Int. J. Electrochem. Sci., 11 **(2016)** 3190 - 3205

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Utilization of Waste Foundry Slag and Alccofine for Developing High Strength Concrete

Devinder Sharma[1,*], *Sanjay Sharma*[2], *Ajay Goyal*[3]

[1]Research Scholar, I.K. Gujral Panjab Technical University, Kapurthala (Pb), India & Associate Professor, Baddi University of Emerging Sciences & Technology, Baddi (HP), India.
[2] Civil Engineering Department, National Institute of Technical Teachers Training and Research Chandigarh, India.
[3] Civil Engineering Department, Baddi University of Emerging Sciences and Technology, Baddi (HP), India.
[*]E-mail: devinder.sharma@baddiuniv.ac.in

Received: 12 January 2016 / *Accepted:* 14 February 2016 / *Published:* 1 March 2016

This paper discusses the strength development of concrete using Foundry Slag(FD) as partial replacement for conventional fine aggregates and Alccofine (AF) as partial replacement of cement. Concrete samples 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 casted and tested for compressive strength(CS), tensile strength(TS) and flexural strength(FS) development at the age of 7, 14, 28, 56 and 90 days. Replacement of fine aggregates with up to 45% of FD showed an increase in CS, FS and TS at all ages but showed a decrease in these properties with 50% of FD. Results suggested that reasonably high strength concrete can be designed by substituting fine aggregates with 10% to 45% of FD and partial replacement of cement with 15% of Alccofine. Carbonation in terms of alkalinity test and Rapid Chloride Permeability Test had also been studied in the present research work. Result showed increase in alkalinity and improvement in permeability of concrete with increase in FD contents at optimized (15%) replacement of Cement with Alccofine.

Keywords: Foundry Slag, Alccofine. High Strength Concrete, Compressive Strength, Flexural Strength, Tensile Strength, Carbonation, RCPT

1. INTRODUCTION

High strength concrete (HSC) has been widely used in civil engineering structures to reduce the size of structural elements i.e. beams and columns of high rise buildings [1]. As per ACI 363[1, 2] concrete having 28days compressive strength of more than 41 MPa is considered as high-strength concrete. Generally, super plasticizers natural pozzolana silica fume etc., are used to achieve high-strength in concrete by keeping water binder ratio at lower level. Shannag [1, 3] have used natural pozzolana and silica fume to produce HSC of 69 MPa to 85 MPa at 28 days with medium workability. For producing high strength concrete, use of FD (consisting of silicates, calcium alumina silicates and an alumino silicate) as replacement for natural conventional aggregate in concrete has also been reported by Alizadeh, et al. [4] and (Naik et al.) [5]. Limbachiya et al. [6] discussed the use of recycled concrete aggregate in high strength concrete. Juan Manso et al. [7] had carried out study on electric arc furnace slag in Concrete. L. Zeghichi [8] had reported replacement of natural aggregates by slag with positive effect on strength properties of concrete. In 2012, Mohammed Nadeem and A. D. Pofale [9] had concluded that granular slag could be utilized as alternative construction material for natural sand in masonry & plastering applications either partially or fully.

FD is a volcanic rock look alike, grayish to black colored by-product obtained during the steel manufacturing process. Thousands of tons of industrial FD is generated each year in India and more than 90 % of which is disposed in landfills posing a threat to our environment. Alccofine, a product of Ambuja Cements Ltd, one of the leading cement companies in the Indian cement industry; is a slag based supplementary cementitious material(SCM) containing high glass content with high reactivity and ultra fineness. Sunil Suthar et al. [10] have studied the effect of alccofine and fly ash addition on mechanical properties of high strength concrete.

Saettaa et al. [11] and Thiery et al. [12] defined Carbonation, a chemical process in which atmospheric CO_2 (a green house gas) in an amount of approximately 0.03% by volume produced due to respiration of living organisms combined with water existed in the capillary pores of concrete produces H_2CO_3 (carbonic acid). Carbonic acid reacts with hydroxides of potassium, sodium and calcium forms carbonates [13]. Pore filling of Concrete vary with respect to porosity and relative humidity in the exposure environment. When diffusion rate of saturated CO_2 is very low approximately 10^{-8} cm^2/s [13], then there is no risk of deterioration from carbonation. Carbonation can not occur at lower relative humidity due to insufficient water retention in concrete pores. The most favorable conditions of relative humidity for carbonation process ranges from 60% to 75%. These conditions help in the concentration of water on pore walls, leaving a hollow space. This permits the CO_2 to penetrate deeper into the pore and react with alkalis [13]. Concrete paste consists of hydrated calcium silicates gel (C-S-H) and react with CO_2 present in concrete paste produces $CaCO_3$ and residual silica-gel [13]. Carbonation is chemically a neutralization reaction in which pH value lowers during the process. The chemical reactions [13] resulting from concrete paste carbonation are given below

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (a)$$

Hydrated calcium silicates(C-S-H) are also responsible for carbonation, and few chemical reactions have also been reported [13, 14] .

$$(3CaO\cdot 2SiO_2\cdot 3H_2O) + 3CO_2 \rightarrow (3CaCO_3\cdot 2SiO_2\cdot 3H_2O) \quad (b)$$

$$(2CaO\cdot SiO_2) + 2CO_2 + nH_2O \rightarrow (SiO_2\cdot nH_2O) + 2CaCO_3 \quad (c)$$

$$(3CaO\cdot SiO_2) + 3CO_2 + nH_2O \rightarrow (SiO_2\cdot nH_2O) + 3CaCO_3 \quad (d)$$

n = No. of moles of H_2O retained in reactions (c) and (d). The reactions given in equation (c) and (d) do not affect alkalinity directly, but if the molecules break hydrated calcium silicate and the paste binders, mechanical properties may decline [13].

