specific gravity of 1.08 is used in the present study.

Test specimens are prepared for compressive strength, tensile splitting strength and flexural strength test. 15 samples are considered for each mix proportions in each test category. Concrete mixing is done using laboratory rotary mixture machine. The workability of the concrete mixtures is measured using the slump cone test according to IS: 1199-1959. Cubes of size 100 x 100 x 100mm (cylinders of size 100 x 200mm and prisms of size 100x100x500 mm are casted for the determination of compressive strength, split tensile strength, and flexural strength respectively. All the specimens are cured in normal tap water at natural weather condition up to 28 days.

Chemical and Physical Properties of SF

Parameter	Specification	Analysis
Chemical Requirements		
SiO_2 (%)	> 85.00	88.42
Moisture Content (%)	< 3.00	0.15
Loss of Ignition (%)	< 6.00	1.50
Physical		

Requirements		
>45 Micron (%)	< 10.00	0.72
Pozz. Activity Index (7d)	> 105	137
Sp.Surface (m^2/g)	> 15.0	19.5
Bulk Density (kg/m^3)	500-700	615

Chemical and Physical properties of FA

Parameter	Specification	Analysis
Chemical Requirements		
SiO_2 (%)	> 35.00	39.88
MgO	< 5.00	1.15
Physical Requirements		
Fineness-Specific surface in m^2/kg	< 320.00	329
> 45 Micron (%)	>34	2.72


Concrete cube


Concrete cylindrical samples


Concrete prism

2.1 Concrete using SF

The first part of this chapter is to study the behaviour of concrete made of PSC cement partially replaced by SF. Seven sets of concrete mixes are prepared by partial replacement of cement with equal weight of SF. Mix designs are prepared as per Indian Standard IS:10262-2009 and weight proportions of cement, SF, natural sand, coarse aggregates, water and admixture are shown in. The SF dosage of 0% (control mix), 5%, 10%, 15%, 20%, 25%, and 30% of the total cementitious material are considered in the present study. The cement content in the control mix is obtained as about 308kg/m3, while the total cementitious content, in the mixtures where SF is used, is increased to be 338 kg/m3 (10% more than the cement content of the control mix) as per IS: 10262: 2009. As the percentage of SF increases the cement contents in SF concrete mixtures reduces from 322 kg/m3 (5% SF) to 237 kg/m3 (30% SF). It can be observed from the table that the total weight of the aggregate reduces with increased percentage of SF. This is due to the increased volume of cementitious materials (specific gravity of SF is lower than that cement). As SF reduces the workability of the fresh concrete, water reducing superplasticizer is added proportional to the dosage of SF. Water content is kept constant (148 kg/m3) for all the mixtures considered in this study.

2.2 Dosage of SF and Workability of Concrete

Workability of SF concrete reduces vigorously due to very high specific surface area of SF. Addition of water reducing admixture (Super plasticizer) is necessary for SF concrete to obtain desired workability. Accordingly, dosage of superplasticizer is increased (keeping the water content of 148kg/m3 constant) with the increase of SF dosage to maintain the slump value within a range of 150 x 30mm. Slump test is conducted on fresh concrete for all the concrete mixes considered in this study. A surface plot between the dosage of SF, dosage of admixture and the slump value obtained.

2.3 Mechanical Properties of SF Concrete

Test specimens are prepared from all the seven mixes for compressive strength, split tensile strength, and flexural strength as discussed in the previous section. Average value of the results of fifteen specimens in each of the selected category is considered as the representative result. This section presents the results obtained from the experimental studies.

