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Experimental Investigation on Effect of Industrial Waste Slag and Alccofine on Durability Properties of High Strength Concrete

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***Abstract*:** *In the present research, industrial waste slag (FD) as partial replacement of sand and Alccofine as partial replacement & addition of PPC was used to study the durability properties of high strength concrete. M100 grade concrete cube samples using water/binder ratio of 0.24, with varying percentage of industrial slag(0 to 50%) and with optimum percentage of Alccofine(15%) were tested for various properties such as Water absorption, water permeability, resistance to sulphate attack, alkali attack and nitrate attack on high strength concrete at different ages. It has been found that Substitution of fine aggregates with up to 45% of industrial slag content and PPC with Alccofine showed an excellent resistance against all the properties at all ages. Comparative statistical analysis between Loss of weight in concrete samples with loss in compressive strength due to sulphate attack, alkali attack and nitrate attack was carried out at the of 365 days. Correlation between loss in weight and loss in compressive strength was developed and found to be excellent.*

Keywords: *Foundry Slag, Alccofine, Water absorption, water permeability, sulphate attack, alkali attack, nitrate attack.*

1. Introduction

Concrete is considered to be the chief construction material in comparison to other materials as it is most easily and readily available with wide range of applications. It has excellent resistance to water permeation and hence more durable than other materials[1].Durability of concrete is the ability of concrete to resist process of deterioration such as chemical attack, weathering action etc. when concrete is exposed to open and harse environment. There are different ways to estimate the durability of concrete. The simplest ways to determine the durability of concrete are resistance to water, chloride and air permeation. The permeation of water and chloride ions into concrete governs the process of deterioration (Monteiro) [2]. The physical and chemical process of water movements and the transportation of OH^- ions and Cl^- ions in concrete depend mainly upon the microstructure of concrete. Thus HSC satisfies both durability as well as the strength criteria.

The process of deterioration of concrete depends upon the permeation characteristics. As the porosity of concrete decreases, durability of concrete increases [3]. Porosity of concrete can be reduced by using pozzolanic by product materials such as slag, silica fume, fly ash, alccofine, metakaolin etc in concrete which also provide the most economic and technological solution to handle and disposal of waste without harming the environment [3,4]. Patil.B. B et al [5] used high reactivity metakaolin for the improvement in compressive strength of concrete. Alizadeh, et al. [6] replaced natural fine aggregate with foundry slag and discussed mechanical and durability properties. Durability of concrete can also be increased by using high strength as it can be achieved by reducing water/cement ratio which help in reducing the voids in concrete. ACI 363[7] called concrete with compressive strength at 28 days of curing greater than 41 MPa as high-strength concrete. Natural pozzolana and silica fume can be used to produce high strength concrete(HSC) of 69 MPa to 85 MPa at 28 days[8, 9]. Limbachiya et al. [10] described the use of recycled concrete aggregate in producing high strength concrete. Juan Mansoet al. [11] had carried out study on electric arc furnace slag in Concrete. Zeghichi [12] reported the substitution of natural fine aggregates by waste foundry slag to discuss mechanical and durability properties of high strength concrete. In 2012, Nadeem and Pofale [13] had used granular slag as alternative construction material for natural fine aggregate in various applications either partially or fully. Sharma et al.[9] reported the substitution of natural fine aggregates by foundry slag and cement by Alccofine with enhancement on mechanical and durability properties of high strength concrete. Mohammed Irshad et al.[14] described the effect of Mineral admixtures on high strength concrete prepared with locally available aggregate.

2. Experimental Program & Methodology

2.1. Materials

Portland Pozzolana Cement (PPC) of specific gravity 3.02 was used which conforms to IS: 1489-1991(Part I), (SSD) crushed coarse aggregate(CA) which is saturated surface dry of maximum size 20 mm and Natural river sand (Zone-II) of Khizrabad (Pb) India conforming to IS: 383-1970[15] was used as fine aggregate(FA). Both Coarse Aggregate and Fine Aggregates were obtained from Ultra-Tech Concrete Ltd. Mohali (Pb) India, waste slag(FD) was used as substitute of natural sand obtained from steel manufacturing plant at Mandi Gobindgarh (Pb) India. Physical properties of CA, FA and FD are shown in Table 1[9, 15].