Present study is an attempt to achieve High Strength Concrete(HSC) by using foundry slag(FD) as partial replacement for conventional fine aggregates and Alccofine (AF) as partial replacement for cement. Use of waste foundry slag in concrete may also assist the user in attaining LEED credits by Green Building Council for new constructions.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Portland Pozzolana Cement (PPC) of specific gravity 3.02 conforming to IS: 1489-1991(Part I), saturated surface dry crushed coarse aggregate (CA) of nominal size 10 mm (40%) & 20 mm (60%); and river sand (Zone-II) of Khizrabad used as fine aggregate (FA), conforming to IS: 383-1970[15]; was procured from Ultra-Tech Ltd. Mohali (Pb), India. Physical properties of CA and FA are shown in Table 1.

Table 1. Properties of Coarse Aggregate and Fine Aggregate (IS: 383-1970)[15]

Characteristic	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

Foundry slag used in the study was obtained from steel plant of Mandi Gobindgarh (Pb) India. The maximum size of slag was taken as 4.75 mm and minimum size was 150 micron. Chemical properties of slag are as shown in Table 2.

Table 2. Specific Gravity of FA combined with FD and Chemical Composition of FD

Sp.Gr of FA combined with varying % of FD								Chemical Composition of FD					
FD%	0	10	20	30	40	45	50	SiO_2	Fe_2O_3	CaO	MgO	Al_2O_3	SO_2
Sp Gr	2.64	2.65	2.68	2.70	2.72	2.73	2.75	31.4	18.20	33.6	1.94	8.20	.22

Table 2 shows that specific gravity increases with the increase in %age of foundry slag(FD) as a replacement of fine aggregate.

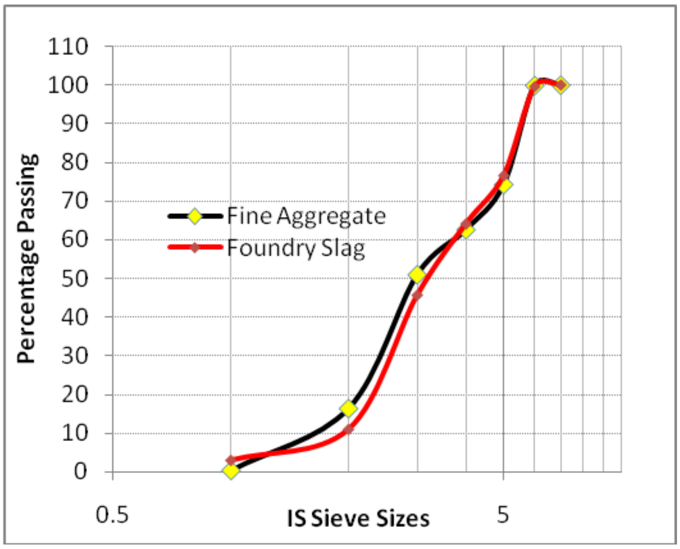

Figure1. Particle Size Distribution Curve of FA substituted with varying %age of FD (IS 383-1970).

From Figure 1 it has been observed that FD and FA conforms to zone II as per IS 383-1970. Normal tap water conforming to IS: 456-2000 was used in concreting and curing work. Commercially available super plasticizer -Master Glenium Sky 8777(Specific gravity 1.18 at 20^0 C) obtained from BASF confirming to IS: 9103-1999 was used to produce high workability in fresh concrete and to reduce water cement ratio. Alccofine1203 (AF), a product of Ambuja Cement ltd is a slag based supplementary cementitious material (SCM) containing high glass content with high reactivity and ultra-fineness. Physical and chemical properties of alccofine conforming to ASTM C 989-99 are tabulated in Table 3.

Table 3. Physical and Chemical Properties of Alccofine 1203[16]

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

For concrete mix design, optimum dosage of AF was determined first by varying the %age from 5% to 20% and CS, TS & FS was determined. Optimum value of alccofine was found to be 15%. Concrete mix of grade M100 was designed as per IS 10262-2009 with water binder ratio (w/b) of 0.239 and a targeted slump of 190 ± 35 by replacing fine aggregate with 10%, 20%, 30%, 40%, 45% and 50% of FD and replacing Portland Pozzolanic cement (PPC) with 15% Alccofine (AF). Comparative results w.r.t. CS, TS and FS with varying percentage of FD and Concrete mix with 0% FD and 15% AF after 7, 14, 28, 56 and 90 days of curing have been considered.

Concrete mixes prepared by replacing fine aggregate with 0%, 10%, 20%, 30%, 40%, 45% and 50% substitution of FD.has been named as control (CTR), F10, F20, F30, F40, F45 and F50 respectively (Table 4). Set of 6 specimens each of 150 mm x 150 mm x 150 mm cubes for compressive strength test, 100 mm x 200 mm cylinders for split tensile strength test (BIS: 5816-1999) and 100 mm x 100 mm x 500 mm beam moulds for flexure strength test; were casted, cured and were tested after the curing age of 7, 14, 28, 56 and 90 days. Vibrating table was used to carry out compaction of concrete cubes, cylinders and beams.

The specimens were covered with plastic sheets in order to reduce the moisture loss and were cured under fully saturated conditions at room temperature [17]. Tests for Compressive, flexure and split tensile strength were carried out in a fully computerized universal testing machine of maximum capacity 3000 KN after 7, 14, 28, 56 and 90 days of curing and as per IS-516-1991 specifications. The properties of fresh concrete were estimated as per IS: 1159-1959.

