Partial Replacement of Steel Slag Aggregates in Concrete as Fine Aggregates (Induction Blast Furnace Slag)

S. Arjun, T. Hemalatha and C. Rajasekaran

Abstract In this study, an attempt has been made to investigate the effect of partial replacement of conventional river sand with steel slag aggregate. The replacement of river sand by slag aggregate provides dual advantage of reducing disposal problems in steel industries and conserving the natural resources. In this study, slag aggregate originated from induction blast furnace has been used. The physical and chemical properties of slag aggregate evidenced the feasibility of using this material as a substitute for river sand. Total of three mixes made with Ordinary Portland Cement (OPC), cement replaced with fly ash and river sand replaced with slag aggregate have been considered for this study. The mix is designed for M40 grade. First mix (Control mix ${}_0M^0$) made of OPC as a binder and 100% river sand, second mix (${}_0M^{50}$) made of OPC and 50% slag aggregate and third mix (${}_{25}M^{50}$) made of 25% OPC replaced by fly ash and 50% river sand replaced by slag aggregate. Mechanical and durability properties of all the three concretes are studied. It is found that the strength results of ${}_0M^0$ and ${}_0M^{50}$ are comparable indicating the suitability of using slag aggregate as an alternative for river sand. However, the third mix with fly ash replacement in binder showed reduced strength in comparison with control concrete. Hence, it is concluded that when slag aggregate is used as a partial replacement for river sand (50%), it is advisable to use OPC than the Pozzolanic Portland Cement (PPC).

Keywords Steel slag aggregates · River sand · Strength · Durability

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1 Introduction

For so many years, river sand is being used as fine aggregates in the making of concrete in the construction industry. Nowadays, due to an increasing demand for river sand, and the rising issues related to the mining of the same, several construction projects are getting a hit in their timely completion and in an economic aspect as well. According to an assessment report of United Nations Environment Programme (UNEP), sand and gravel held a major share of worldwide non-metallic extraction in 2010. It was 40.8% of gravel and 31.1% of sand and, concrete for the buildings was reported as the largest consumer of these mined sand and gravel by sector [1]. Due to excessive mining and exploitation of the river beds, sand which is now available is very coarse and have a high percentage of silt and clay contents. When silt content is more than 5% in the sand and the same when used for the concreting, there appears to be a higher chloride ion permeability in the Rapid Chloride Ion Penetration Test (RCPT) thus questioning the durability of the concrete [2]. The silt content and degrading quality of river sand have forced the construction industry to look for an alternative. One of many issues in the construction industry is the lack of availability of river sand for the concrete and plastering work. Hence, this study is focused on addressing this particular issue by finding out a potential solution for the same.

M sand being the current alternative to the river sand, is again a product of nature. With the growing ideology of conservation of natural resources and future sustainability at stake, M sand may soon get a thumbs down.

Presently, with the development of iron and steel industries in terms of production, there is a lot of waste that is being generated in the form of slag which is reported to be dumped at landfills without any effective usage. This is becoming a serious threat to the environment in the sense of ecological destruction and environmental pollution that needs to be resolved. Globally, researchers are focused on the utilization of waste materials and by-products from industries as a partial or total replacement for the conventional concrete constituents. Usage of such by-products and waste materials in concrete may have negative or positive impacts on them. In steel manufacturing, 150–200 kg of slag is generated per tonne of liquid of steel and the steel slag output is 20–30% by mass of crude steel output in India [3].

This method of usage of waste materials from the industries into the construction practices can solve the problems arising due to lack of aggregates at the construction site and at the same time, reduce the environmental issues related to waste disposal and mining, for the need of aggregates [4].

1.1 Steel Slag (from Induction Blast Furnaces)

The chemical composition of steel slag will vary depending upon the method of steelmaking and the furnaces used. Studies are on, to use the steel slag as coarse and/or fine aggregates for the concrete after grounding it to the requisite size. Steel slag aggregates contain a significant percentage of free iron, which will give the composite a high density and improved hardness and thus make it suitable to use in the construction industry, especially as an artificial source of aggregates in road construction [5]. More extensive studies are being done for a broad application of steel slag aggregates in the construction field and it has been reported that usage of steel slag aggregates as partial or complete replacement for blue metal (CA), the compressive strength, flexural strength and split-tensile strength are seen improving more than what the samples with normal aggregates give [6–9].

Steel slag aggregates possess a greater value of specific gravity and hence the resulting concrete as well. Water penetration depth in the durability test conducted, slag aggregate concrete had lesser water penetration depth than the conventional control concrete mix, which is due to the impervious nature of steel slag aggregates [10].