TABLE I: Physical Properties of Coarse and Fine Aggregates
(IS: 383-1970) [9, 15]

Properties					
Materials	Colour	Maximum Size (mm)	Specific Gravity	Fineness Modulus	Water Absorption
Coarse Aggregate	Grey	20	2.69	7.69	0.51
Fine Aggregate	Light Grey	4.75	2.64	2.95	1.63
Slag	Black	4.75	2.78	3.00	0.43

Chemical properties of waste slag(FD) are as shown in Table 2.

TABLE II: Chemical Composition of Slag [9]

Chemical constituents						
composition	SiO_2	Fe_2O_3	CaO	MgO	Al_2O_3	SIO_2
(% age) content	31.4	18.20	33.6	1.94	8.20	0.22

Tap water from civil engineering Laboratory as per IS: 456-2000 was used for concrete work and curing. To produce high workability with low water binder ratio, Super plasticizer -BASF 8777 having Specific gravity of 1.18 at 20^0 C confirms to IS: 9103-1999 was used.Ultra Fine slag (Alccofine1203) (AF) is a supplementary cementitious material (SCM) containing high glass content with high reactivity, produced by Ambuja Cement ltd. Physical and chemical properties of alccofine conforms to ASTM C 989-99 are given in **Table** 3[9,15].

TABLE III: Properties of AF [9,15].

Physical Properties		Chemical Properties	
Specific Gravity	2.9	CaO	31-33%
Density(Kg/m3)	600-700	Al_2O_3	23-25%
D_{10}	1-2	SiO_2	33-35%
D_{50}	4-5	Glass conten[t]	>90%
D_{90}	8-9		

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

2.2. Mix Proportion

Optimum dosage of Alccofine (AF) was determined by varying the alccofine(AF) content from 5% to 20% by weight of PPC for designing concrete mix of M100 grade, and was found to be 15%. Concrete mix was designed by using IS 10262;with a 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 and15% Alccofine(AF) contents was added in Portland pozzolanic cement (PPC). Concrete mixes prepared by replacing FA with 0%, 10%, 20%, 30%, 40%, 45% and 50% of FD have been represented by (CTR), F10, F20, F30, F40, F45 and F50 respectively (**Table 4**)[9,15]. 150mm x150mm x150 mm cubes(Set of 6 each) specimens for water absorption test (28 days) , water permeability test , sulphate resistance test, nitrate resistance test and alkali resistance test, were casted, cured, dried and tested after the curing age of 28, 90,180 and 365 days for determining water permeability, sulphate resistance, nitrate resistance, alkali resistance as per IS specifications.

TABLE IV: Proportion of HSC Mixes [9, 17]

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. Water Absorption

ASTM C642-81 describes the method to determine water absorption in concrete. 150mm x150mm x150 mm cubes (Set of 6 specimens each) were casted and cured [18]. All the specimens were cured for a specified period of 28 days and then taken out from the curing tank. Now the specimens were dried at 105^{0}C temperature in an oven for 24 hours and weight of the specimens were noted down. Then, these specimens were immersed in water for 48 hours and again the weight of specimens were taken and noted after wipe of water from the surface with dry cloth. %age of water absorption was given by a formula give below.

%age water absorption = Saturated weight - Dry weight / Dry weight

2.4. Water Permeability

A water permeability test was carried out based on the Specifications given by Bureau of Indian Standards (BIS) IS: 3085-1965. 150mm x150mm x150 mm cubes (Set of 6 specimens each) were casted for each variation of waste foundry slag and fixed content of Alccofine (15%) and cured for a period of 28 days. Permeability apparatus consists of permeability cell, control panel and glass bottles for collecting water. The specimens were dried at 105^{0}C in an oven for a period till constant mass was attained. Specimens were then placed in the permeability cell. The space between specimen and cell were then tightly sealed with cotton soaked in bee- wax to prevent ingress of water from the sides during the test. After sealing, cell assembly was connected to the water tank through the pipe. 5 to 15 kg/cm^2 pressure was applied to the specimens and initial reading of gauge glass was noted. The rate of flow readings were taken with a burette after the specimens were saturated, by measuring the changing of volume of water over time [19]. After reaching steady state, the test was continued for 100 hours. The coefficient of permeability was determined by Darcy's Law:

k = QL / AH, Where k = coefficients of permeability (m/s)

