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Research paper

Utilization of Fly Ash and Iron Slag in Concrete - An Experimental Study

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Abstract

The cement industry is responsible for about 6% of all CO_2 emissions in the environment and numerous waste products out from the industries which is generating a lots of dumping problems and global warming. The main aim of this present study is to experimentally study the influence of partial replacement of cement with fly ash (FA) and partial replacement of fine aggregate with iron slag (IS) on the mechanical properties of concrete. Totally 10 mixes were prepared with 10, 20 and 30% replacements level of cement with fly ash and fine aggregate is replaced with 10, 20 and 30% by steel slag. The compressive and splitting tensile strength tests were found out after 7, 14, 28 and 7, 28 days age of curing for all the mixes respectively. Results were compared with conventional concrete and the optimum replacement percentage of FA and IS has reported.

1. Introduction

Concrete is the one of the main most commonly used constructing material in the world. Cement is the main essential material in the manufacturing of concrete. Cement industry is responsible for CO_2 emissions in the environment which causes global warming. In this regard mineral admixtures comes in place of cement. High content silica and alumina admixtures like fly ash added to cement which increases the mechanical performance of concrete. These admixtures can also improves the pore structure in concrete. [1] Ashish Kumer Saha have investigated the inclusion of fly ash of grade class F decreases the sorptivity of concrete in early and late ages. Due to greater specific area the void between the materials in concrete decreases. Therefore, the sorptivity was decreased. By inclusion of fly ash results shows increased density and dense structure. [4] M. Ahmaruzzaman have studied the application of fly ash in concrete. [4] Investigated the present of unburnt carbon in fly ash increases the adsorption capacity of concrete. [3] G.C. Isaia et al studied variation of strength of concrete after adding the mineral admixtures. Results shows the improvement in mechanical as well as durability properties when compared to control mixes. [6] Investigated samples with fly ash inclusion shows early age compressive strength but less strength in late ages as comparison of control mixes that is no addition of fly ash. High content of fly ash with low binder ratio shows less strength at both early and late ages. On the other hand low volume fly ash shows increase in strength at late age. [5] Studied the influence of replacing iron slag as sand. Results shows that the strength of mortars increases with increment of slag percentage. It also increased the density of mortar. [7] Studied the usage of steel slag in concrete. Results of this investigation indicated that when the steel slag replacement level increases the workability of concrete reduces on comparison of conventional concrete but it improves the all other characteristics of concrete mainly split tensile strength. Addition of slag minimize the weight loss in acid tests.

In this study concrete was prepared using the fly ash and iron slag. Cement was replaced with class F fly ash (10, 20, and 30%) and fine aggregate with iron slag (10, 20, and 30%) by keeping the fly ash replacements constants at each percentages. Ceraplast 300M was used as super plasticizer. Before preparing the concrete the physical tests were done. The mixing done at room temperature and specimens cured at different durations (7, 14 and 28 days) in water. The mechanical tests were conducted. Chemical analysis was done by using XRF analysis.

2. Experimental Investigations

Cement

Cement used for this work wasOrdinary Portland cement (OPC 53) gradeconfirmed to IS 12269: 2013 [13]. The specific gravity of the cement is 3.14.

Fine Aggregate and Coarse Aggregate

Sand was used in this project as fine aggregate, which is confirmed by grading zone-II of BIS: 383-1970. Size of sand was used in this work was less than 4.75 mm. Fineness modulus and specific gravity were 2.70 and 2.68 respectively. Gravel of sizes 12.5 mm and 20 mm were used as coarse aggregate and its specific gravity and fineness modulus values were 2.75 and 6.8 respectively.

Fly Ash (FA)

In this work, fly ash was used. Fly ash is byproduct of pulverized coal and for this study low lime content fly ash is used i.e. class F grade fly ash. The color of FA was grey and particle less than 45µm. Specific gravity of FA was 2.1 and fly ash as shown in figure 2.

Iron Slag (IS)

Iron slag was collected from local iron and steel manufacturing factory. The specific gravity of IS is 2.58. The color of IS is black and fineness modulus value are 2.78. Chemical composition of IS was shown in Table 1. IS as shown in figure 1.

Chemical Admixtures

Ceraplast 300M was used as super plasticizer. It was Brown in color and 0% chloride content. Its specific gravity was 1.2 and it can be used range of 0.3% to 1.5% weight of cement.

Fig. 1: Steel slag

Fig. 2: Fly ash

Table 1: Chemical composition of Cement, Fly ash and Iron slag done using XRF analysis.

Parameter	Cement (%)	Flyash (%)	Iron Slag (%)
SiO_2	20.12	58.62	55.10
Al_2O_3	6.30	29.39	16.50
Fe_2O_3	3.60	5.28	2.21
TiO_2	-	1.80	0.05
K_2O	1.30	1.55	0.06
CaO	63.00	1.45	22.80
MgO	2.40	0.65	0.93
P_2O_5	-	0.58	0.13
SO_3	1.78	0.21	0.66
Na_2O	0.30	0.13	0.18
BaO	-	0.08	-
MnO	-	0.04	0.62
Cr_2O_3	-	0.04	0.14
Cl	-	0.04	0.09
PbO	-	0.03	-
ZrO_2	-	0.03	-
ZnO	-	0.02	0.33
CuO	-	0.01	0.19

3. Methodology

Mix Design and Proportions

The quality of concrete mainly depends upon the proportioning of its constituent materials.