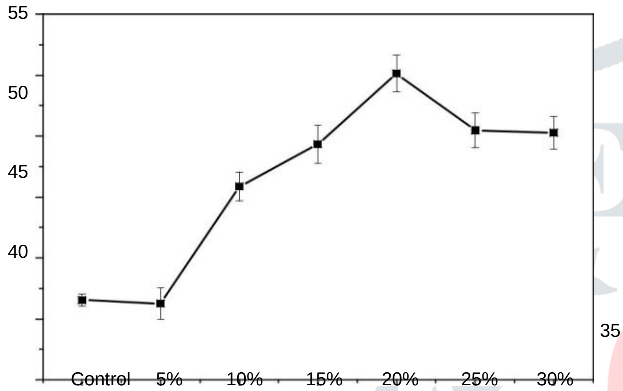
2.3.1 Compressive Strength

Mean compressive strength of concrete obtained for each SF dosage is plotted in. It can be seen that the compressive strength, in general, increases with increase of SF dosage. For SF dosage of 5% there is hardly any change in compressive strength. However, as the SF dosage increases beyond 5%, the strength increases gradually to reach a maximum value at 20%. The increase in compressive strengths of about 29%, 40%, 59% and 44%, are observed for the corresponding SF dosages of 10%, 15%, 20% and 25% respectively. There is no further increment in compressive strength observed beyond the SF replacement of 20%.
A number of published literature [Khedr and Abou-Zeid 1994; Mazloom et al. 2004; Bhanjaa and Sengupta 2005; Poon et al. 2006; Bingöl and Ilhan 2013; and Sarıdemir 2013] report similar observations. This study is different and unique in terms of two aspects: (a) use of PSC concrete and (b) use of additional 10% cementitious materials for SF concrete. Although the designed strength of the control mix for all these studies are not same, the relative increase of compressive strength (due to SF) obtained in these studies are compared with the results of present study.
It can be seen that at 5% replacement, the study carried out by [Sarıdemir 2013] is found to be the maximum at about 22% while [Bhanjaa and Sengupta 2005] and present studies

yield hardly any improvement in compressive strength. However, at 20% replacement the present study shows an increase in compressive strength of about 59% compared to 38% by [Khedr and Abou-Zeid 1994] which is maximum among the previous studies considered. At 15% replacement, the present study shows that the increase in compressive strength is comparable with that of previous studies. It can be concluded that if the guidelines suggested by IS code is followed in the replacement of SF, a cap of about 21% (59% - 38%) in compressive strength can be

Control 5% 10% 15% 20% 25% 30%

achieved at 20% replacement.



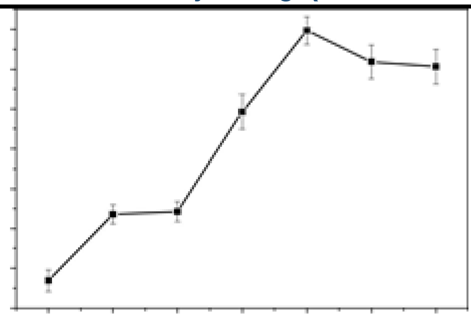
Doses of Silica Fume (%)

Effect of SF on compressive strength development of concretes

2.3.2 Tensile Splitting Strength

Tensile splitting strength of SF concrete for selected SF dosages is presented. This figure shows that as the SF dosage increases the tensile splitting strength increases gradually to reach a maximum value of 3.8 MPa at a dosage of 20%. It can be seen that the strength reduces for further increase of SF content. The increase in tensile splitting strength are about 12%, 13%, 33%, 49%, 43% and 42% at 5%, 10%, 15%, 20%, 25% and 30% of SF dosages respectively.

It is to be noted that the behaviour of strength increments and the optimum dosage of SF is almost similar for both compressive and tensile splitting strength. The maximum strength is achieved in both cases for SF dosage between 15% and 25%. The relative increase of split tensile strength (due to SF) obtained in two previous studies [Bhanjaa and Sengupta 2005; and Sarıdemir 2013] are compared with the results of present study and presented in. It can be seen that for all replacement, the increase in strength is lower in the present study in comparison with previous studies considered. At lower replacement the difference in strength is higher, however at higher replacement, the difference is comparable.