Q = rate of flow (m^3/s)

A = area (m^2)

L = depth of specimen (meter)

H = head of water (meter)

3. Results And Discussion

3.1. Optimization of Alccofine

In order to find out the optimum contents of Alccofine(AF), quantity of AF substituted from cement (PPC) was varied from 0% to 20% by weight of PPC and specimens were casted and tested for finding out CS after curing age of 28 days as per IS Specifications. Results of the tests are shown in the**Figure1**. Maximum values of CS were observed at 15% substitution of PPC with AF. Hence Optimum dosage of AF was found to be 15% by weight of cement.

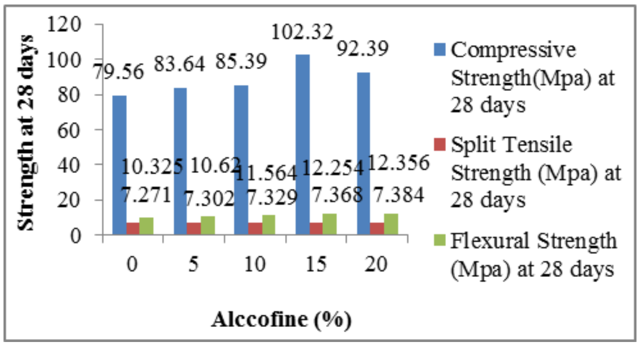

Fig. 1: Optimization of Alccofine

3.2. Water Absorption

Results of the water absorption are as shown in the figure2. Water absorption of high strength concrete sample was very low which indicate very less porosity of concrete made with waste slag and Alccofine. Water absorption of controlled concrete was found to be 0.309% which means the water absorbed by the concrete sample was very – very less and this may be due to the pore filling ability and optimized particle size distribution of Alccofine. From the figure2, it is clear that water absorption was reduced with the increase in waste foundry slag upto 45% replacement level. This has happened due to the pores in the concrete filled with additional C-S-H gel produced by increased contents of waste slag and also due to excellent bonding between cement paste and aggregate because of angularity and higher toughness of slag particles. Reduction in water absorption was found to be 23.30%, 30.74%, 38.83%, 54.37%, 62.14 % and 38.83% as compared to control sample. Maximum reduction in water absorption was found to be in the samples made with waste slag content at 45% replacement level. Khatib et al. [20], Pourkhorshidi et al.[21] and Vinod et al.[22]reported water absorption values 4.2% to 5.4% in samples made with metakaolin, 2.9% to 4.8% in silica fume concrete and 0.792% to 2.216% respectively.

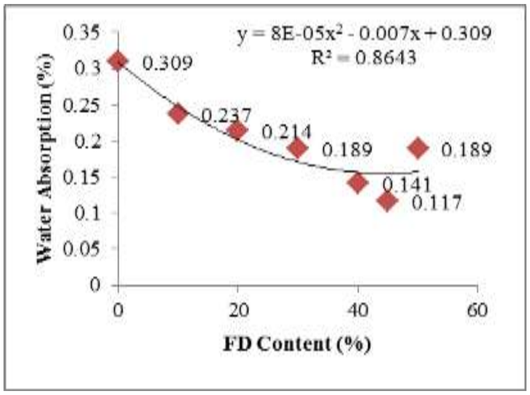

Fig. 2: Variation of Water Absorption (%) with Waste Slag Content(%)

3.3. Water Permeability

Water permeability test were conducted at the age of 28, 90, 180 and 365 days on specimens made with various %ages of slag and optimized contents (15%) of Alccofine 1203 (AF). Results of water permeability test are shown in the figure. Permeability of concrete was found to be reduced very much for high strength concrete. Results showed reduction in permeability from $5.20x10^{-17}$ m/s to $1.86x10^{-17}$m/s with increase in waste slag content and age upto 45% replacement level. Reduction in the coefficient of permeability at the age of 365 days with the increse in slag content FD(F10 F50)was found to be 8.47%, 19.61%, 28.81%, 47.94%, 56.65% and 51.33% as compared to control sample(CTR).This may be due to the excellent physical and mechanical properties of slag aggregate and alccofine .Pattern of reduction of water absorption and water permeabilty was found to be same in the present study.

