MIX DESIGN OF HIGH PERFORMANCE CONCRETE WITH SILICA FUME AND FLY ASH

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Introduction

Concrete is currently the most widely used construction material in the world. Ordinary Portland Cement (OPC) is the main ingredient used for the production of concrete and still no alternatives are found for complete replacement. The cement production evolves a large amount of Carbon Dioxide into the atmosphere, so it has been identified as a major contributor for greenhouse effect and global warming. Hence, finding of potential replacement materials for OPC is extremely important.

It has been found that OPC can partly be replaced with Supplementary Cementitious Materials (SCMs) which are industrial by products such as Silica Fume, Fly ash, Ground Granulated Blast Furnace Slag (GGBS), Rice husk ash, Meta kaolin etc. [01]. SCMs improve concrete strength mainly in two ways: increase the generation of more Calcium Silicate Hydrate (C-S-H) through a pozzolanic reaction with $Ca(OH)_2$; and contribute in providing denser concrete due to better close packing of particles [1]. In addition the use of SCMs controls concrete workability and it enhances the durability as well. Amongst SCMs, Silica Fume and Fly ash are the most common SCMs used in the concrete industry. Silica Fume is a waste by-product of the production of silicon and silicon alloys and it improves bond strength, compressive strength and abrasion resistance of concrete. Fly ash is a waste by-product of coal power generation and its particle size is comparatively small. It primarily acts as a filler material for the concrete.

In the past SCMs were used individually in concrete production. With the current trend of production of high performance concrete, investigations are carried out into the possibility of using several SCMs together. In this context, this study looks into identify the optimum replacement levels of Silica Fume and Fly ash to produce high performance concrete having strength in excess of 70 MPa though an experimental investigation. Optimum use of the two materials in teams of concrete workability is also studied.

Materials and Methods

Material Specification

Ordinary Portland Cement (OPC) was used as the main binder. After conducting trial mix designs, coarse aggregate passing the 14 mm sieve and retained in the 10 mm sieve and fine aggregate passing the 2.36 mm sieve were identified as suitable aggregates to achieve high level of strength.

Micro silica (SF) of market name “MB-SF” by BASF Construction Chemicals (Hong Kong) limited and class F fly ash (FA) were used SCMs. A high range water reducing admixture (HRWRA) named Rheobuild 1000 was used primarily to achieve the required workability.

Material Testing

Different testing methodologies were followed during the experimental procedure satisfying the ASTM, EN and BS standards for material and specimen testing.

Specific gravity of hydraulic cement was found to be 3.15 conforming to the ASTM Designation C188 – C95. An AIV value of 34.17 was obtained from the AIV test carried out for the coarse aggregate according to BS 812: Part 103.1: 1985 and the specific gravity of coarse aggregate was found to be 2.76 (BS 812: Part 2:1997). Fine aggregate was analyzed using the Sieve analysis procedure with sieve sizes 5 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm and 75 µm (conforming to BS 812: Part 103.1: 1985) and the fineness modulus was found as 3.16. In addition to the sieve analysis, fine aggregate was tested for the amount of organic impurities present conforming to ASTM Designation C40-99 and colour code 3 was observed.

Methodology

Mix design of the control mix was carried out conforming to the ACI manual 211.4R-93 [2] and the resulting mix proportions were 550 kg m^{-3} cement, 1088 kg m^{-3} coarse aggregate, 543 kg m^{-3} sand, 194 kg m^{-3} water, and 1.2 % of High Range Water Reducing Admixture.

Table 1. Proposed Mix Proportions

Sample	Cement (kg m^{-3})	Silica Fume (kg m^{-3})	Fly Ash (kg m^{-3})	Coarse Agg: (kg m^{-3})	Fine Agg: (kg m^{-3})	Water (kg m^{-3})	HRWR (L m^{-3})
S0F0	550.0	00.0	00.0	1088	543	194	6.6
S5F0	522.5	27.5	00.0	1088	543	194	6.6
S5F5	495.0	27.5	27.5	1088	543	194	6.6
S5F10	467.5	27.5	55.0	1088	543	194	6.6
S5F15	440.0	27.5	82.5	1088	543	194	6.6
S5F20	412.5	27.5	110.0	1088	543	194	6.6
S10F0	495.0	55.0	00.0	1088	543	194	6.6
S10F5	467.5	55.0	27.5	1088	543	194	6.6
S10F10	440.0	55.0	55.0	1088	543	194	6.6
S10F15	412.5	55.0	82.5	1088	543	194	6.6
S10F20	385.0	55.0	110.0	1088	543	194	6.6