Table 4. Mix Proportion of Control Mix [18]

Material (Kg/m^3)	CTR	F10	F20	F30	F40	F45	F50
Cement PPC	460	460	460	460	460	460	460
Alccofine1203	69	69	69	69	69	69	69
W/b ratio	0.239	0.239	0.239	0.239	0.239	0.239	0.239
Water content	126.19	126.19	126.19	126.19	126.19	126.19	126.19
CA (10mm)	459	459	459	459	459	459	459
CA (20mm)	688	688	688	688	688	688	688
FA	735	662	588	514	441	404	367.5
FD	0	73	147	221	294	331	367.5
Super plasticizer	6.9	6.9	6.9	6.9	6.9	6.9	6.9

2.3 Carbonation

Reinforced Concrete Structures (RCC) such as bridge decks, marine structures etc which are exposed to harsh environment generally lead to deterioration by corrosion. Rate of corrosion mainly depends on Carbonation and chloride ion penetration in concrete [19]. Carbonation in concrete is related to alkanity which in turn depends upon the pH value of concrete. pH value of concrete was determined by alkalinity test. As the pH value of concrete decreases, alkanity decreases and carbonation increases. Carbonation occurs when there is a sharp drop in pH from an average of 13 to 8 in completely carbonated areas. When the carbonation reaches the steel reinforcement, corrosion process starts due to loss in thermodynamic stability of protective passive film. Specimens were taken out curing tank after 365 days and dried for 24 hours in an oven at 105 degree centigrade temperature.

Then these specimens were cooled to room temperature. Mortars of these samples were grounded into powder form and this powder was sieved through 150 micron sieve. Mortar powder in an amount of 10gm was diluted in 50ml of distilled water and stirred completely. pH value was noted after immersing pH meter into solution.

2.4. Rapid Chloride Permeability Test (RCPT) [20]

There are many techniques for estimation of Chloride ion penetration such as Diffusion tests (AASHTO T259 Test, Bulk diffusion test), electrical conductivity tests (rapid chloride permeability test, the rapid migration test, and electrical migration technique), resistivity techniques [19], etc. Rapid chloride permeability test), test is a quick test and standardized as AASTHO T 277 or ASTM C1202 [19, 20] carried out to estimate the electrical conductivity of concrete which indicate penetration resistance of chloride ion in concrete. This test was developed by D. Whiting [21]. In the present study, concrete specimens of 50 mm thick and 100 mm diameter were cut from the cylindrical specimens of 100 mm diameter and 200 mm long using foundry slag(FD) in 0-50% and alccofine in 15% content. These specimens were cured for 28, 90, 180 and 360 days. Before testing, the specimens were dried completely. Specimens were put in a vacuum chamber for 3 hours to remove air from the voids and soak in water for a period of 18 hours [19, 20]. RCPT is a two component cell cathode and anode assembly.

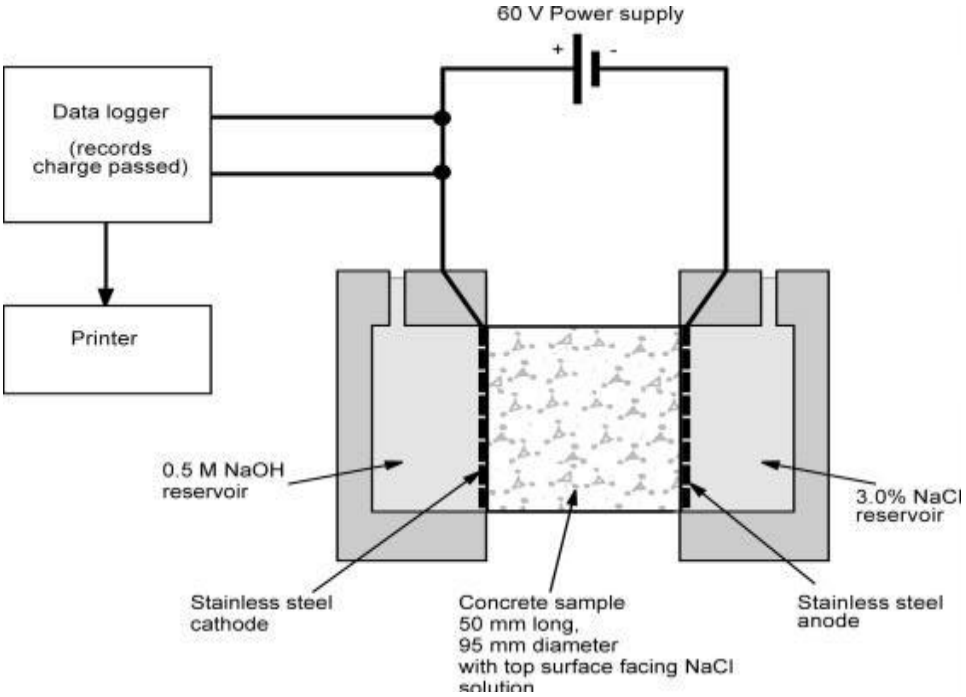

Figure 2. Rapid Chloride Permeability test setup (ASTM C1202)

The cathode is filled with 3% NaCl solution and anode with 0.3M NaOH solution .The above specimens were placed in between cathode and anode. Then electric current is passed between cathode and anode from a 60V DC power source up to 6 hours and readings are taken after every 30 minutes. Average current flowing through one cell is calculated in terms of coulombs at the end of 6 hours gives the chloride permeability by using the formula

$$Q = 900 (I_0 + 2I_{30} + 2I6_0 + 2I_{90} + 2I_{120} + 2I_{150} + 2I_{180} + \text{--------} + 2I_{360})$$

Q = Charge passed in coulombs, I_0 =current immediately after voltage is applied, I_t =current at t minutes. Poorer the quality of concrete, higher the current at a given voltage and hence more the heat produced. This heating leads to more charge passed. Permeability of concrete is directly proportional to water cement ratio [22]. Higher the water cement ratio, higher will be the permeability at same curing period and same curing temperature [23]. The RCPT test set up is as shown in figure2.Rating of RCPT test as per ASTM C1202 is given in the table 5 below.