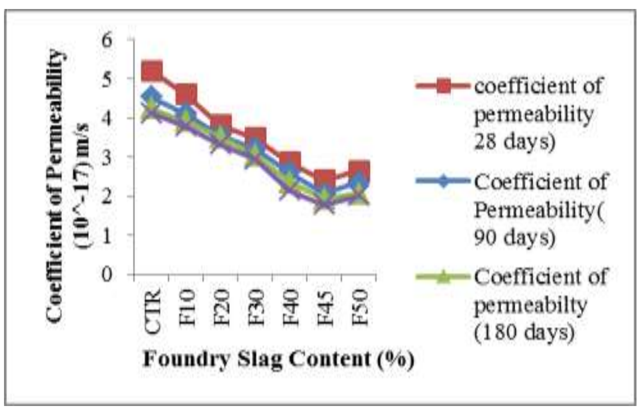

Fig. 3: Variation of Coefficient of Permeability (10-17) m/s with increase in FD content (%) and Age

3.4. Resistance To Sulphate Attack Test

Table 5 presents the results of sulphate resistance test. Results showed very small decline in weight less than 0.072% and compressive strength less than 0.40% only after 365 days. F45 specimens show 0% loss in weight and compressive strength. These results show approximately no deterioration in concrete after one year. Figure 4 show the variation of weight loss (%) and CS loss (%) with FD content (%). There is reduction in weight loss after immersion in sulphate solution with increase in slag content and at 45% and 50% replacement level of natural sand with slag content, weight loss reduces to zero. This may be due to the dense packing of aggregates in concrete paste. Figure 5 show the correlation between loss of weight (%) and loss of CS (%) and found to be very strong as the correlation coefficient was 0.879.

TABLE V: Weight of Cubes at 365 Days of Immersion in Sulphate Solution

Content(%)	W-1	W-2	WL (%)	CS-1	CS-2	Loss in CS
CTR	8.258	8.252	0.072	113.26	112.8	0.40
F10	8.428	8.424	0.047	113.7	113.32	0.33
F20	8.454	8.45	0.047	116.22	115.9	0.28
F30	8.496	8.494	0.024	118.34	118.01	0.28
F40	8.554	8.552	0.023	122.65	122.6	0.20
F45	8.522	8.522	0	126.16	126.16	0.00
F50	8.626	8.626	0	119.76	119.7	0.05

W-1= Weight of cubes before immersion in sulphate solution

W-2= Weight of cubes after immersion at 365 days

WL= Weight loss at 365 days (%)

CS-1= Compressive Strength of cubes before immersion in sulphate solution

CS-2= Compressive Strength of cubes after immersion at 365 days

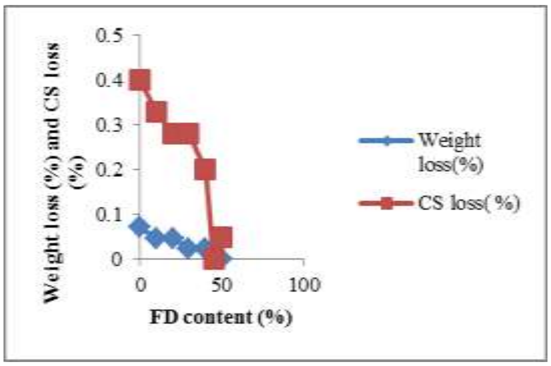

Fig. 4: Variation of weight loss(%) and CS loss(%) with variation of slag content (%) due to alkali attack at 365 days

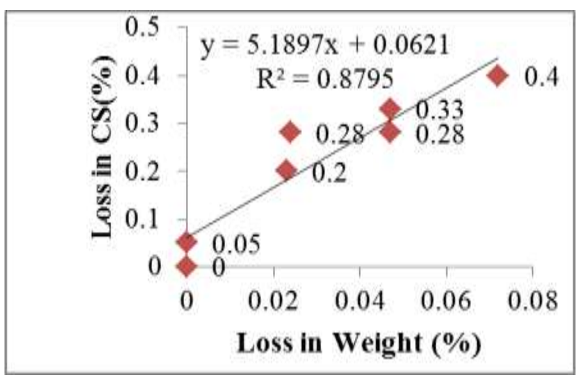

Fig. 5: Relation b/w Loss of weight (%) and loss of CS (%) at 365 days due to Sulphate Attack