With the past several researches and papers published across the world, it was evident that slag's chemical composition varies with different source and the type of furnace used. A lot of studies had been done with Electric Arc Furnace (EAF) slag aggregates as a whole/part of concrete's fine aggregate and in this study, Induction blast Furnace slag has been used as a partial replacement for the river sand (fine aggregate).

Typical chemical composition of the received steel slag is given in Table 2.

2 Materials

2.1 Cement

Ordinary Portland Cement (OPC) of Grade 53 from the same manufacturer was used in the study. The specific gravity was found to be 3.10 and the Initial Setting Time (IST) and Final Setting Time (FST) were 35 and 310 min respectively. The chemical composition of the cement is given in Table 2.

2.2 Aggregates

The river sand and the coarse aggregates (CA) were sourced from a local dealer. The CA was the blue metal of size 12 mm and down while river sand was sieved under IS 2.5 mm sieve and was then used for the experiments. They were stored in lab conditions prior to the casting. The specific gravity of river sand and CA were 2.73 and 2.63, respectively. By sieve analysis, it was found that the river sand belonged to Zone II and FM was 3.12.

Table 1 Physical properties of fine aggregates

	Slag aggregates	River sand
Specific gravity	3.23	2.73
Water absorption	6.08%	1.69%
Sieve analysis	Zone 2 FM[a] = 2.80	Zone 2 FM = 3.21

[a]FM—fineness modulus

Physical properties of the received steel slag aggregates and river sand are presented in Table 1.

2.3 Fly Ash

Class F fly ash was used in the third mix of the study in which cement was replaced by 25% fly ash. Its specific gravity was 2.21. The chemical composition of the fly ash is given in Table 2.

3 Experimental Study

3.1 Mix Design

A general control mix was designed as per IS 10262: 2009 (Concrete Mix Proportioning—Guidelines). Based on this control mix, 2 other mixes were designed by taking 0% fly ash and 50% slag (of fine aggregates weight) aggregates and 25% fly ash (of cement weight) and 50% slag aggregates. The details of the mix proportion are given in Table 3.

Table 2 Chemical composition of materials (in %)

Compound	OPC	Fly ash	Steel slag
CaO	64.1	1.10	3.140
SiO_2	21.0	53.85	65.50
Al_2O_3	5.1	22.90	8.430
Fe_2O_3	3.1	4.296	14.82
MgO	2.5	0.341	0.723
SO_3	2.2	0.452	0.351
K_2O	0.7	1.07	0.325
Na_2O	0.3	0.080	1.25
MnO	–	–	3.886
Chlorides	0.03	–	–
Insolubles	0.3	2.00	–
Loss on ignition	0.6	4.35	–
Free lime	0.8	–	–

Table 3 Mix details in kg/m^3

	$_{0}M^{0}$ (control mix)	$_{0}M^{50}$	$_{25}M^{50}$
Cement	380	380	285
Fly ash	0	0	95
River sand	960	480	480
Slag aggregates	0	480	480
Coarse aggregates	860	860	860
Water	210	210	210

3.2 Sample Preparation

Concrete specimens of cube, cylinder and prism were cast for carrying out mechanical testing. The geometry of the specimen, its size and numbers (per mix) are presented in Table 4.

Moulds were cleaned and greased prior to the casting. Materials were batched and the casting was done. A similar mixing protocol was followed for all the mixes.

4 Results and Discussion

4.1 Fresh Property Results

For each and every mix, prior to casting, slump tests was carried out. Soon after the completion of concrete mixing, the fresh mix was taken and poured into the slump cone. Typical slump height measurement is shown in Fig. 1.

It is noticed that the requirement of superplasticizer is high for mixes with the slag aggregates than compared with river sand mix as shown in Table 5. This is due to the fact that slag aggregate absorbs more water owing to the presence of dust particles. Water content was kept constant in all the mixes. The dosage of super-plasticizer and the resulting slump values of all the mixes are given in Table 5.

Table 4 Details of specimens

Specimen type	Tests to be carried out	Days of testing	Total number of specimens
100 mm cubes	Compression test	3d, 7d, 28d, 90d	12
100 × 100 × 500 prisms	Flexural strength test	28d, 90d	6
100 × 200 cylinders	Split-tensile test RCPT	28d, 90d 28d, 90d	6 2

Fig. 1 Typical slump test

4.2 Hardened Properties

The samples were tested for the compression strength, tensile strength, flexure strength and chloride penetration. The test procedures were carried out as per IS standards corresponding to the test, except for the Rapid Chloride Penetration Test which was done with respect to American standard.

4.2.1 Compressive Strength

100 mm cubes were subjected to compression and the peak load at which cubes fail is noted and the corresponding stress value is determined. The rate of loading was kept at 2.33 kN/s (constant throughout the study). Testing was carried out on 3d, 7d, 28d and 90d. Three cubes were tested on each day and the average was taken as the final value. The test results are given in Fig. 2.

