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Comparative Studies on Mechanical Properties of High Strength Concrete Using Foundry Slag and Alccofine

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ABSTRACT

The main purpose of this research study is to compare the strength properties (Mechanical) of High Strength Concrete (HSC) using Foundry Slag (FD) and Alccofine (AF) for different curing ages (7, 14, 28, 56 and 90 days). This paper discussed the use of Foundry Slag (FD) as partial replacement for conventional fine aggregates and Alccofine (AF) as partial substitute for cement. Concrete specimens of M100 grade using water/binder ratio 0.239, with varying percentage of FD (0 to 50%) and with optimum percentage of AF(15%) were cast and tested for development of compressive strength (CS), tensile strength (TS) and flexural strength (FS) after curing age of 7, 14, 28, 56 and 90 days. Results suggested that reasonably high strength concrete can be prepared by replacing fine aggregates (FA) with FD and cement with 15% of AF. Results showed an increase in mechanical properties (CS, TS and FS) of HSC with the increase in FD content up to 45% and with age. A straight line equation from the regression analysis has been formed from the results obtained by means of best fit.

Keywords: *Foundry Slag (FD), Alccofine (AF). HSC, Compressive Strength (CS), Flexural Strength (FS), Tensile Strength (TS).*

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1.0 Introduction

The use of High strength concrete (HSC) [1] has been widely spread in civil engineering structures like bridges, high rise buildings etc. in these days due to their economical and technical advantages. Such types of materials are characterized by improved strength and durability properties due to incorporation of pozzolanic admixtures like Fly Ash, Silica Fume, Metakaolin, Rice Husk Ash, Wheat Straw Ash and Alccofine. These pozzolanic admixtures with super plasticizers are generally used to produce high strength concrete keeping lower water binder ratio. Ajay Goyal et al. [1, 2] studied the synergic effect of Wheat Straw Ash and Rice-husk Ash on strength Properties of Mortar. Concrete having CS (28 days) higher than 40 MPa is considered as high-strength concrete (HSC) [1, 2]. Silica fume, Alccofine, Rice husk Ash and other pozzolanic materials can be used to produce high strength concrete (HSC) of 69 MPa to 85 MPa at 28 days with medium workability [1, 4]. Naik [5] and Alizadeh [6] were reported to use Foundry slag (FD) as a replacement for natural conventional aggregates for producing high strength concretes. L. Zeghichi [7] has studied the effect of slag as a replacement material on strength properties of concrete. Juan Manso et al. [8] has been reported to use electric arc furnace slag as a partial replacement of fine aggregates in Concrete. Mohammed Nadeem and A. D. Pofale [9] had used granular slag as an alternative replacement material for natural sand in civil engineering applications either partially or fully.

Alccofine (AF), a supplementary cementitious material (SCM) containing high glass content with high reactivity and ultra fineness is a product manufactured by Ambuja Cements Ltd. Sunil Suthar et al. [10] have been reported to study the effect of alccofine and fly ash on mechanical properties of HSC.

The objective of the present research study is to compare mechanical properties of high strength concrete (HSC) using foundry slag (FD) as partial replacement for conventional fine aggregates and Alccofine (AF) as partial substitute of cement for different curing ages (7,14,28,56 and 90 days). CS, TS and FS of HSC at water binder ratio of 0.239 have been investigated experimentally and relationships between these properties have been analyzed. Straight line equations have been derived by using regression analysis for the development of correlation between CS &TS, CS & FS and TS & FS.

2.0 Experimental Program

2.1 Materials

Portland Pozzolana Cement (PPC) having specific gravity 3.02 conforming to IS: 1489-1991(Part I), saturated surface dry (SSD) crushed coarse aggregates (CA) of maximum size 20 mm and Natural river sand (Zone-II) of Khizrabad (Pb) India conforming to IS: 383-1970 [10] was used as fine aggregates (FA). Both CA and FA were procured from Ultra-Tech Ltd. Mohali (Pb) India, Foundry slag (FD) used as replacement of river sand in the study was procured from steel plant of Mandi Gobindgarh (Pb) India. Physical properties of CA, FA and FD are shown in Table 1.

Table 1. Physical Properties of CA and FA (IS: 383-1970) [1, 11].

Properties	CA	FA	FD
Colour	Grey	Light Grey	Black
Maximum Size(mm)	20	4.75	4.75
Specific Gravity	2.69	2.64	2.78
Fineness Modulus	7.69	2.95	3.00
Water Absorption (%)	0.51	1.63	0.43

Chemical properties of slag are as shown in Table 2.