3.5. Resistance To Alkali Attack Test

Table 6 presents the results of alkali resistance test. Results showed very small decline in weight less than 0.12% and compressive strength less than 0.39% only after 365 days. F45 specimens show minimum loss of 0.02% in weight and0.13% in compressive strength. These results show approximately no deterioration in concrete after one year. Figure 6 show the variation of weight loss with FD content. There is reduction in weight loss after immersion in NaOH solution with increase in FD content. This may be due to the dense packing of aggregates in concrete paste. Figure 7 show the correlation between loss of weight (%) and loss of CS (%) and found to be very strong as the correlation coefficient was 0.842.

TABLE VI: Weight and CS of Cubes at 365 days of Immersion in NaOH Solution

FD Content (%)	W-1	W-2	WL	CS-1	CS-2	Loss in CS at 365 days
CTR	8.104	8.114	0.12	111.22	111.65	0.39
F10	8.258	8.266	0.1	113.44	113.73	0.25
F20	8.392	8.398	0.07	114.89	115.2	0.27
F30	8.684	8.69	0.07	116.67	116.96	0.25
F40	8.576	8.58	0.05	120.44	120.62	0.15
F45	8.578	8.58	0.02	122.22	122.38	0.13
F50	8.732	8.736	0.04	116.11	116.31	0.17

W-1 = Weight of cubes before immersion in NaOH solution

W-2= Weight of cubes after immersion at 365 days

WL= Weight loss at 365 days (%)

CS-1 = Compressive strength of cubes before immersion in NaOH solution

CS-2= Compressive strength of cubes after immersion at 365 days

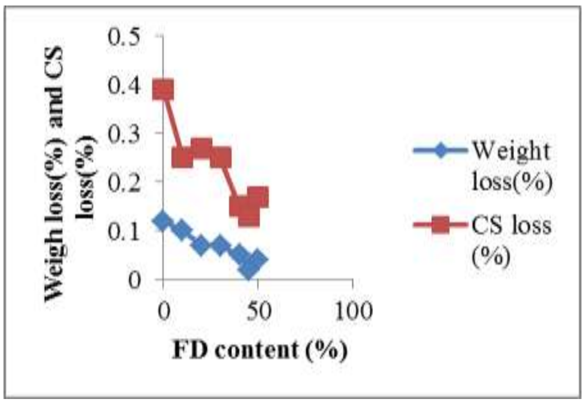

Fig. 6: Variation of weight loss and CS loss with variation of FD content (%) due to alkali attack at 365 days

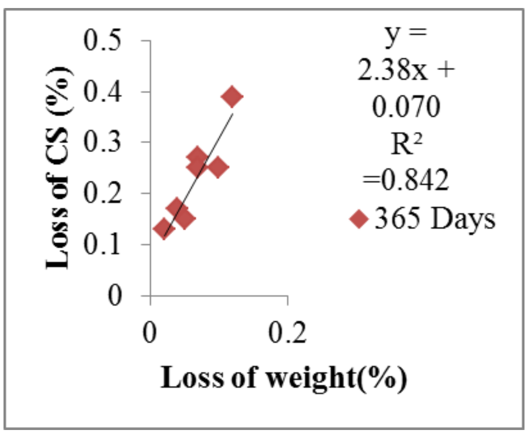

Fig. 7: Relation b/w Loss of Weight (%) and Loss of CS (%) at 365 Days Due to Alkali Attack

3.6. Resistances To Nitrate Attack Test

Table 7 presents the results of nitrate resistance test. Results showed very small decline in weight less than 0.14% and compressive strength less than 0.32% only after 365 days. F45 specimens show minimum loss of .05% in weight and 0.08% in compressive strength. These results show approximately no deterioration in concrete after one year. Figure 8 show the variation of weight loss with FD content. There is reduction in weight loss and CS loss after immersion in KNO_3 solution with increase in FD content. This may be due to the dense packing of aggregates in concrete paste. Figure 9 show the correlation between loss of weight (%) and loss of CS(%) and found to be very strong as the correlation coefficient was 0.842.

