Chloride Permeability and Abrasion Resistance of Self-Compacting Concrete Incorporating Iron slag

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Abstract

The dumping of industrialized by-products is a primary burden because of ironclad environmental rules. Adoption of industrial by-products as an alternative fine aggregate in the concrete is the only quick fix. This study shows the exchange of iron slag with fine aggregate (sand) in self-compacting concrete (SCC). Percentages of iron slag 0, 15, 30 and 45 were incorporated. Rice husk ash (15%) was used to prepare control mix in addition with cement. Experimental tests were conducted to check the fresh properties, strength and durability properties of SCC with iron slag. Tests were conducted for slump flow, V-funnel, U-box, L-box, compressive strength, rapid chloride permeability and abrasion resistance. The test finding (up to 90 days) of compressive strength and chloride ion permeability indicate that iron slag can be suitable used in making SCC. SCC mixes containing up to 45% iron slag gave lower permeability values than control SCC mix. The results of compressive strength of SCC are significantly better than control SCC.

Keywords: Compressive strength, Chloride permeability, Abrasion, Iron Slag.

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1. Introduction

The evolution of self-compacting concrete is treated as a landmark effort in concrete technology due to a lot improvement. In order to be self-compactable, the raw concrete must develop high fluidity besides good cohesiveness [1]. In normal practices, concrete is compacted by internal shakings to remove the entrapped air, thus making it impenetrable and consistent; Compaction is the key to producing useful concrete with optimum strength and durability [2]. By reason of the increasing reinforcement quantity with smaller steel bars and a shortage in proficient construction workers, appropriate compaction was difficult work, leading to poor compaction and condition of concrete [3]. Change to concrete will have a large impact in the construction and building sector. As the heed is drawn close to energy-efficient and zero emission buildings of concrete will be imperative [4]. Zero emission building are only possible with the use of industrial by-products and waste in concrete by reducing the carbon emission and to save the natural resource from depletion due to increased consumption of concrete.

It is conspicuous that the level of each year aggregate production has a serious impact on the surroundings. It is our obligation to reduce the usage of natural mineral resources and to escalate the use of alternate materials [5]. These matters can be cleared up by using SCMs (Supplementary Cementitious Materials) that are by-products of industrial [6-7]. Resultantly, auxiliary materials are being explored such as industrial by-products. The use of industrial by products is a crucial component in the economics of many trades. Concrete could be a viable solution to environmental problems since it is also possible to re-use solid by-products from other industries for concrete production [8].

There are several categories of industrial by-products that adopted as fine aggregates in concrete. One similar by-product is iron slag (IS). Iron slag is non-metallic output dwell substantially of silicates and alumino-silicates of calcium and other bases that is "produced in a liquefied condition simultaneously with iron in a blast furnace." It is a man-made liquefied rock, analogous in several respects to volcanic lavas. There are lots of disparate types of iron slag, some were made by smelting, others by smithing; few are

large, few so miniature they are unseen to the bare eye when in the soil, some are magnetic, others not. The compressive strength of self-compacting concrete (SCC) produced with 20% of eggshell powder (ESP) and granulated ground blast furnace slag (GGBFS) as exchange with cement is higher than control mix [9]. Waste Copper Slag was used in disparate percentages (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%) as a natural coarse aggregate replacement in SCC, incorporating 100% WCS as coarse aggregates in SCCs jumped 27%, 29%, and 26% growth in compressive, split, and flexural strengths in 28 days, respectively [10]. Utilization of by-product Ferro Nickel Slag (FNS) will also lessen the risk of environmental pollution. Outcome depicts that concrete having up to 40% FNS fine aggregate met all the necessary criteria of EFNARC for SCC without any segregation in the flow and J-ring tests, and no stopage in the L-box and V-funnel tests [11]. The test result shows that SCC incorporating 40% iron slag replaces with fine aggregates gives better strength and durability than control mixture of SCC [12]. Steel Slag Powder enhanced filling capability and passing capability of SCC, however, adversely affected the segregation resistance. It was found that 10% replacement ratio of Steel slag powder to ordinary Portland cement (OPC) in SCC showed superior mechanical properties and higher durability performance in resisting chloride penetration and carbonation[13]. The use of ladle furnace slag improved fresh concrete properties and as well as compressive
Strength of SCC [14]. At initial stages the compressive strength of SCC with granulated blast furnace slag as fine aggregates is same to the SCC with fine aggregates, but at 90 and 365 days, the strength is better than normal SCC [15]. The response of oxidizing and reducing slag obtained from stainless steel making as sand on the concrete properties. Study found all engineering properties were comparable with control mix and it could cut the cost up to 43% with 100% exchange of stainless-steel oxidizing slag as coarse aggregates and 30% part of stainless-steel reducing slag exchange to Portland cement in SCC [16].
Goal of this experimental work was to make sustainable SCC with iron slag and examine the fresh SCC properties (L-box, U-box, Slump flow, V-funnel), compressive strength, and durability properties such as rapid chloride permeability, and abrasion resistance of self-compacting concrete made from iron slag.