Dosage of Silica Fume (%)

2.4 Correlation between Different Properties of SF Concrete

The compressive strength of concrete is generally treated as the significant parameter for the quality governor. Design codes express the other parameters in terms of compressive strength. The pair of values obtained for the tensile splitting strength and compressive strength from 105 data-set (seven concrete mixes with 15 numbers of samples each). Similar plots for flexural strength and compressive strength are presented in. The data are analysed statistically and best fitted empirical relationships are developed between these quantities by performing a regression analysis and presented in Eqs. 2.1-2.2:

fsp = a x fcc ^b (2.1)

f fl = c x fcc ^d (2.2)

Where fsp, ffl and fcc denote tensile splitting, flexural and compressive strengths of concrete, expressed in MPa, respectively. The values obtained for the constants (a, b, c and d) along with R2 value from the regression analysis in the present study are compared with [Bhanjaa and Sengupta 2005]

The UPV tests are carried out on all concrete cubes at 28 days as per IS: 13311(Part1)-1992; before conducting the compressive strength test. UPV measurements are conducted using PUNDIT Lab+ device manufactured by PROCEQ, Switzerland. UPVs were evaluated using direct transmission (cross probing) with path length equal to the concrete specimen width (100 mm).

A relationship between UPV values and compressive strengths from 105 data-set is developed using regression analysis as follows:

fcc = 0.006 v + c (2.3a)

Where, c = 4.75 + 0.03s(50 - s) (2.3b)

Where fcc denotes compressive strengths of concrete (in MPa), v denotes ultrasonic pulse velocity, and s denotes amount of SF replaced (in %).

The application of these equations, however, is limited to moderate grade of control mix (M20-M30). Presents the experimental data set of compressive strengths of hardened concrete and corresponding ultrasonic pulse velocities along with the Eq. 4.3 for six different mixes involving SF. This figure shows Eq. 4.3 is fairly matching the experimental values for different concrete mixes.

UPV test set up

2.5 Conclusions

The experimental investigation is carried out to study the enhancement of properties such as compressive strength, tensile splitting strength and flexural strength of concrete made of PSC using SF and FA. The salient conclusions of the present study are as follows:

1.General behaviour of medium grade PSC concrete partially replaced with SF is found to be similar to that of Portland cement concrete as reported in
previous literature. Incorporation of SF is found to be increasing the compressive, tensile splitting and flexural strength of concrete made of PSC.

2. The compressive strength of concrete increases gradually from a SF dosage of 5%, to reach an optimum value at 20%. The percentage of increment in strength is observed to be about 29%, 40%, 59% and 44%, for the corresponding SF dosages of 10%, 15%, 20% and 25% respectively. A cap of about 21% in comparison with previous studies is found at 20% replacement. This cap can be attributed to the use of 10% extra cement.

3. The splitting strength of concrete cylinders increases gradually with the SF dosages to reach an optimum value at 20%. When compared with previous studies, it is found that the increment of strength is lower at lower dosages of SF but it is comparable at higher dosages of SF.

4. The flexural strength of concrete prism increases gradually with increase of SF dosage, to reach an optimum value at 25%. The increase in flexural strengths is about 4.45%, 5%, 12%, 33% and 18% at the SF replacements of 10%, 15%, 20%, 25 and 30% respectively. A cap of about 10% in comparison with previous studies is observed at 20% replacement.

5. Best fitted empirical relationships are developed for representation of the properties such as flexural strength and tensile splitting strength in terms of compressive strength for PSC SF concrete. The average ratio between the flexural and tensile splitting strengths of SF concrete is found to be slightly more than ACI recommended values.

6. A single equation is proposed to express compressive strengths in terms of UPV and percentage replacement of SF for PSC SF medium grade concrete. This equation is found to be fairly matching the experimental values for different concrete mixes.

7. Up to 20% of FA replacement in concrete made of PSC shows increase in compressive strength of concrete with no degradation of its tensile splitting and flexural strength. But at 40% and 60% replacement yields inferior quality of concrete.

5.0 References

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