Table 5. Ratings of RCPT as per ASTM C1202

Total charge passed (Coulombs)	Chloride ion permeability	Type of concrete
> 4000	High	High w/c ratio (> 0.60) conventional Portland cement concrete (PCC)
2000 - 4000	Moderate	Moderate w/c ratio (0.40-0.50) conventional PCC
1000 - 2000	Low	Low w/c ratio (< 0.40) conventional PCC
100 - 1000	Very low	Latex modified or internally-sealed concrete
< 100	Negligible	Polymer-impregnated concrete, polymer concrete

RCPT test has simple setup and procedure, results are easy to interpret, can be correlated with 90 days salt ponding test. These are some advantages of RCPT test. This test is not suitable for concretes containing steel, carbon fiber and other conducting materials. It has less repeatability. The average charge passed through the concrete samples during the test measures the movement of all ions (not just chloride ion) in the pore solution. Supplementary cementitious materials like fly ash, silica fume, rice husk ash, alccofine or ground granulated blast-furnace slag etc. can produce misleading results because of chemical composition of pore solution. These are the main disadvantages of this test. Despite many drawbacks, this test can be performed in a short period of time in comparison to the other tests and is widely used, so in the present study, this test has been used to determine the permeability of chloride ion.

3. RESULTS AND DISCUSSION

3.1 Optimization of Alccofine

Table 6. Results of CS, TS and FS with varying %age of Alccofine after 28 days of curing

Alccofine (%)	CS (MPa)	TS (MPa)	FS (MPa)
0	79.56	5.270	7.335
5	83.64	6.302	7. 82
10	85.39	6.729	8.964
15	102.32	7.271	10.325
20	92.39	7.024	10.156

Test specimens with varying %age of AF (0% -20%) were casted and tested for CS, TS and FS after 28 days of curing and as per IS specifications. Test results are given in the Table5. Maximum CS, TS and FS was obtained at 15% replacement of PPC with AF, defining optimum dosage of AF as 15%.

3.2 Workability Test

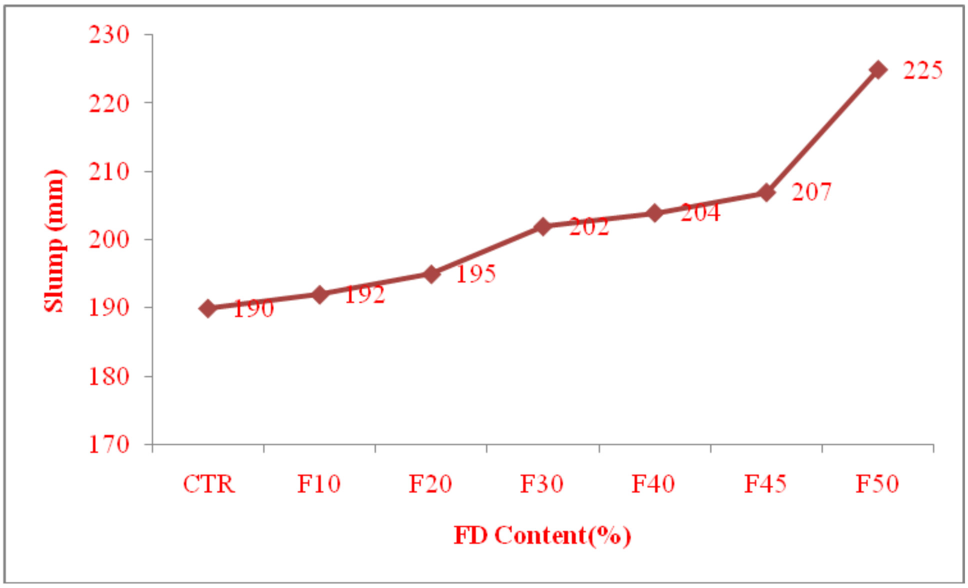

Figure 3. Slump variations with varying % age of FD

Super plasticizer Master Glenium Sky 8777 obtained from BASF conforming IS: 9103-1999 (1.5% of PPC) was used to increase the workability of fresh concrete and to reduce the w/b ratio. In this study, slump cone test was used to measure workability of fresh concrete and was carried out according to IS: 1199-1959. Slump cone test consists of mould known as a slump cone. The mould is placed on a smooth and hard non-absorbent surface. Concrete is placed in four layers of equal height and each layer is tamped 25 times with a rod. At the end, concrete is leveled with a trowel at the top and the mould is carefully lifted vertically upwards, without disturbing the concrete cone. Concrete gets subside. This subsidence.(mm) is called as slump. Slump cone test determines the wetness of concrete. Increase in workability with increase in FD contents are as shown in Figure3.

It is clear from the results of slump cone test that as the percentage of FD is increased, slump value is also increased. This has happened due to the fact that water absorption of FD is very less as compared to FA. With the increase in FD, free water content also increases which helps in increasing the slump of concrete [24].

3.3 Compressive Strength (CS)

Table 7. Results of CS, TS and FS test

	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

Table 7 shows the CS test results of concrete mix (CTR and F10 – F50), tested after 7, 14, 28, 56 and 90 days of curing. At all curing ages, all concrete mix exhibited higher CS than CTR. After 28 days of curing, the CS of F10, F20, F30, F40, F45 and F50 was 102.88MPa, 103.67MPa, 103.82MPa, 105.12MPa, 105.72MPa and 102.20MPa respectively which is higher than exhibited by CTR

(102.32MPa). CS of all concrete mix showed a normal progression in strength with increase in curing age which signifies that there was no adverse effect of substituting FA with FD. After 90 days of curing CS of F10 – F50 ranged from 107.24MPa to 110.86MPa (1.03 to 1.15 times of CTR). These results are consistent with Wen et al. [25] and Qasrawi et al. [26]. F10-F45 exhibited higher strength than F50. Optimum dosage of AF due to its ultra-fineness and optimized particle size distribution [27] (average size of 4 micron) have resulted in developing higher early strength than with other Pozzolanic materials and silica fume [28]. Hydration and Pozzolanic reaction of AF with packing effect improved the pore structure of concrete [29]. The C_3S, C_2S and C_4AF present in FD had helped in improving the mechanical properties of concrete [30]. The high content of SiO_2 in FD had reacted with $Ca(OH)_2$ and had produced additional C-S-H gel which helped in improving the CS at later ages [31]. Free chloride ions in concrete also affect the strength properties of concrete [13]. Lesser the penetration of free chloride ions in concrete, higher will be the strength of concrete. Partial replacement of FA with FD contents and cement with optimized quantity of AF reduces the chloride ion permeability and helped in the improvement of strength.

