Int. J. Chem. Sci.: 14(2), 2016, 1015-1025
ISSN 0972-768X
www.sadgurupublications.com

ACID RESISTANCE AND RAPID CHLORIDE PERMEABILITY OF HIGH PERFORMANCE CONCRETE

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ABSTRACT

This paper presents the results of a study conducted to evaluate the effect of steel slag aging on acid resistance and rapid chloride permeability of high performance concrete (HPC). Effect of different aging periods (6, 12, 18, 24, 30, 36 and 42 months) of steel slag aggregates (SSA) on acid resistance and rapid chloride permeability of concrete was studied. Water cement ratio and cement/cementious materials contents are kept constant as 0.32 and 584 Kg/m^3, respectively. It was observed that the aging process of SSA improves the acid resistance and rapid chloride permeability of HPC made with SSA. A minimum of 30 to 36 months aging of SSA is required to achieve the acid resistance and rapid chloride permeability of HPC at par with conventional concrete.

Key words: Acid resistance, Water absorption, Rapid chloride permeability, durability, Steel slag aggregate, High performance concrete.

INTRODUCTION

HPC is the concrete, which meets special performance and uniformity requirements that cannot always be achieved with techniques and materials adopted for producing conventional cement concrete. The major difference between conventional cement concrete and high performance concrete is essentially the use of chemical and mineral admixtures. Thus, the combined use of chemical and mineral admixtures results in economical concrete with enhanced properties[1]. Aggregates are the important constituents of concrete that help in reducing shrinkage and impart economy to concrete production. Most of the aggregates used are naturally occurring aggregates, but some artificial aggregates can be used to make concrete. These artificial and processed aggregates react with the cement paste and chemically combine to improve the properties of concrete[2].

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Steel slag is a by product of steel industries. It is produced during the separation of the molten steel from the impurities in steel making furnaces. This by product is broken down to smaller sizes to be used as aggregate in asphalt and concrete. Many researchers tried on concrete and other construction materials using steel slag aggregates and the results are found satisfactory[3-7]. The 2012 world output of steel furnace slag (SFS) was on the order of 150 to 230 million tons, while in the United States, the amount of iron and steel-making slag was around 17 to 22 million tons[8]. Presently, total steel production in India is about 72.20 million metric tons and steel slag waste generated annually is around 18 million metric tonnes, but hardly 25% is being used in cement production[9]. However, steel slag has not been used efficiently and thoroughly for long, which causes its great accumulation, waste of land, and serious air and water pollution. In the present work, an effort has been made to focus on the complete replacement of natural coarse aggregate (NCA) with steel slag aggregate (SSA) in high performance concrete.

Because of the producing process of steel slag, there is great probability that steel slag is contaminated with free lime, which could result in some serious problems by volume expansion in concrete, due to the delayed hydration of free lime. It was observed that steel slag must be allowed to aging, before it is used as aggregates. There are different opinions about the aging period of steel slag[6,10-13]. Also there is insufficient information to definitively conclude the optimum aging period of steel slag and the effect of different aging periods of steel slag on durability properties (Acid resistance and rapid chloride permeability) of concrete. Hence, a detailed study has been made to evaluate the effect of different aging periods of steel slag on durability of high performance concrete. The results obtained in this investigation would be useful in establishing an optimum aging period of steel slag aggregate to be used in concrete and to obtain better mixture proportion for HPC using steel slag as coarse aggregate along with chemical and mineral admixtures. The use of this type of waste material can solve the problem of lack of aggregate in various construction sites and reduce environmental problems related to aggregate mining and waste disposal. The use of waste materials as aggregates can also reduce the cost of the concrete production.

EXPERIMENTAL

Materials and methods

Materials

Ordinary Portland cement (OPC) of grade 53 conforming to IS 12269-1987[14], river sand (RS) of grading zone II obtained from Cauvery river bed (Karur), 20 mm down blended well graded hard blue granite (HBG) stone aggregates were used for the investigation. Class F Fly ash (FA) of specific gravity 2.15 was obtained from Mettur thermal power plant and was used as mineral admixture. Sulphonated naphthalene based super plasticizer CONPLAST SP 430 (SP) confirming to IS 9103-1999[15] was used as chemical admixture. The steel slag was produced from Raja Steels Pvt. Ltd., Coimbatore. Potable water was used for mixing concrete and curing of cast specimens. The physical and mechanical properties of cement and aggregates are given in Tables 1 and 2, respectively.