2. Experimental Details

2.1 Material Used

Cement
Ordinary Portland cement 43 grade conforming to BIS: 8112-1989[17]

Fine aggregates & Coarse aggregates
River sand was used as fine aggregates. They were chapar kandi, Punjab, near Ghaggar River.

Iron slag
Collected from Dhiman iron and steel rolling mills, Mandi-Gobindgarh, Fatehgarh Sahib, Punjab India.

Admixture
Auramix-400 low viscosity high performance super-plasticizer based on polycarboxylic technology is used.

Table: 1 Physical properties material used.

Ordinary Portland cement	Results	Physical Properties	Fine Aggregates	Coarse Aggregates	Iron Slag	Rice husk Ash
Colour	Grey	Color	Light Brown	Grey	Black	Carbon black
Specific Gravity	2.98	Specific Gravity	2.61	2.74	2.68	3.16
Specific Surface area, m^2/kg	728.9	Water absorption (%)	0.52	0.21	.18	
Initial setting time, min	129	Fineness Modulus	5.97	2.65	2.32	-
Final setting time, min	263	Compacted bulk density(g/cc)	1.89	1.57	1.51	-
3-day compressive strength	23.41	Percentage voids after compaction	29.33	42.71	45.17	-
7-day compressive strength	27.27	Loose bulk density(g/cc)	1.74	1.31	1.54	-
28-day compressive strength	42.17	Percentage voids at loose condition	33.72	51.73	49.17	-

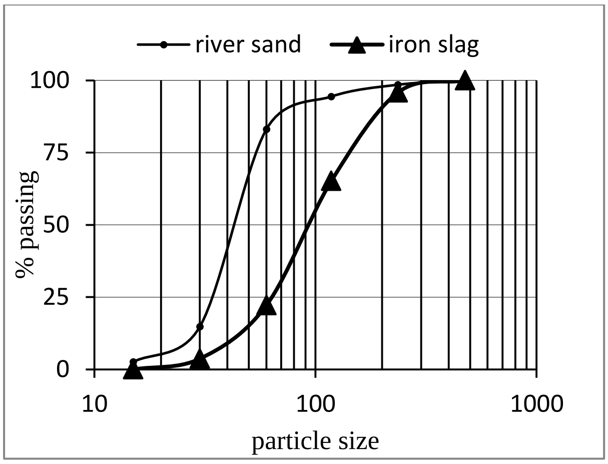

Fig: 1 Grading of river sand and iron slag of iron slag.

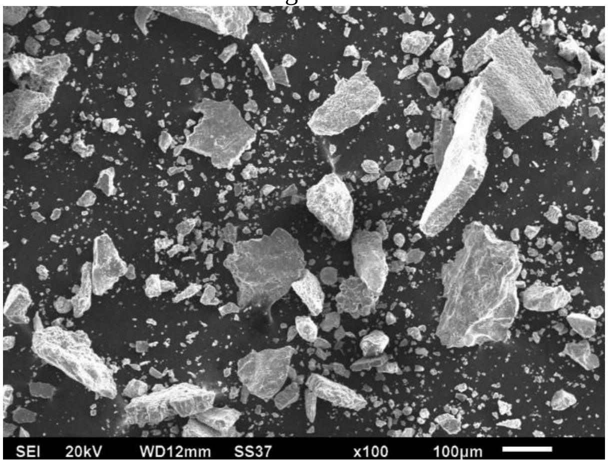

Fig: 2 SEM Image of Iron Slag

Table: 2 Mixture proportion of SCC.