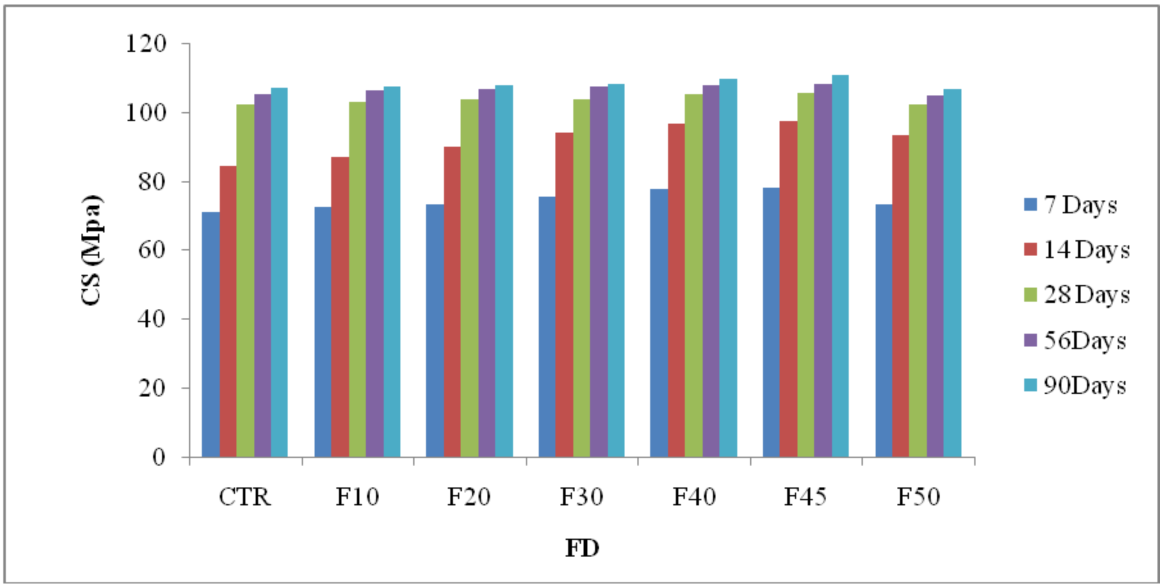

Figure 4. Compressive Strength (MPa) vs. Age with varying % of FD. (IS: 516-1999)

3.4 Tensile Strength (TS)

Results obtained from the split tensile test were carried out on 100 mm x 200 mm cylindrical samples (210 samples) for determining TS which indicated that specimens F10-F45 exhibited more TS than CTR (Figure 5).

The maximum TS was obtained for F45. Percentage (%age) increase in TS for F45 was 2.71% at 7days, 6.66% at 14 days, 1.68% at 28 days, 0.8% at 56 days and 0.86% at 90 days respectively. These results are consistent with the results as reported by Siddique [32].

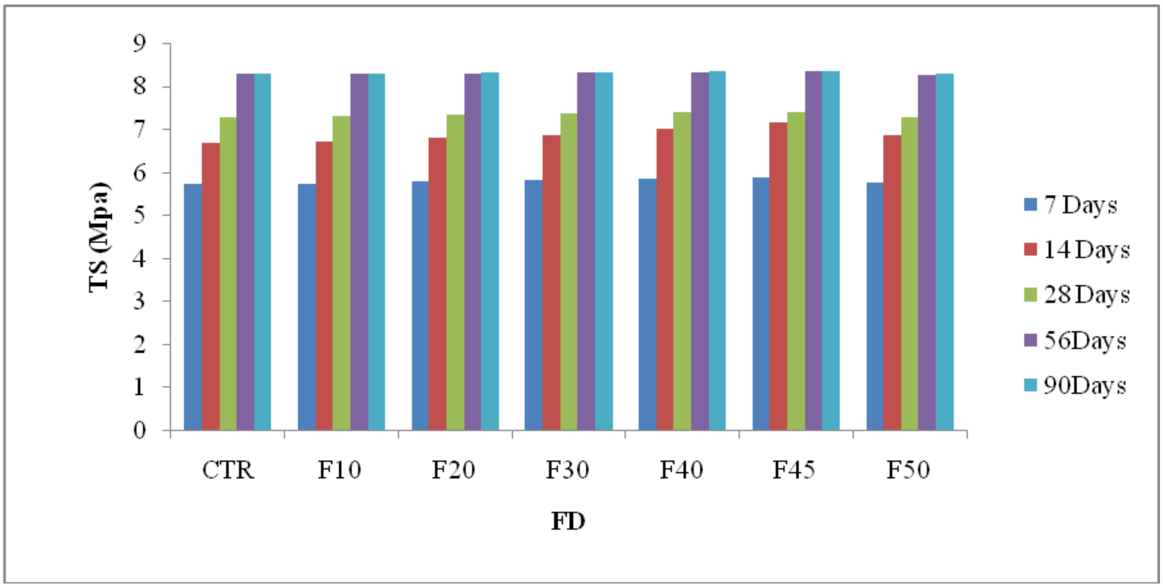

Figure 5. Tensile Strength (MPa) of vs. Age with varying % of FD. (IS: 516-1999)

Rate of increase in TS increased upto 14 days and then it got reduced with increase in age and compressive strength. Ratio of TS and CS was found to be varied from7 to 8% which was lower than high performance fine grained concrete HPFGC (9.6%-11.0%) and ordinary concrete (10.5%-15.2%) [33].These results are consistent with the findings of Komlos [34]. Reduction in TS in F50 might have been due to free water content available in the concrete that might have caused the weaker bond between cement paste and aggregate.