TABLE 7: Weight and CS of Cubes at 365 days of Immersion in KNO_3 Solution

FD Content (%)	W-1	W-2	WL	CS-1	CS-2	Loss in CS at 365 days
CTR	8.304	8.292	0.14	109.33	108 .98	0.32
F10	8.574	8.566	0.09	111.41	111.09	0.29
F20	8..358	8.35	0.1	112.33	112.03	0.27
F30	8.398	8.39	0.09	113.42	113.17	0.22
F40	8.624	8.618	0.07	115.33	115.18	0.13
F45	8.634	8.63	0.05	117.12	117.02	0.08
F50	8.596	8.59	0.06	113.33	113.18	0.13

W-1 = Weight of cubes before immersion in KNO_3 solution

W-2= Weight of cubes after immersion at 365 days

WL= Weight loss at 365 days (%)

CS-1 = Compressive strength of cubes before immersion in KNO_3 solution

CS-2= Compressive strength of cubes after immersion at 365 days

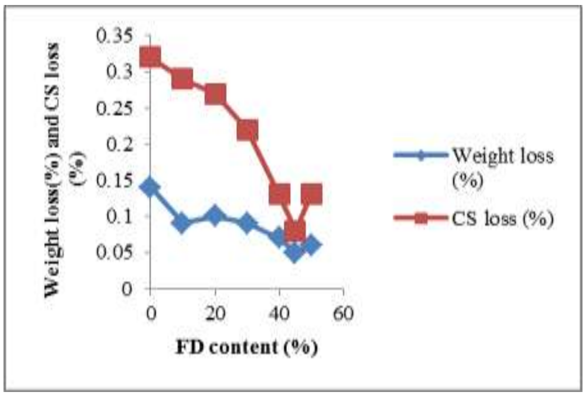

Fig. 8: Variation of Weight Loss and CS Loss with Variation of Slag Content (%) due to Nitrate Attack at 365 days

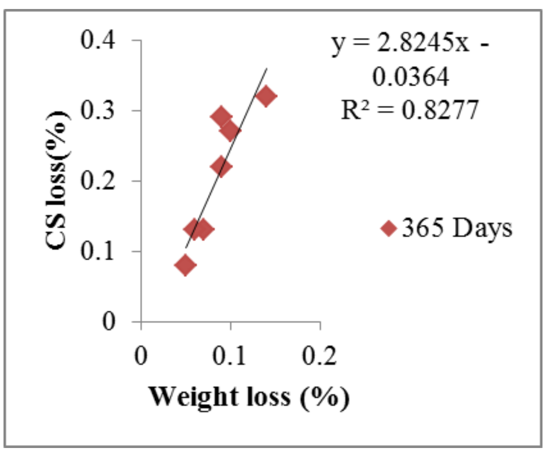

Fig. 9: Relation b/w Loss of Weight (%) and Loss of CS (%) at 365 Days Due to Nitrate Attack

4. Conclusion

- Water absorption of high strength concrete samples were found to be very low which indicate very less porosity of concrete made with industrial waste Slag and Alccofine.
- Reduction in water absorption was found to be 23.30%, 30.74%, 38.83%, 54.37%, 62.14 % and 38.83% as compared to control sample.
- Permeability of concrete was found to be reduced very much for High Strength Concrete. Results showed reduction in permeability from 5.20x10-17 m/s to 1.86x10-17m/s with increase in slag content and age upto 45% replacement level .
- Results of sulphate attack showed very small decline in weight less than 0.072% and compressive strength loss less than 0.40% only after 365 days.
- Results of nitrate attack test showed very small decline in weight less than 0.14% and compressive strength less than 0.32% only after 365 days.
- Results of Alkali attack test showed very small decline in weight loss of 0.12% and compressive strength loss less than 0.39% only after 365 days.
- Correlation between loss in weight and loss in compressive strength was found to be excellent in sulphate attack, nitrate test and alkali attack test.

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