Table 1: Physical and mechanical properties of cement

Specific gravity	Standard consistency	Initial setting time	Final setting time	Compressive strength (Mpa)			Soundness
				3 Days	7 Days	28 Days	
3.15	32%	58 min	215 min	27.50	41.61	57.32	3 mm

Table 2: Physical and mechanical properties of aggregates

Aggregate type	Specific gravity	Fineness modulus	Water absorption (%)	Unit weight (Kg/m^3)	Crushing value (%)	Impact value (%)	Abrasion value (%)
HBG	2.71	7.06	0.40	1719	26	25	23
SSA	2.89	6.64	1.90	1611	27	23	29
RS	2.64	2.67	1.00	1669	----	----	----

Aging of steel slag aggregates

Conventional concrete (CC), was prepared as reference mix. High performance concrete using conventional materials and fly ash (HPC) was also prepared for a detailed study. Steel slag was obtained in the form of boulders. Steel slag aggregate was prepared by crushing the boulders and sorting it via sieves into two groups. Fraction1-passing through 20 mm and retained on 10 mm **(F1)**, and fraction 2-passing through 10 mm and retained on 4.75 m **(F2)**. The steel slag aggregate was found to be angular and having rough surface as shown in Fig. 1. This feature provides an excellent bond with cement paste matrix. From literature, it was observed that steel slag must be allowed to aging, before it is used as aggregates. Hence, SSA were subjected to air aging in stock piles and used as coarse aggregate after every 6 months to produce high performance concrete mixes (HPC1, HPC2, HPC3, HPC4, HPC5, HPC6, and HPC7). There are several methods of aging to reduce the expansibility of steel slag aggregate, namely air aging, hot water aging and steam aging[16]. Here, air aging (left out in the open for weathering in air) method was applied, which is easier and cost effective. Physical and mechanical properties of aggregates were determined according to IS2386-1963[17] and found to confirm with IS 383-1970[18]. To investigate the effect of aging period of steel slag, concrete containing steel slag aggregates (HPC1 to HPC7) after different aging periods (6, 12, 18, 24, 30, 36 and 42 months) were investigated.

Mixing proportion

The absolute volume method was used in the calculation of concrete mixtures to obtain denser concrete. The mix design was carried out as per ACI211.4R-93[19] to obtain M60 grade concrete. After extensive trials, water cement ratio and the cement concrete were determined as 0.32 and 584 Kg/m^3, respectively. Unlike CC, the main feature of HPC is the inclusion of chemical and mineral admixtures. In this work, sulphonated naphthalene based super plasticizer (Conplast SP 430) was used as chemical admixture and Class F fly ash was used as mineral admixture at 2% and 25% of weight of cement, respectively as per the guidelines given in ACI 211.4R-93[19] and IS 456-2000[20]. Mix proportions for various mixtures are given in Table 3.

Table 3: Mix proportions for various mixes

Mix	w/c	Materials (kg/m^3)									Aging period of SSA (months)
		C	FA	RS	HBG		SSA		Water	SP	
					F 1	F2	F 1	F2			
CC	0.32	584	-	596	687	458	-	-	187	11.7	-
HPC	0.32	438	146	596	687	458	-	-	187	11.7	-
HPC1	0.32	438	146	596	-	-	716	478	187	11.7	6
HPC2	0.32	438	146	596	-	-	716	478	187	11.7	12
HPC3	0.32	438	146	596	-	-	716	478	187	11.7	18
HPC4	0.32	438	146	596	-	-	716	478	187	11.7	24
HPC5	0.32	438	146	596	-	-	716	478	187	11.7	30
HPC6	0.32	438	146	596	-	-	716	478	187	11.7	36
HPC7	0.32	438	146	596	-	-	716	478	187	11.7	42

The weighed ingredients for the batch were mixed in a tilting drum type concrete mixer. Workability (slump test) of concrete mixes produced was determined according to IS1199-1959[21]. The specimens were cast in steel moulds and compacted thoroughly. After about 24 hr after casting, specimens were demoulded and placed immediately in a water tank for curing.