3.5 Flexure Strength (FS)

Flexure strength (FS) results (Figure 6) were higher in all the mixes at 7, 14, 28, 56 and 90 days for F10 to F45. From the results it has been observed that FS has increased with the increase in FD content upto 45%. There is reduction in the FS in F50. Percentage increase in FS for F45 after 7, 14, 28, 56 & 90 days of curing is 6.34%, 3.96%, 20.71%, 10.05%, & 12.10% respectively. Increase in FS is due to angularity, excellent roughness and higher toughness of slag which ensures strong bonding and adhesion between slag particles and cement paste [35]. Higher SiO_2 content of slag also caused improvement in the flexural strength of concrete. Flexural strength for F50 has been reduced due to the presence of courser particle size and the increase in availability of free water. As the %age of FD increased, the free water in the mix also increased and caused formation of pores in the concrete, this porosity weakened the bond between aggregates and cement paste.

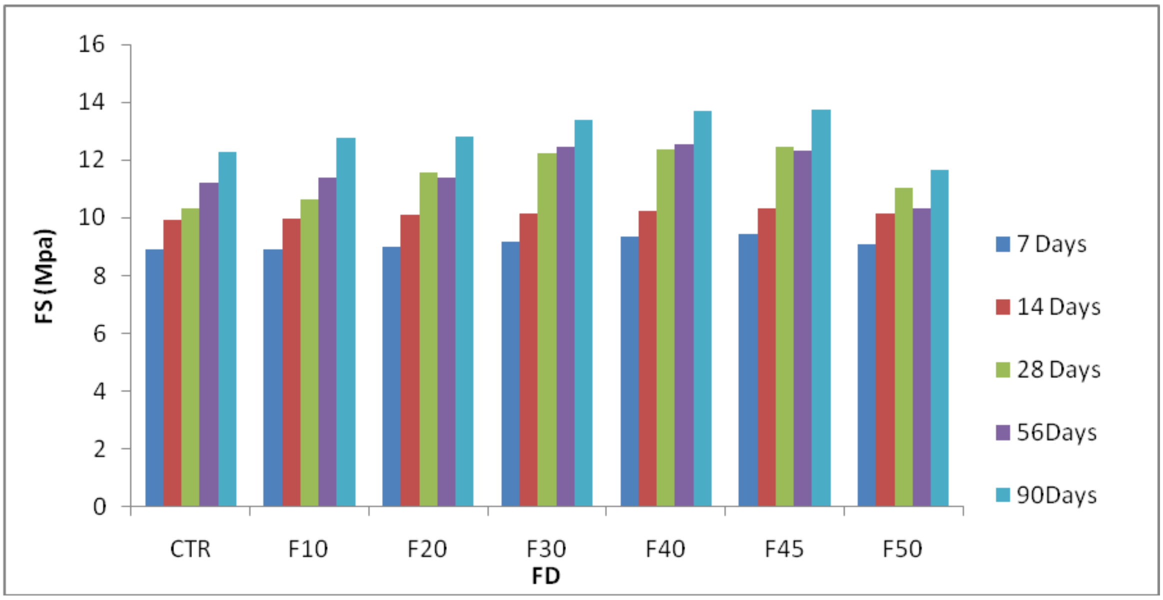

Figure 6. Flexural Strength (MPa) vs. Age with varying % of FD. (IS:516-1999)

3.6. Carbonation

Results of alkanity test are given in the table 8. pH value of concrete was increased slightly with the increase in FD content and the concrete was found to be safe from carbonation and reduced the chances of corrosion. Alkalinity of concrete depends upon the strength and water binder ratio. In ultra high strength concretes, water binder ratio was lowered due to the addition of ultrafine material like alccofine and this additive material consumed most of $Ca(OH)_2$ during the reaction. But the additional $Ca(OH)_2$ was produced due to increased quantity of cement used along with the additional amount of CaO, Na_2O and K_2O present in the ultrafine material as well as in foundry slag.

Reason for increase in alkalinity of concrete with the increased FD content at optimized addition of alccofine (15% by weight of cement) was the lime stone which the foundry slag contained, when it reacted with water, and the completely packed internal pore structure due to additional C-S-H gel produced during the reaction which prevent the penetration of CO_2 and water into the concrete [36].

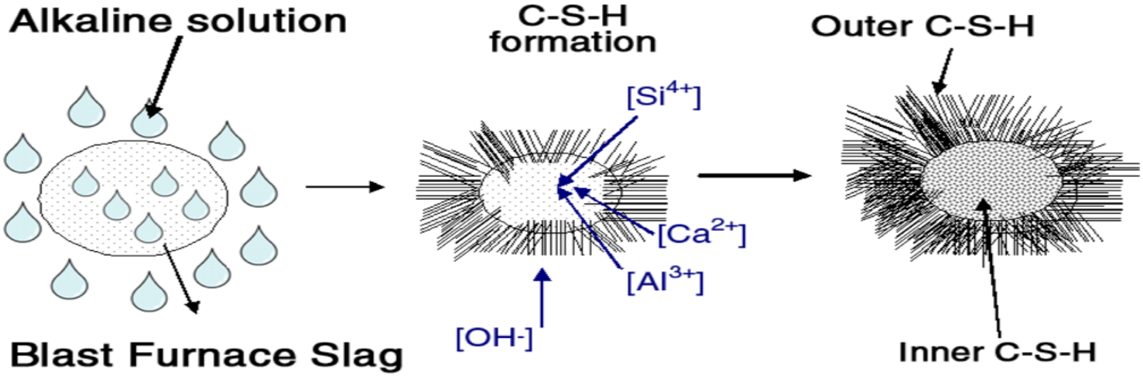

Figure 7. C-S-H formation Process

Chemical reaction [30] during the hydration process is given below

Hydrated calcium silicate(C-S-H) + CO_2 $\rightarrow$ $CaCO_3$ + Residual silica gel --- (e)

The above reaction did not affect alkalinity of pore solution because C-S-H solubility is lower than that of $Ca(OH)_2$[13,37,38,39]. The high alkalinity of concrete pore solution (pH >12.5) form an oxide /hydroxide film at the steel surface to provide insulation to the steel from electrolytes which make the rate of corrosion negligible [13].