Table 2. Chemical Composition of FD [1].

Chemical Composition of FD						
Constituents	SiO_2	Fe_2O_3	CaO	MgO	Al_2O_3	SO_2
Composition (% age)	31.4	18.20	33.6	1.94	8.20	.22

Laboratory tap water conforming to IS: 456-2000 was used for concreting and curing. Super plasticizer -Master Glenium Sky 8777 of Specific gravity 1.18 at 20^0 C procured from BASF confirming to IS: 9103-1999 was used to produce high workability and to reduce water binder ratio. Alccofine1203 (AF), is a ground granulated blast furnace slag (GGBFS) based supplementary cementitious material (SCM) containing high glass content with high reactivity and ultra-fineness, manufactured by Ambuja Cement ltd[1]. Physical and chemical properties of alccofine conforming to ASTM C 989-99 are given in Table 3.

Table 3. Physical and Chemical Properties of Alccofine 1203[1, 12].

Physical Properties*					Chemical Properties*			
Specific Gravity	Density (kg/m^3)	D_{10}	D_{50}	D_{90}	CaO	Al_2O_3	SiO_2	Glass content
2.9	600-700	1-2	4-5	8-9	31-33%	23-25%	33-35%	>90%

*As per specifications supplied by manufacturer "Ambuja Cement Ltd."

2.2 Mix Proportion

Optimum dosage of AF was determined by varying the contents of alccofine (AF) from 5% to 20% for preparing concrete mix design of M100 grade, and was found to be 15%. Concrete mix was designed as per IS 10262;with a water binder ratio (w/b) of 0.239 and a targeted slump of 190 ± 35, by substituting fine aggregate with 10%, 20%, 30%, 40%, 45% and 50% of FD and Alccofine 1203 was used in addition to Portland pozzolanic cement (PPC) in 15% amount. Concrete mixes prepared by substituting FA with 0%, 10%, 20%, 30%, 40%, 45% and 50% FD have been given name as control (CTR), F10, F20, F30, F40, F45 and F50 respectively (Table 4). 150 mm x 150 mm x 150 mm cubes (Set of 6 specimens each) for compressive strength test, 100 mm x 200 mm cylinders (Set of 6 specimens each) for split tensile strength test and 100 mm x 100 mm x 500 mm beam moulds (Set of 6 specimens each) for flexure strength test; were casted, cured, dried and tested after the curing age of 7, 14, 28, 56 and 90 days for determining CS, TS and FS as per IS specifications[1].

The values of CS, TS and FS are compared with each other after curing period of 28 days and a correlation was developed in between CS & TS, CS & FS and TS & FS in terms of linear equation.

Table 4. Details of HSC Mixes [1, 13].

FD content (%)	Cement PPC (Kg/m^3)	Alccofine 1203 (Kg/m^3)	W/b ratio	Water content (Kg/m^3)	CA (10mm) (Kg/m^3)	CA (20mm) (Kg/m^3)	FA (Kg/m^3)	FD (Kg/m^3)	Super Plasticizer (Kg/m^3)
CTR	460	69	0.239	126.19	459	688	735	0	6.9
F10	460	69	0.239	126.19	459	688	662	73	6.9
F20	460	69	0.239	126.19	459	688	588	147	6.9
F30	460	69	0.239	126.19	459	688	514	221	6.9
F40	460	69	0.239	126.19	459	688	441	294	6.9
F45	460	69	0.239	126.19	459	688	404	331	6.9
F50	460	69	0.239	126.19	459	688	367.5	367.5	6.9

3. Results and Discussion

3.1 Optimization of Alccofine

In order to determine the optimum contents of Alccofine (AF), quantity of AF substituted from cement was varied from 0% to 20% by weight of cement and test specimens were cast and tested for determining CS after curing age of 28 days as per IS Specifications. Test results are given in the Table 5. Maximum values of CS, TS and FS were observed at 15% substitution of PPC with AF. Hence Optimum dosage of AF was found to be 15% by weight of cement.

Table 5. Results of CS, TS and FS with varying % age of Alccofine after 28 days of curing [1].