Durability tests

The methods of durability tests such as water absorption, acid resistance and rapid chloride permeability are explained in this section. The water absorption of concrete mixes was determined on 150 mm cube specimen at the age of 28 days curing as per ASTM C642[22]. Acid resistance of concrete was determined in terms of weight loss and residual compressive strength. For this test, concrete cubes of size 150 mm x 150 mm x 150 mm were cast and stored in a place at a temperature of 27°C for 24 hrs and then the specimens were water cured for 28 days. After 28 days curing, the specimens were taken out and allowed to dry for one day. Initial weights of the cubes were taken. For acid attack test, 5% of dilute sulphuric acid (H_2SO_4) by volume of the water with pH value of about two was used (Fig. 2). After taking initial weights, the cubes were immersed in the above said acid water for a period of 28 days (Fig. 3). After immersion in the above said acid water, the weight loss and residual compressive strength of the cubes are determined. Rapid chloride permeability test (RCPT) was carried out as per ASTM C1202[23]. Test setup is shown in Fig. 4. Concrete disc specimens of size 100 mm diameter and 50 mm thick were cast for various HPC mixes. After 24 hrs, the disc specimens were removed from the mould and subjected to curing for 90 days. After curing, the specimens were tested for chloride permeability. All the specimens were dried free of moisture before testing. A batch of specimens is shown in Fig. 5. Disk specimen is assembled between the two compartments cell assembly and checked for air and water tight. The cathode compartment is filled with 3% NaCl solution and anode compartment is filled with 0.3 normality NaOH solutions.

Table 4: Rapid chloride permeability of concrete as per ASTM C1202

Charge passed (Coulombs)	Chloride ion permeability
> 4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
< 100	Negligible

Then, the concrete specimens were subjected to RCPT by impressing a 60V from a DC power source between anode and cathode. Current was recorded over a period of 6 hrs at an interval of 30 min. Based on the results of this test, chloride permeability of concrete can be classified as high/low/moderate/very low as shown in Table 4. For all the durability tests, three specimens were cast and tested for each mix and average value is taken for the study.

RESULTS AND DISCUSSION

Workability

The results of slump test are shown in Table 5. As it can be seen in the Table 5, the workability of all HPC mixes is higher than that of CC, because of addition of fly ash and super plasticizer. The spherical shape of fly ash particles and their lesser grain sizes have beneficial effect on workability. But the workability of HPC mixes containing SSA decreased with increasing aging period of SSA. As the aging period increases, hardness and surface roughness of SSA were increased due to weathering and resulting harsh mix with reduced workability. Dosage of super plasticizer may be increased to increase the workability. But in this work, it was kept constant for better comparison.

Table 5: Results of slump test

Mix	CC	HPC	HPC 1	HPC 2	HPC 3	HPC 4	HPC 5	HPC 6	HPC 7
Slump (mm)	20	95	89	75	68	62	58	55	52

Water absorption

The results of water absorption test of concrete mixes are given in Table 6. The water absorption of HPC is 21% less than that of CC. The water absorption of HPC1, HPC2 and HPC3 are 49%, 39% and 18% more than that of CC. But water absorption of HPC4, HPC5, HPC6 and HPC7 are 2%, 16%, 22% and 29% less than that of CC.

Acid resistance

The results of acid resistance test of concrete mixes are given in Table 7. Acid resistance of concrete mixes are measured in terms of residual compressive strength. A batch of specimens after acid resistance test is shown in Fig. 6. Residual compressive strength of CC and HPC are found to be 52.67 MPa and 53.67 MPa, respectively. It was expected that increase in aging period of SSA will increase the acid resistance of concrete (residual compressive strength). Residual compressive strength of HPC mixes with SSA and fly ash ranged between 25.86 MPa and 59.48 MPa. It was observed that residual compressive strength increases as the aging period of SSA was increased. Highest residual compressive strength was achieved in mix HPC7 (after 42 months of aging of SSA), which is 13% more than that of CC. It is also observed that residual compressive strength of HPC mix attains the result at par with CC, when the SSA are used in concrete after 30 months of aging period (HPC5).

Table 6: Water absorption test results

Mix	Wet weight (Kg)	Dry weight (Kg)	Saturated water absorption (%)
CC	8.50	8.20	3.66
HPC	8.53	8.29	2.90
HPC1	8.70	8.25	5.45
HPC2	8.70	8.28	5.07
HPC3	8.69	8.33	4.32
HPC4	8.68	8.38	3.58
HPC5	8.67	8.41	3.09
HPC6	8.67	8.43	2.85
HPC7	8.66	8.44	2.61

Table 7: Acid resistance test results

Mix	Weight before immersion (Kg)	Weight after immersion (Kg)	Weight loss (%)	Residual compressive strength (MPa)
CC	8.32	7.99	3.97	52.67
HPC	8.29	8.01	3.38	53.67
HPC1	8.36	8.02	4.07	25.86
HPC2	8.40	8.07	3.93	27.52
HPC3	8.45	8.14	3.67	31.75
HPC4	8.49	8.19	3.53	39.63
HPC5	8.53	8.25	3.28	54.70
HPC6	8.55	8.28	3.16	57.83
HPC7	8.59	8.33	3.03	59.48