Mixture	Cement (kg/m³)	Husk Ash (kg/m³)	W/P ratio	Sand (kg/m³)	IS (kg/m³)	IS (%)	CA (kg/m³)	Admixture (%)
C-SCC	440	66	0.45	950 0	0	0	780	1.1
15-SCC	440	66	0.45	807	143	15	780	1.1
30-SCC	440	66	0.45	665	285	30	780	1.1
45-SCC	440	66	0.45	576	522	45	780	1.1

(15, 30, 45 are the percentage replacement of iron slag with river sand), C- control mix, CA-coarse aggregates, IS-Iron Slag)

2.2 Mixture Proportions

The Blend weight of SCC was chosen on the ground of trials. Table 2 shows blended proportion ratios. Control-SCC was designed to attain 30 MPa compressive strength at 28-day. Then fine aggregates was exchanged with sand by 15, 30 and 45% of iron slag. Control-SCC mixture was designated as "C-SCC", and SCC mixtures with 15, 30 and 45% iron slag were labelled as 15-SCC, 30-SCC and 45-SCC respectively. All mixes also incorporate 15% of rice husk ash by weight of cement and 1.1% of super plasticizer was poured by weight of cement.

2.3 Test Attempt Methods

Raw SCC were investigated as per the instruction of EFNARC [18]. Compressive strength test executed on 150 mm size cube, up to the age of 91 days as per BIS: 516-1959 [19]. Rapid chloride permeability tests were done on circular specimen of diameter 100mm and 50mm length up to 91 days of curing period as per ASTM C 1202-10[20]. Abrasion resistance of concrete evaluated according to procedure mentioned in BIS: 1237-2012 [21].

3. Result and discussion

3.1 Fresh Concrete Properties

SCC was verified for fresh concrete properties. The water-powder ratio was 0.44 and admixture was 1.1% by mass of powder. Slump flow, L-box, U-box and V-funnel results shows that exchange of iron slag as fine aggregates meets the need of SCC as per EFNARC. But, the results of

Slump flow, L-box declined and the values of U-box, V-funnel jumps with the increase of iron slag percentage. The results findings of fresh properties of SCC are mentioned in Table 3.

Table: 3 Fresh Properties of SCC mixes

Mix ID	Slump Flow (mm)	Average Slump flow (mm)	L-box ratio (H2/H1)	Average L-box ratio (H2/H1)	U-box (H2-H1) in mm	Average U-box (H2-H1) in mm	V-funnel time (Sec.)	V-funnel time (sec.)
C-SCC	774	794	0.92	0.90	32	31	10	10.5
C-SCC	790		0.91		30		11	
C-SCC	810		0.90		31		11	
C-SCC	800		0.88		31		10	
15-SCC	733	734	0.87	0.87	31	32.25	11	10.75
15-SCC	745		0.89		32		10	
15-SCC	735		0.88		33		12	
15-SCC	720		0.86		33		10	
30-SCC	723	708	0.86	0.86	35	34	11	11.5
30-SCC	720		0.87		32		12	
30-SCC	700		0.86		34		12	
30-SCC	690		0.85		35		11	
45-SCC	687	674	0.81	0.82	36	34.75	13	12.5
45-SCC	677		0.84		35		12	
45-SCC	670		0.82		34		12	
45-SCC	665		0.83		34		13	

3.2 Compressive Strength

Fig.3 depicts that exchange of fine aggregates gives better strength at any time-stage of testing. Compressive strength at 7 days of mixtures formed with 15, 30 and 45% of iron slag gained 7, 9 and 20% respectively more compressive strength in comparison with normal SCC (without iron slag). At the age of 28 days, mixtures with 15, 30 and 45% iron slag as fine aggregates gained 6, 12% and 21% respectively more compressive strength as compared to 28 days SCC mixture without iron slag. At the curing period of 91 days, mixtures incorporating 15, 30 and 45% iron slag as fine aggregates gained 11, 14 and 25% respectively more compressive strength in comparison with 91days C-SCC mix. Providing better compressive strength to the mix by iron slag is due to the presence of silica that forms calcium silicates and aluminates hydrates after reacting with calcium hydroxide, which pack the pores and dense the microstructure of the matrix.

Gupta and Siddique reported that compressive strength of self-compacting concrete increased as the content of copper slag escalated. Sheen et al. [16] mentioned compressive strength of mix declines after the replacement ratio of stainless steel oxidizing slag aggregates decreases.