Alccofine (%)	CS (MPa)
0	79.56
5	83.64
10	85.39
15	102.32
20	92.39

3.2 Compressive Strength (CS)

The 150 mm x 150 mm x 150 mm size cube specimens (210 No.) of varying % ages of FD (CTR and F10-F50) with AF (15%) have been cast and tested for compression strength test of HSC after different curing ages (7,14,28,56 and 90 days). Table 6 shows the CS, TS and FS test results of concrete mixes. All concrete mix exhibited higher CS than that CTR at all curing ages. F45 mix exhibited maximum CS of 78.2, 97.3, 105.72, 108.31 and 110.86 after curing of 7, 14, 28, 56 and 90 days respectively than other mixes [1]. These results are consistent with Wen et al. [14] and Qasrawi et al. [15] have exhibited approximately same results.

F-50 has exhibited lower CS than F10-F45 mixes. Rate of development of CS was found to be higher up to 28 days and then reduced. Faster development of strength at early ages was due to faster rate of heat of hydration reaction of Alccofine.

3.3 Tensile Strength (TS)

100 mm x 200 mm cylindrical specimens (210 specimens) of varying % ages of FD (CTR and F10-F50) with fixed contents of AF (15%) have been used for tensile strength (TS) test of HSC. Outcome of TS test is same as that of CS. Ratio of Split Tensile Strength (TS) to Compressive Strength (CS) varies from 7% to 8% [1, 16]. These results are lower than high performance fine grained concrete (HPFGC) (9.6%-11.0%) and normal strength concrete (10.5%-15.2%) [17]. From the results, it is clear that for ultra high strength concrete, ratio of TS to CS reduces [18].

3.4 Flexure Strength (FS)

100 mm x 100 mm x 500 mm prismatic samples (210 samples) of varying % ages of FD (CTR and F10-F50) with fixed contents of AF (15%) have been used for flexural strength (FS) test of HSC. Outcome of FS test is same as that of CS and TS. Ratio of Flexural strength (FS) to Compressive strength (CS) is found to be varied from 10% to 12.491%. The results of the present study are consistent with Kaplan [19] and Cook [20].

Table 6. Results of CS, TS and FS test [1].

	Specimen	Curing Age (days)				
		7	14	28	56	90
CS (MPa)	CTR	71.22	84.44	102.32	105.13	107.11
	F10	72.56	87.22	102.88	106.21	107.34
	F20	73.33	90.11	103.67	106.75	107.87
	F30	75.55	94.22	103.82	107.33	108.24
	F40	77.66	96.56	105.12	107.62	109.72
	F45	78.2	97.3	105.72	108.31	110.86
	F50	73.33	93.33	102.2	104.8	106.66
TS (MPa)	CTR	5.73	6.685	7.271	8.27	8.276
	F10	5.734	6.706	7.302	8.284	8.291
	F20	5.777	6.786	7.329	8.296	8.304
	F30	5.798	6.853	7.368	8.313	8.329
	F40	5.832	7.002	7.384	8.329	8.341
	F45	5.885	7.162	7.393	8.336	8.348
	F50	5.765	6.866	7.264	8.257	8.276
FS (MPa)	CTR	8.896	9.928	10.325	11.195	12.274
	F10	8.914	9.974	10.62	11.374	12.758
	F20	8.998	10.096	11.564	11.374	12.796
	F30	9.178	10.165	12.254	12.444	13.398
	F40	9.34	10.245	12.356	12.55	13.703
	F45	9.46	10.322	12.464	12.32	13.76
	F50	9.1	10.128	11.034	10.324	11.67

3.5 Relationship between CS & FS, CS & FS and TS & FS

Figures 1, 2 and 3 show empirical relationships for CS vs. TS, (CS) vs. FS) and TS vs. FS after 28 days of curing. Equations and coefficient of regression (R^2) are shown in Table 7. A linear relationship in form of (ax + b) equation seems to be the best fit data. Results show higher coefficient of regression (R^2) at all curing ages which indicate strong relationships between CS & TS, CS & FS and TS & FS. An increase in compressive strength in HSC using FD and AF leads to an increase in TS and FS.