Table 8. Results of Alkalinity Test

Sr. No.	FD content	pH value of solution after 365 days of curing	Potential for corrosion
1	CTR	12.70	Low
2	F10	12.70	Low
3	F20	12.80	Low
4	F30	12.86	Low
5	F40	12.95	Low
6	F45	13.10	Low
7	F50	13.10	Low

3.7. Rapid Chloride Permeability Test

Test results of RCPT are given in table9. These results show that charge passed for foundry slag mixed concrete has shown slightly lower values than control mix CTR. Permeability of concrete decreased with the increase in foundry slag upto 45% replacement level and then increased slightly. Replacement of Fine aggregate with foundry slag(FD) and cement with optimized content of alccofine (15% by weight of cement) reduced the pores of concrete and make concrete impermeable. Permeability of concrete depend upon the internal pore structure which in turn depend upon the extent of hydration of cement paste. Hydration and Pozzolanic reaction of AF with filler effect improved the internal pore structure of concrete [29]. The high content of SiO_2 in FD has also reacted with $Ca(OH)_2$ and has produced additional C-S-H gel which fills the pores and helped in lowering the permeability of concrete[40]. Replacement of fine aggregate with foundry slag(FD) upto 45% and PPC with alccofine(AF) also reduced the penetration of free chloride ion in the concrete[41]. Ann et al. [13,42] studied the impact of fly ash and blast furnace slag on the concrete's resistance to chloride ion penetration and the results showed the improvement in the concrete resistance to chloride ion penetration with the addition of fly ash and blast furnace slag [13,43,44]. Key factors on which the durability of concrete depend is the free chloride ion [13,45]. More the free chloride ion in the concrete, lesser the compressive strength and accelerated the process of corrosion of steel reinforcement in concrete [46,47,48]. When free chloride ion, oxygen and water exist at the surface of reinforcement, the chemical reaction occurs as [13,49].

$Fe + 2Cl^- \rightarrow FeCl_2 + 2e \rightarrow Fe^{2+} + 2Cl^- + 2e$ ---------------- (1)

$O_2 + 2H_2O + 4e \rightarrow 4OH^-$ ----------------------------------- (2)

Fe^{2+} combined with OH^- in water produced $Fe(OH)_2$ which expands and destroy concrete. But in the present research study, FD and AF with improved pore structure in ultra high strength concrete helped in reducing the free chloride ion in the concrete.

Table 9. Chloride Permeability with FD content and Age

FD content	Charge passed in coulombs			
	28 days	90 days	180 days	360 days
CTR	395	102	89	75
F10	376	96	78	70
F20	371	89	75	68
F30	363	81	71	64
F40	352	74	67	61
F45	341	71	63	57
F50	366	83	74	69

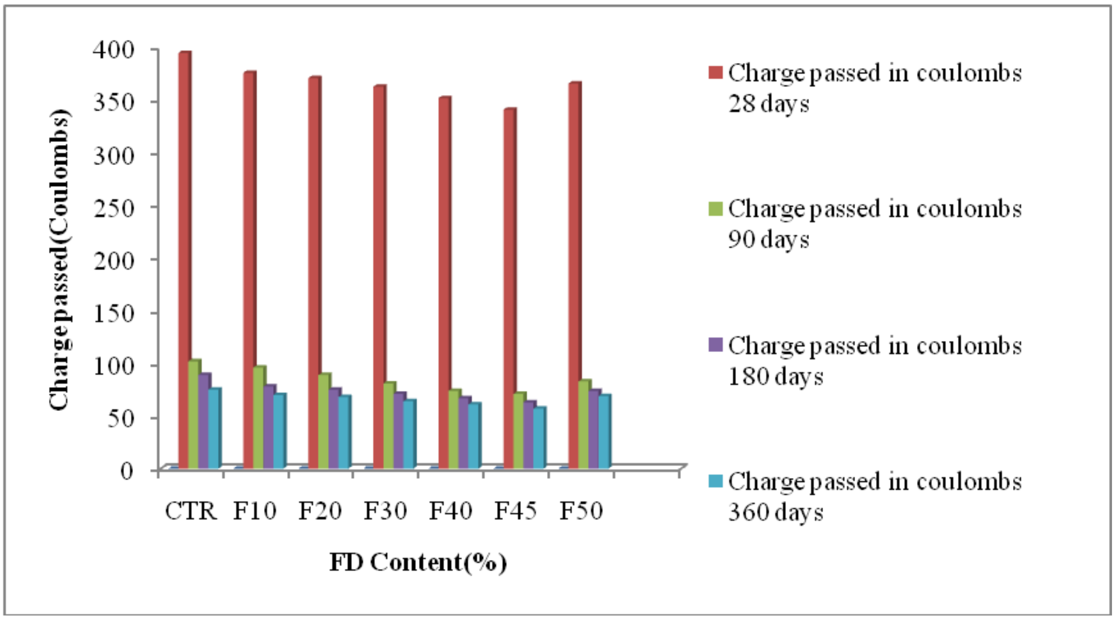

Figure 8. Charge Passed (Coulombs) with FD content and Age.

4. CONCLUSIONS

1. Results showed that Alccofine (AF) a commercially available product in combination with Foundry slag (FD) can be used to replace PPC and FA respectively to produce high strength concrete and thereby reducing the impact on environment by saving the natural resources.

2. Results showed that reasonably high strength concrete mix can be designed by substituting fine aggregate with 10% to 45% of FD and partial replacement of cement with 15% of Alccofine.
3. Significant increase in CS, TS and FS over CTR has been affected with optimum substitution of FA with FD.
4. pH value of concrete was increasing slightly with the increase of FD content and the concrete was found to be safe from carbonation and reduced the chances of corrosion.
5. Replacement of FA with FD up to 45% reduced the permeability of concrete and showed that the concrete permeability decreased with the increase in FD content, age and strength.