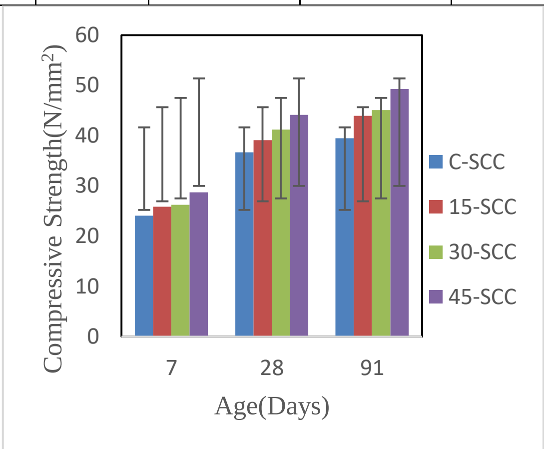

Fig: 3 Effect of iron slag on compressive strength

3.3 Rapid chloride permeability test

Fig.4. shows insignificant reduction in permeability at all replacement of sand with iron slag and presents that significant permeability decline with passage of time at all replacement levels. It shows the result figure of 7 days are 1598, 1510, 1461and 1390 coulombs at 0, 15, 30 and 45% replacements of sand with iron slag and the result figure at 28 days are 1297, 1230, 1190 and 1100 coulombs at 0, 15, 30 and 45% replacements of sand with iron slag. Furthermore at 91 days the result values are 1104, 1068, 1035 and 1015 coulombs at 0, 15, 30 and 45% replacements of sand with iron slag.

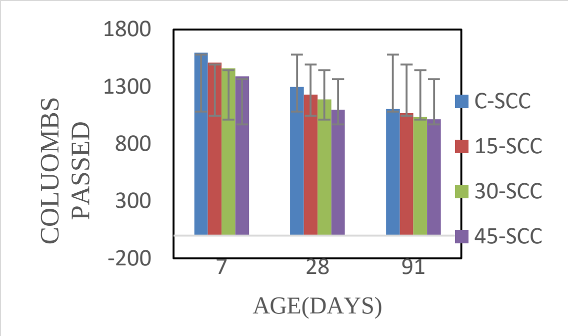

Fig: 4 Chloride ion penetration of SCC verses age

3.4 Abrasion Resistance

The test results of wear depth of iron slag SCC and control SCC are shown in Figs5-7. Test results show that average depth of wear increased with increase in abrasion time. A research finding indicates that average depth of control SCC mix was higher than SCC with varying iron slag percentages. As iron slag content increased, the depth of wear decreased and also the depth of wear decreased with increase of age. The continued matrix densification of SCC matrix with increasing age may be a possible cause of decrease in average depth. At 7 days, the average depth of wear with 15, 30 and 45% iron slag for 15 minutes of wear time was 3.35, 5.71 and 12.26%, respectively, lower than the control SCC (0.648 mm average depth of wear). At 28 days, average depth of wear was 1.1, 10.00 and 14%, respectively, lower than that of control SCC (0.53 mm average depth of wear). At 91 days, average depth of wear of SCC mixes with iron slag was 2, 8.16 and 12.61%, respectively, lower than the control SCC (0.50 mm average wear of depth of control SCC).

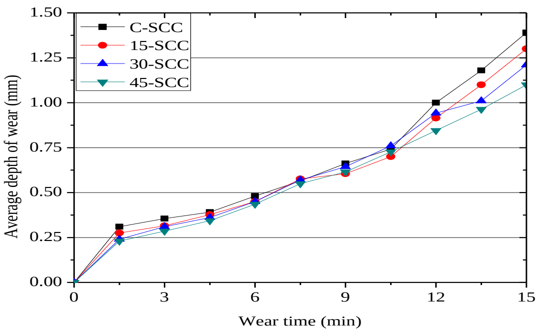

Fig: 5 Variation in depth of wear with iron slag content in SCC at 7 days of curing age

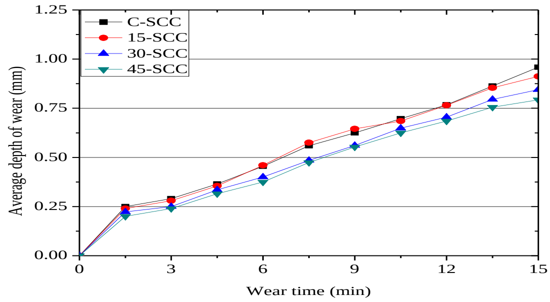

Fig: 6 Variation in depth of wear with iron slag content in SCC at 28 days of curing age