Table 7. Relationship between CS & FS, CS & FS and TS & FS

Sr. No.	Days	Equation showing relationship b/w CS and TS	R^2
1	28	y = 0 .037x +3.424	0.915
Sr. No.	Days	Equation showing relationship b/w CS and FS	R^2
2	28	y = 0.575x – 48.18	0.787
Sr. No.	Days	Equation showing relationship b/w TS and FS	R^2
3	28	y =15.35x – 101.0	0.867

Yun Wang Choi, [21] have proposed similar equation y = 0.076x + 0.5582 for relationship between CS and TS, where x=CS & Y=TS at 28 days. American Concrete Institute (ACI) had proposed the following equation to predict TS from CS.

$$F_t = 0.56\,(f_c)^{0.5} \quad (1)$$

Where F_t =TS and f_c = CS

From the current study it has been found that 28 days tensile strength (TS) is nearer to the corresponding values estimated from the equation proposed by Yun Wang Choi [21]. Central Road Research Institute (CRRI) has also suggested the equation for CS and FS y=11.0x – 3.4 for relationship between CS and FS, where y= CS and x = FS at 28 days. IS 456-2000 had also recommends the equation given below for the determination of FS from CS.

$$f_r = 0.7\,\sqrt{f_c} \quad (2)$$

Where f_r = FS and f_c = CS

It has been observed that 28 days flexural strength for the present study is more than that of corresponding predicted values from IS-456-2000[22]. The reason for this may be that the formula of code was given for normal strength concrete where as current study is for HSC or Flexural strength of HSC is better than NSC.

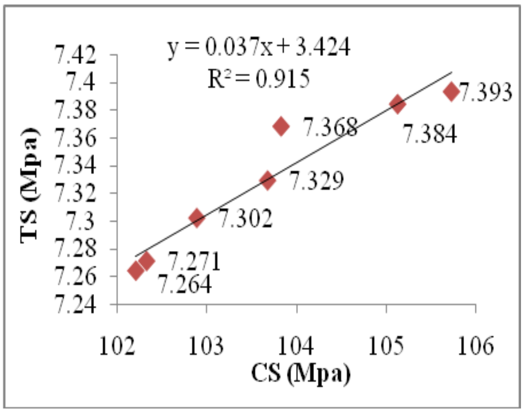

Figure 1. Relationship b/w CS and TS

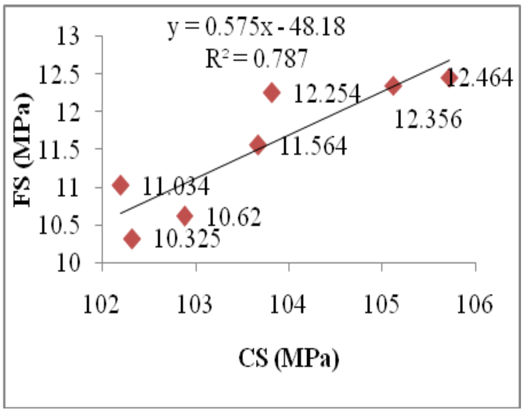

Figure 2. Relationship b/w CS and FS

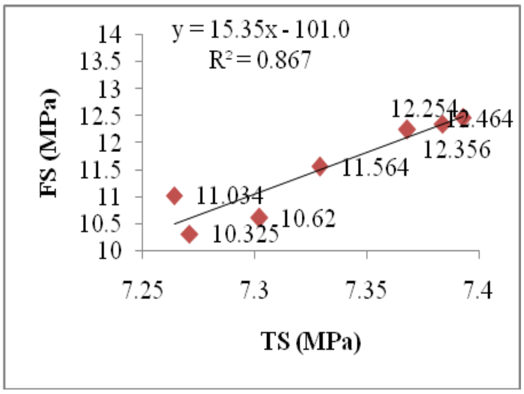

Figure 3. Relationship b/w TS and FS

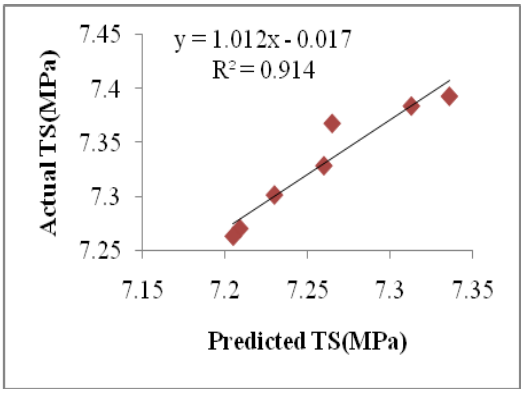

Figure 4. Actual TS and predicted TS

3.5.1 Validity of the Equations

Figures 4, 5 & 6 represented the coefficient of regression R^2 of 0.914, 0.786 & 0.867 respectively, which indicate that the equations derived for the correlation between CS & TS, CS & FS and TS &FS are valid and indicate strong relationship between CS &TS, CS & FS and TS & FS as shown in Tables 8, 9 and 10.