Table 2: Concrete mix combinations

Mix no	Cement (%)	Fly ash (%)	Fine aggregate (%)	Iron slag (%)	Coarse aggregate (%)	Super plasticizer (%)
1	100	0	100	0	100	100
2	90	10	90	10	100	100
3	90	10	80	20	100	100
4	90	10	70	30	100	100
5	80	20	90	10	100	100
6	80	20	80	20	100	100
7	80	20	70	30	100	100
8	70	30	90	10	100	100
9	70	30	80	20	100	100
10	70	30	70	30	100	100

In this work M30 grade concrete used and the designed mix ratio is 1:2.01:3.30 with W/C ratio is 0.4 specifications confirmed according to IS 10262: 2009. Totally 10 mixes were prepared. 10 mix proportions divided into 4 batches, first batch was control mix designated as "CM". Second batch was 10% replacement of cement with fly ash maintained constant and 10, 20 and 30 % of replacements level of sand with iron slag designated as F1S1, F1S2 and F1S3 respectively. Same for replacements of 20% and 30% of cement by fly ash and sand replaced by iron slag with replacement levels of 10, 20 and 30% designated as F2S1, F2S2, F2S3, F3S1, F3S2 and F3S3 respectively. All the mixtures were contained constant water-cement ratio and 1.5% of super plasticizer was added. The concrete mix combinations is shown in Table 2.and mix proportions is shown in Table 3.

Table 3: Concrete mix proportions

Mix ID	OPC (kg/m^3)	Fly ash (kg/m^3)	Fine aggregate (kg/m^3)	Iron slag (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)	Water/Cement ratio
CM	370	0	745	0	1247	148	5.55	0.40
F1S1	333	37	670.5	74.5	1247	148	5.55	0.40
F1S2	333	37	596.0	149	1247	148	5.55	0.40
F1S3	333	37	521.5	223.5	1247	148	5.55	0.40
F2S1	296	74	670.5	74.5	1247	148	5.55	0.40
F2S2	296	74	596.0	149	1247	148	5.55	0.40
F2S3	296	74	521.5	223.5	1247	148	5.55	0.40
F3S1	259	111	670.5	74.5	1247	148	5.55	0.40
F3S2	259	111	596.0	149	1247	148	5.55	0.40
F3S3	259	111	521.5	223.5	1247	148	5.55	0.40

4. Test Methods

Compressive Strength Test
The compressive strength test was done using cube specimens of cross section 100 mm x 100 mm x 100 mm. The cubes were casted using design mix ratio of 1:2.01:3.3 with water binder ratio of 0.4.

Fig. 3: Compressive strength test

Fig. 4: Split tensile strength test

After one day the specimens were demoulded and cured in water. After the curing period the cubes were taken dried out and tested in the compression testing machine (CTM)as per Indian standards IS 516:1959 [16] and the strength values are recorded. The test setup was shown in Figure 3.

Split Tensile Strength Test
The test was done using cylindrical specimens. The cross section of the specimens were 100 mm x 200 mm. The cylindrical specimen's casted using design mix ratio of 1:2.01:3.3 with W/B ratio of 0.4. After 1 day the specimens were removed from mould and cured at different ages. After the curing period the cubes were taken dried out and tested. The strength values are recorded. The test was done using CTM according to Indian standards IS 516:1959 [16]. The test setup was shown in Figure 4.

5. Results and Discussion

Compressive Strength
The mean strength of 10 mix combinations for different curing durations is shown in Table 4 and the variations of strength shown in figure 5. The results shows that control samples (CM) shows high early strength 22.29 MPa at 7 days curing. The strength improved sharply at 14 and 28 days curing with 28.30 MPa, 37.26 MPa respectively. On the other side fly ash and iron slag inclusion samples shows less strength at the age of 7 and 14 days curing. The highest strength achieved after addition of fly ash and iron slag were F2S2 and F2S3 samples. The compressive strength values of these samples at 7 days were 21.77 MPa, 22.13 MPa and 14 days were 25.89 Mpa and 26.48 MPa respectively. It can clearly shows that there is no sharply increasing compressive strength from 7 days to 14 days. This is because the present of lime content in class-F fly ash and iron slag is very low. Fly ash decreases the rate of hydration in concrete mixes at early ages. Compressive strength of F2S2 and F2S3 samples at 28 days curing were 37.44 Mpa and 38.71 MPa respectively. It can clearly show that approximately 4% increment in compressive strength for 20% fly ash and 30% iron slag (F2S3) sample is found out on comparison of control mix sample (CM). The 10% and 30% of fly ash addition corresponding to 10, 20 and 30% iron slag addition showed low compressive strength compared to control mix (CM) samples. The size of fly ash particles is small with high surface area and high content of silica compared to ordinary Portland cement impart the pozzolanic reaction (PR) thus improve the compressive strength value of concrete. The 20% of fly ash replacement in cement and 20% and 30% iron slag samples showed high strength than other samples. Excess of fly ash (>20%)causes reduction in compressive strength.