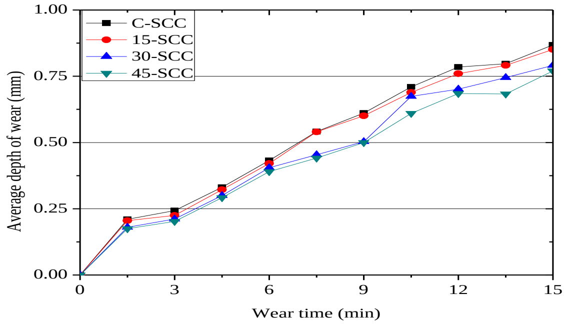

Fig: 7 Variation in depth of wear with iron slag content in SCC at 91 days of curing age4.

4. Relation between Compressive Strength and Chloride Permeability

Fig. 8 shows that the rapport between compressive strength and cumulative charge passed of iron slag concrete mixes. The equation presenting the relationship tween compressive strength σ and cumulative charge passed C, with the coefficient of R^2 given below.

σ= -22.50C+ 2081.8 R^2 =0.950 (Present research)

Where, σ = compressive strength in MPa, C= total charge passed (coulombs)

Coefficient of R^2 gives good relation tween data points and curve.

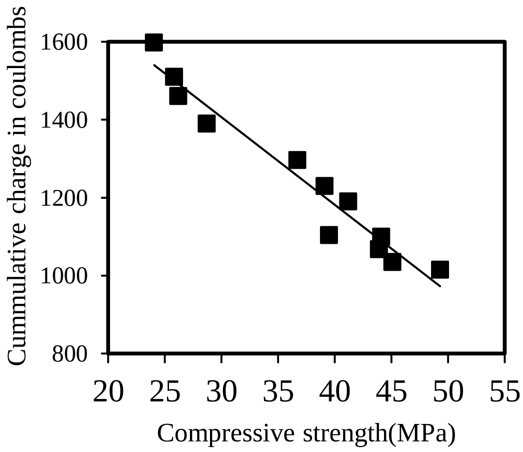

Fig: 8 Relation between compressive strength and Chloride permeability of SCC

5. Relation of Compressive Strength and Abrasion Resistance

Fig 9 depicts interrelationship of abrasion resistance and compressive strength for total value up to 91 days. findings shows that abrasion resistance of SCC jumps with an increase of compressive strength and relationship between them can be worked good with perfect logarithmic formula as shown in equation and evidence by a good coefficient of determination (R^2=0.938)

$$d = -0.255 \, Ln(F_t) + 1.433, \quad R^2 = 0.938 \text{ for 15 min abrasion (Present research)}$$

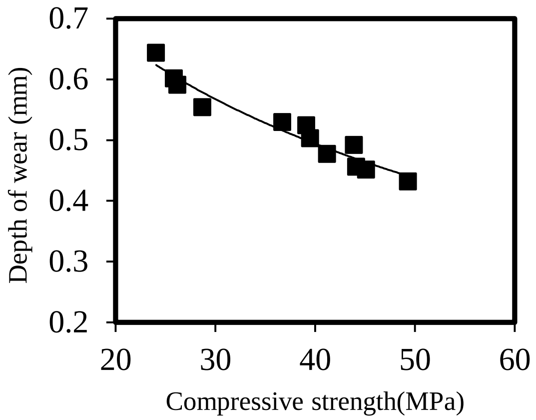

Fig: 9 Relation between compressive strength and depth of wear of SCC

6. Conclusions

- Slump flow, L-box and U-box values declines with jump in iron slag percentage whereas there is increase in V-funnel time. Workability of SCC decreases by reason of increase iron slag percentage cause may be multi-angle and harsh in exteriors of iron slag aggregates. Increases friction between particles may factor for the results.
- Compressive strength of SCC mixtures increase with iron slag addition, and also with age. At 91 days, strength increases by 25% over control SCC.
- Iron slag SCC mixture have good resistance to chloride ion penetration. The cumulative charge passed through iron slag mixes was lesser than that passed through SCC mixture without iron slag.
- SCC mixtures with iron slag demonstrated higher abrasion resistance than control SCC mixture. Average wear depth of all SCC mixtures was much lesser than 2mm for 7.5 minutes of wear time specified in BIS: 1237-2012 for heavy duty tiles.
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