Table 8. Relationship b/w CS and TS at 28 days

FD content 1	Actual TS 2	Predicted TS from existing equation Y=0.076x+.5582 3	%Error in TS from existing equation (3-2)/2x100 4	Predicted TS from present equation y=.037x+3.424 5	%Error in TS from present equation (2-5)/2x100 6
CTR	7.271	8.334	14.62	7.209	0.853
F10	7.302	8.377	14.72	7.230	0.986
F20	7.329	8.437	15.12	7.260	0.941
F30	7.368	8.449	14.67	7.265	1.405
F40	7.384	8.547	15.75	7.313	0.962
F45	7.393	8.593	16.23	7.336	0.771
F50	7.264	8.325	14.61	7.205	0.812

Table 9. Relationship b/w CS and FS at 28 days

FD content 1	Actual FS 2	Predicted FS from existing equation $f_r = 0.7\sqrt{f_c}$ 3	%Error in FS from existing equation (3-2)/2x100 4	Predicted FS from present equation Y =0.575x-48.18 5	%Error in FS from present equation (2-5)/2x100 6
CTR	10.325	7.08	31.42	10.654	-3.186
F10	10.620	7.10	33.15	10.979	-3.350
F20	11.564	7.13	38.34	11.430	1.158
F30	12.254	7.13	41.81	11.517	6.014
F40	12.356	7.18	41.89	12.264	0.744
F45	12.464	7.20	42.23	12.609	1.163
F50	11.034	7.08	35.83	10.585	4.069

Table 10. Relationship b/w TS and FS at 28 days

FD content 1	Actual FS 2	Predicted FS from present equation y=15.35x-101.0 3	%Error in FS from present equation (2-5)/2x100 4
CTR	10.325	10.609	-2.751
F10	10.620	11.086	-4.387
F20	11.564	11.500	0.553
F30	12.254	12.099	1.265
F40	12.356	12.344	0.097
F45	12.464	12.483	0.152
F50	11.034	10.502	4.821

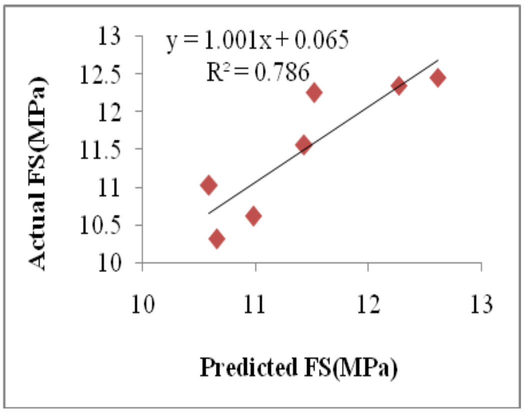

Figure 5. Actual FS and predicted FS

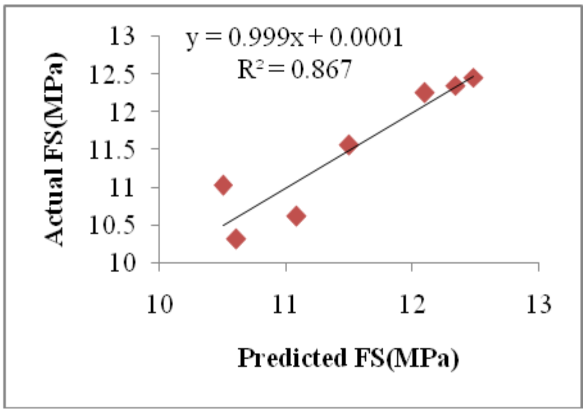

Figure 6. Actual FS and predicted FS

4. Conclusions

Based on the results of this study, the following conclusions may be drawn:

1. All concrete mix exhibited higher CS than that CTR at all curing ages. F45 mix exhibited maximum CS of 78.2, 97.3, 105.72, 108.31 and 110.86 after curing of 7, 14, 28, 56 and 90 days respectively than other mixes.

2. Results showed that outcome of TS and FS are same as that of CS in all the mixes at all curing ages.

3. Ratio of Split Tensile Strength (TS) to Compressive Strength (CS) is found to be varied from 7% to 8%.

4. Ratio of Flexural Strength (FS) to Compressive strength (CS) is found to be varied from 10% to 12.491%.

5. Rate of development of CS is faster up to 28 days and then reduced.

6. Results showed strong Relationships between CS&TS, CS&FS and TS&FS which means an increase in CS leads to an increase in TS and FS.

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