S12.5F0	481.3	68.8	00.0	1088	543	194	6.6
S12.5F5	453.8	68.8	27.5	1088	543	194	6.6
S12.5F10	426.3	68.8	55.0	1088	543	194	6.6
S12.5F15	398.8	68.8	82.5	1088	543	194	6.6
S15F0	467.5	82.5	00.0	1088	543	194	6.6
S15F5	440.0	82.5	27.5	1088	543	194	6.6
S15F10	412.5	82.5	55.0	1088	543	194	6.6
S15F15	385.0	82.5	82.5	1088	543	194	6.6

Sx Fy notation stands for x % replacement of cement with Silica Fume and y % replacement of cement with Fly Ash

The results found in the literature upon single use of SCMs, the optimum replacement level of silica is in a range of (10-15) % [03], and the optimum replacement level of fly ash is 10% [4][5] in the perspective of concrete strength. Depending on these results, 18 mix combinations of silica fume and fly ash were proposed as shown in Table 1. These mix combinations were mainly categorized into four silica fume series namely S5, S10, S12.5 and S15 series. i.e. S5 stands for replacement of OPC with 5 % silica fume etc. Fly ash content in each of the series was varied as 0 %, 5 %, 10 %, 15 % and 20 %.

Four cubes of 150×150×150 mm^3 for each mix combination were cast and each mix combination was tested for its' workability through the slump test according to ASTM C143 guidelines. Out of the four cubes casted, two cubes were tested for 7-day early compressive strength and the other two cubes were tested for 28- day compressive strength conforming to BS 1881-116:1983 using the Auto-test Compression Testing Machine.

Results and Discussion

The test results were analysed considering the relative 7-day and 28-day compressive strength variation and the workability variations of each mix combination. Compressive strength results obtained for all 19 mix combinations are shown in Table 2. The 7-day average compressive strength and 28-day average compressive strength results are graphically illustrated via four main silica fume categories S5, S10, S12.5 and S15 in Figures 1 and 2 respectively. Different hatching patterns have been used to distinguish between four silica fume categories.

Table 2. Average compressive strength results of concrete samples

Sample	7-Day (MPa)	28-Day (MPa)	Sample	7-Day (MPa)	28-Day (MPa)

S0 F0	49.43	65.09	S10F20	39.96	65.60
S5 F0	50.39	66.12	S12.5F0	49.47	69.93
S5 F5	49.42	71.12	S12.5F5	47.16	72.13
S5 F10	46.77	70.76	S12.5F10	45.83	70.12
S5 F15	45.46	66.39	S12.5F15	44.22	65.78
S5 F20	44.96	62.91	S15F0	46.65	64.40
S10F0	53.14	69.67	S15F5	44.30	65.82
S10F5	51.30	70.62	S15F10	40.49	62.98
S10F10	48.69	68.72	S15F15	37.25	61.16
S10F15	43.77	67.43			

When all silica fume series are compared together, it is observed that the highest 7-day compressive strength is found for the combination with no Fly ash in each of the series (50.39 MPa, 53.14 MPa, 49.47 MPa and 46.65 MPa in S5, S10, S12.5 and S15 series respectively) and out of them maximum 7-day compressive strength of 53.14 MPa is found in the S10F0 combination. It also can be observed that the increase in addition of fly ash from 0% - 20% has caused a gradual decrease in 7-day compressive strength in each of the silica fume series.