Table 4: Compressive strength test values

Mix ID	Compressive strength (MPa)		
	7 Days Strength	14 Days Strength	28 Days Strength
CM	22.29	28.30	37.26
F1S1	17.84	23.95	33.91
F1S2	18.70	24.02	34.26
F1S3	20.17	25.44	36.11
F2S1	20.00	25.12	36.44
F2S2	21.77	25.89	37.44
F2S3	22.13	26.48	38.71
F3S1	18.78	23.19	35.96
F3S2	19.49	23.62	36.20
F3S3	19.80	24.68	36.62

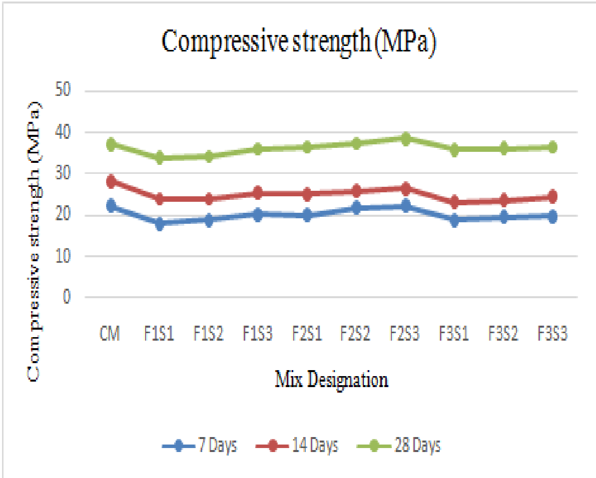

Fig. 5: Variation in compressive strength (MPa).

Split Tensile Strength
The results for various mix combinations shown in table 5. The results proven that after inclusion of fly ash and iron slag the strength improves on comparison of control mix samples. The strength of CM samples at the age of 7 and 28 days are 2.02 MPa, 3.21 MPa respectively. On the other hand inclusion of fly ash as well as iron slag samples shown approximately similar split tensile strength. The early age 7 days curing split tensile strength approximately same as the control mix was obtained for all mixes. At 28 days curing F2S2, F2S3 and F3S3 samples shows the increase in split tensile strength about 28%, 30% and 25% on comparison of control mix sample. The highest strength obtained at the age of 28 days is 4.20 MPa (F2S3) on other hand control mix (CM) sample shows 3.21 MPa.

Table 5: Split tensile strength values

Mix ID	Split tensile strength (MPa)	
	7 Days Strength	28 Days Strength
CM	2.02	3.21
F1S1	2.32	3.78
F1S2	2.45	3.81
F1S3	2.52	3.90
F2S1	2.46	3.81
F2S2	2.59	4.12
F2S3	2.61	4.20
F3S1	2.36	3.92
F3S2	2.39	3.99
F3S3	2.47	4.02

The tensile properties of iron slag improves the split tensile strength of concrete. The 20% fly ash inclusion in cement and 30% iron slag inclusion in sand shows highest split tensile strength. Excess of fly ash shows reduction in split tensile strength. The variation in split tensile strength shown in figure 6.

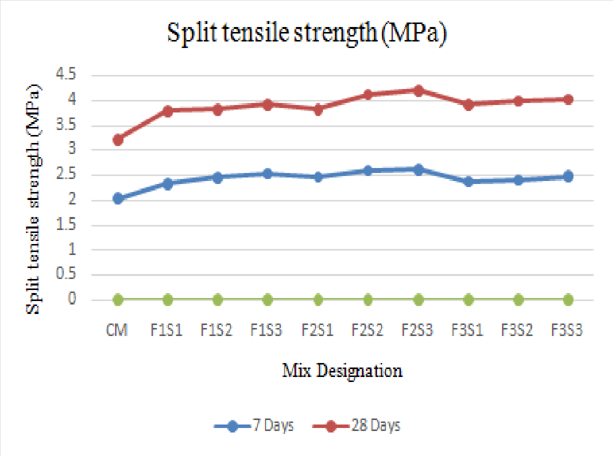

Fig. 6: Variation in split tensile strength (MPa)

6. Conclusion

From the above experimental test results, the following conclusions were made.

- The partial replacement of cement with class-F fly ash (80% + 20%) and sand with iron slag (70% + 30%) (F2S3) mix was the best replacement which shows high split tensile strength. On the other side 20% inclusion of fly ash and 30% of iron slag (F2S3) was the best mix combination for high compressive strength.
- High split tensile strength was obtained at late age 28 days curing for F2S3 with an increment of 30% on comparison with control mix samples.
- Low compressive strength was obtained at early age of 7 and 14 days all fly ash and iron slag inclusion samples. But at the age of 28 days curing F2S3 sample shown better compressive strength than control mix sample which is about 4%.
- All samples with inclusion of fly ash and iron slag shows better split tensile strength than the control mix samples at all ages.
- For optimum mix 20% of fly ash in cement and 30% of iron slag in fine aggregates shows the high characteristics strength of concrete.

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