References

1. C. Jaturapitakkul, K. Kiattikomal, V. Sata and T. Leekeeratikul, *Cement and Concrete Research,* 34(2004)549.
2. ACI Committee 363-92, *American Concrete Institute*, *Detroit*, 2000.
3. M.J. Shannag, *Cem.Concr.Compos.*, 22 (2000) 399.
4. Alizadeh, M. Chini, P.Ghods, M. Hoseini, Montazer Sh., M.Shekarchi, *6th CANMET/ACI International Conference on Recent Advances in Concrete Technology, Bucharest*, *Romania,* (2003)451.
5. T.R.Naik, S.S. Singh, M.P.Tharaniyil, R.B.Wendorf, *ACI Mater. Jour.,* 93(1996)41.
6. M.C.Limbachiya, T.Leelawat, R.K.Dhir, *Concr. Mater. Struc.*, 33(2000)574.
7. J.M.Manso, J.J. Gonzalez, J.A. Jand Polanco, *ASCE J. Mater. Civil Engg.,* 16 (2004)639.
8. L.Zeghichi, *Asian J. Civil Engg. (Building and Housing),* 7(2006)27.
9. Mohammed Nadeem, A.D.Pofale, *Int. J. of Engg. Research and Applications*, 2(2012)1258.
10. S.Suthar, B.K.Shah, P.J.Patel*, I. J. Scientific Res. Dev.*, 1 (2013) 464.
11. A.V.Saettaa, R.V.Vitaliani, *Cement and Concrete Research,* 35 (2005) 958.
12. M.Thiery, P.Dangla, G.Villain, G.Platret, *Int. Conference on Durability of Building Materials and Components*, (2005) 17.
13. E. Chávez-Ulloa, R. Camacho-Chab, M. Sosa-Baz, P. Castro-Borges and T. Perez Lopez, *Int. J. Electrochem. Sci.,* 8 (2013) 9015.
14. M.A.Peter, A.Muntean, S.A.Meier, M.Böhm, *Cement and Concrete Research,* 38 (2008) 1385.
15. IS 383-1970, New Delhi
16. Alccofine, *Counto Micro Fine Products Pvt. Ltd. (Ambuja Cement Ltd.)*
17. Mohammed Nadeem, A.D.Pofale, *Open Journal of Civil Engineering*, 2(2012) 96.
18. IS 10262-1982,2009, New Delhi, India.
19. E.Vivas, A.Boyd and H.R.Hamilton, Final Project Report, University of Florida, (2007).
20. ASTM C1202, *Annual Book of ASTM Standards*, 04(1994)620 .
21. D.Whiting, FHWA RD-81-119, *Federal Highway Administration, Washington, DC,* (1981)173.
22. C.Andrade, *Cement and Concrete Research,*23(1993)724.
23. S.H.Kosmatka, B.Kerkhoff, et al., Skokie, Portland Cement Association, (2002).
24. J.Z.Xion, *Science China Technological Sciences,* (2012).
25. X.L.Wen, D.Ouyang, P.Pan, *Concrete (in Chinese),* 6(2011) 73.
26. Hisham Qasrawi et al. *Construction and Building Materials,* (2009) 1118.
27. Y.Patel, P.J.Patel, J Patel, H.S.Patel, *International journal of advanced engineering research and studies,* 11(2013) 154.
28. D.soni, S Kulkarni.V.Parekh, *Indian Journal of Research,* 3(2013)84.

29. Ajay Goyal, K.Hattori, H.Ogata, M.Garg, A.M.Anwar, M.Ashraf, *Journal of Applied Sciences,* 7 (2007)3256.
30. M.Thiery, P.Dangla, G.Villain, G.Platret, *Cement and Concrete Research,*37(2007)1047.
31. J.Z.Zhang, L.Lu, Y.Wang, J.D.Wang, *Advanced Material Research,* 163(2010)3200.
32. R.Siddique, G.Singh, B.Rafik, A.Mokatar, K.Kunal, *Construction and Building Materials,* 15(2015).
33. M.S.Shetty, *Concrete technology (theory and practice,)* New Delhi, India (2003).
34. K.Komlos, *Magazine of Concrete Research,* 22(1970) 232.
35. M.Ashraf, A.Naeem Khan, A.Qasai, J.Mirza, A.Goyal, A.M.Anwar, *Construction and Building Materials,* 23(2009) 2207.
36. A.T.Barreira, A.J.Cama, and J.M.Soler. *Physics and Chemistry of the Earth Parts A/B/C*, 2013.
37. M.Thiery, P.Dangla, G.Villain, G.Platret, E.Massieu, M.Druon, V.Baroghel-Bouny, *BLPC.*, (2004) 252.
38. J De Han, G H Pan, W Sun, C H Wang, D Cui, *China Tech. Science*, 55 (2012) 616.
39. T.Ishida, C.H Li., *Journal of Advanced Concrete Technology*, 6 (2008) 303.
40. A. Ibrahim, S. AL-Jumaily, N.Najib, Q.Kareem, *International Journal of Enhanced Research in Science Technology & Engineering,* 4 (2015) 81.
41. X.Liu, H.Z.Du, M.H.Zhang, *Construction and Building Materials*, 80(2015)255.
42. K.Ann, H.Moon, Y.Kim, and J.Ryou, Waste Management, 28(2008)993.
43. R.S.Ahari, T. K.Erdem, K Ramyar, *Construction and Building Materials*, 79(2015)326.
44. X.Liu, M.Zhang, Proceedings of conference, Kingston, Kingston University, U.K.,(2008).
45. L.Evangelista and J.Brito, *Cement Concrete Composite*, 32(2010)9.
46. D.Conciatori, F.Laferriere, E.Brubwiler, *Cement and Concrete Research*, 40(2010)109.
47. K.Xiao, Z.Lin, H.Wan, Shandong, *Build Mater.*, 25(2004)31.
48. C.Lima, A.Caggiano, C.Faella, *Construction and Building Materials*, 47(2013)547.
49. W Pengcheng, W.Xuefeng, H.Tianrong, Z.Weiting, *Int. J. Electrochem. Sci.*, 9 (2014)3513.