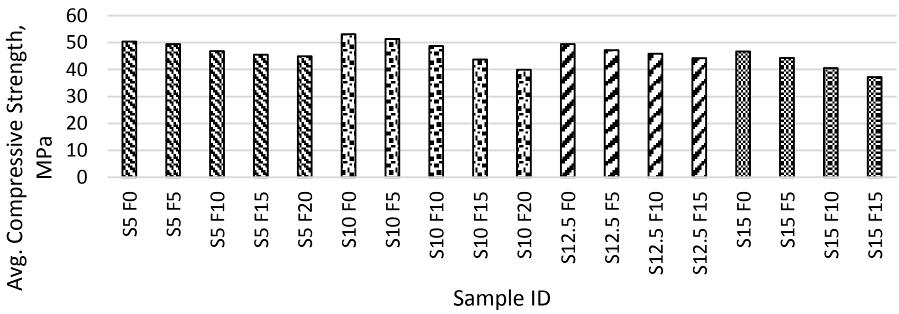

Figure 1. Variation of 7-day compressive strength of concrete samples

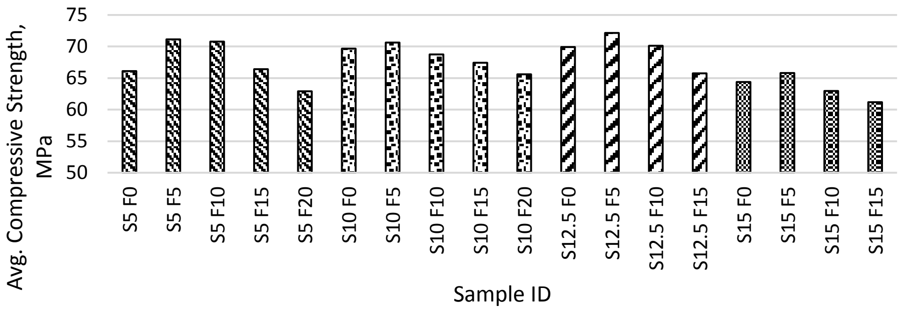

Figure 2. Variation of 28-day compressive strength of concrete samples

Meanwhile, the variation of 28-day compressive strength is in a different pattern. It is noticed that the highest 28-day compressive strength is found in the 5% replacement of OPC by Fly ash in each of the silica fume series (71.12 MPa, 70.62 MPa, 72.13 MPa and 65.82 MPa in S5, S10, S12.5 and S15 series respectively) and starts to decrease with the increasing replacement levels of fly ash 10 %, 15 %, and 20 % in each of the silica fume series. Out of all the combinations tested, the S12.5F5 combination finds the maximum 28-day compressive strength of 72.13 MPa.

Workability of the test specimens was tested using the slump test and the resulting slump values are illustrated in Figure 3. It is observed that the workability increases in the S5 series with the increase of the fly ash amount from 0 % - 20 %.

But when it comes to S10 and S12.5 series, the slump drops although the fly ash amount is increased. This may be mainly due to the dominant action of silica fume (more than 10 %) over fly ash. Existence of extra silica fume will produce more Calcium Silicate Hydrate (C-S-H) which is the concrete binder and hence the workability will be reduced significantly.

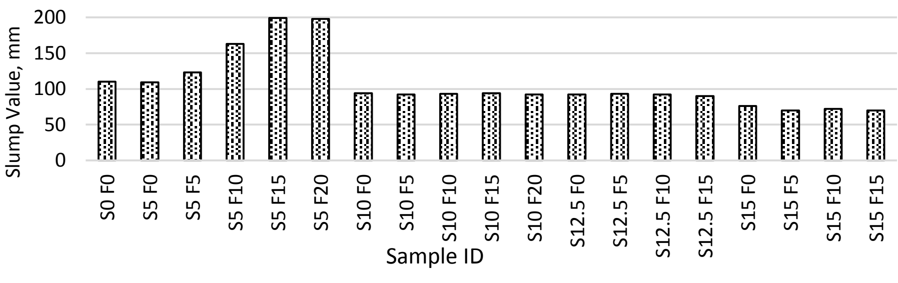

Figure 3. Variation of slump value with different mix combinations

Conclusions

Based on the results of the study, the following conclusions can be drawn.

1. Maximum 7-day compressive strength is found in the mix combination with 10% Silica and no Fly ash.

2. Maximum 28-day compressive strength is found in the combination with 12.5% Silica and 5% Fly ash.
3. 28-day compressive strength starts to decrease with the increasing replacement levels of fly ash 10%, 15%, and 20%.
4. Workability of concrete increases with the increase of fly ash amount when silica fume content is less than 10% and reduces when silica fume content is more than 10%.

References

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