Fig. 1: Steel slag aggregates

Fig. 2: Sulphuric acid

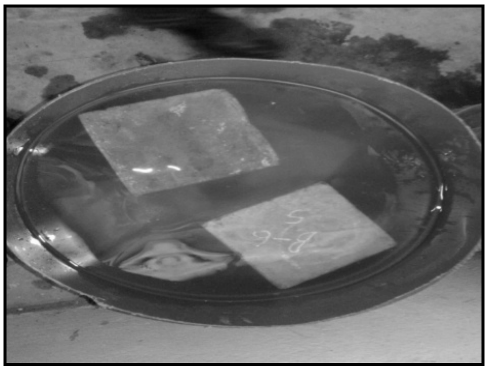

Fig. 3: Acid resistance test

Fig. 4: RCPT test assembly

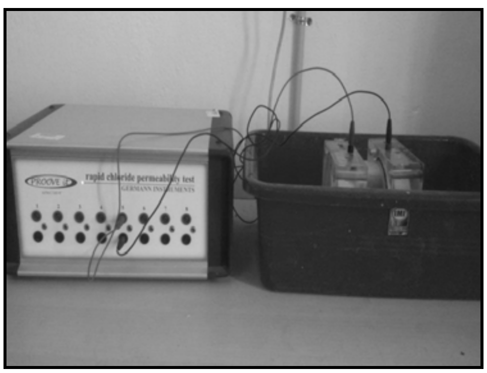

Fig. 5: Specimens for RCPT test

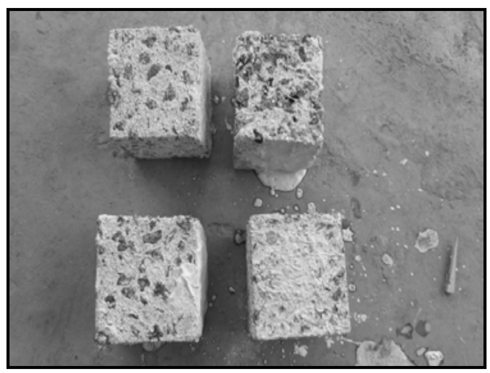

Fig. 6: Specimens after acid resistance test

Rapid chloride permeability

The rapid chloride permeability test results of concrete mixes are given Table 8. From this table, it is clear that HPC6 and HPC7 showed high resistance against chloride ion penetration, which is 35% and 41% less penetration than that of CC. These concrete mixes are classified as "very low" category of chloride ion penetration as per ASTM C1202.

Table 8: Rapid chloride permeability test results

Mix	Charge passed	Chloride permeability	Relative charge passed (%)
CC	1414	Low	100
HPC	1286	Low	91
HPC1	2642	Moderate	187
HPC2	2289	Moderate	162
HPC3	1810	Low	128
HPC4	1458	Low	103
HPC5	1124	Low	79
HPC6	915	Very low	65
HPC7	840	Very low	59

CONCLUSION

From the results of present study, the following conclusions can be drawn.

(i) Steel slag aggregates have physical and mechanical properties similar to that of natural coarse aggregates. Hence, they can be utilized as alternative to natural coarse aggregates in concrete production.

(ii) Workability of concrete decreases with increase in the aging period of steel slag aggregates. Dosage of super plasticizer may be increased to increase the workability. But in this work, it was kept constant for better comparison.

(iii) The aging process of steel slag affects the durability properties of concrete made with steel slag as coarse aggregate. Increase in aging period of steel slag aggregate, reduces the water absorption of concrete. Increase in aging period of steel slag aggregate, increases the acid resistance of concrete. Increase in aging period of steel slag aggregate, reduces the chloride permeability of concrete.

(iv) A minimum of 30 to 36 months aging of steel slag is required to achieve durability properties of HPC (made with steel slag aggregates) at par with conventional concrete.

(v) It can be concluded that, after sufficient aging, the steel slag can be used as concrete aggregate along with chemical and mineral admixtures, to produce a higher quality concrete.

(vi) The use of steel slag aggregate, can solve problem of lack of aggregate in various construction sites and reduce environmental problems related to aggregate mining and waste disposal. The use of steel slag aggregate can also reduce the cost of the concrete production.

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Accepted : 09.05.2016