4.2.2 Split-Tensile Strength

Split-tensile test was conducted on 28d and 90d where the concrete cylinders (100 mm diameter and 200 mm height) are tested for their tensile strength in an

Table 5 Fresh property results

Mix id	SP dosage (%)	Slump (mm)
${}_{0}M^{0}$	0.2	75
${}_{0}M^{50}$	0.8	65
${}_{25}M^{50}$	0.5	65

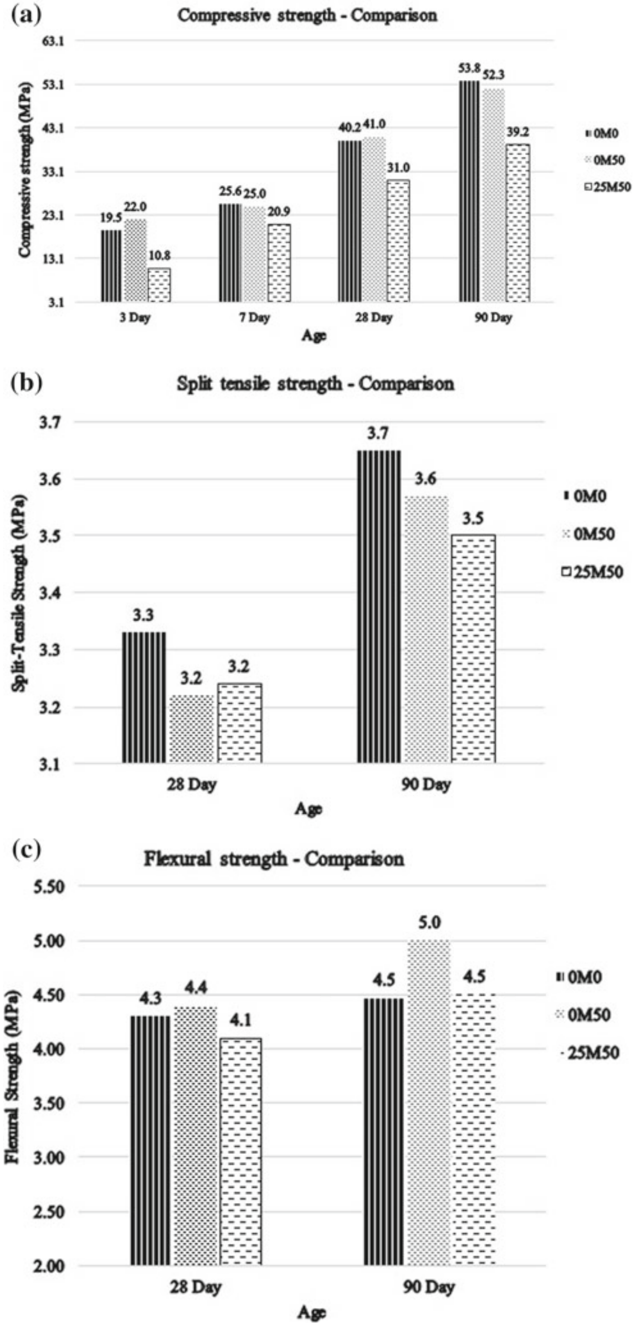

Fig. 2 Mechanical properties of three mixes **a** compressive strength **b** split-tensile strength **c** flexural strength

indirect manner. The rate of loading was kept at 1.2 kN/s, uniformly for all the specimens. The results are given in Fig. 2.

4.2.3 Flexural Strength

Flexural strength results are given in Fig. 2. The rate of loading was kept at 0.03 kN/s. The 100 × 100 × 500 prisms were subjected to 4 point loading during the test. Test was done as per IS 516:1959 (Method of tests for strength of concrete).

At all ages, the mixes made of OPC with river sand ($_{0}M^{0}$) and slag aggregate ($_{0}M^{50}$) showed almost similar strength. Whereas mix with fly ash ($_{25}M^{50}$) showed reduced strength low (around 10 MPa less than the other two mixes) from an early age to 28 days.

4.2.4 Rapid Chloride Penetration Test (RCPT)

RCPT was carried out on cylindrical slices cut from the specimens. The test was carried out as per ASTM C-1202. In this test, the total electric current passed through the 50 mm thick and 100 mm diameter cylinders over a 6 hour cycle was measured, when a constant voltage of 60 V (DC) is maintained across the ends. The cell is fitted at both the ends and one end forms the cathode, which is filled with NaCl solution (30 g NaCl dissolved in 1 liter distilled water) while the other end anode is filled with 0.3 N NaOH solution (12 g NaOH dissolved in 1 liter of distilled water). A typical RCPT setup in the laboratory is shown in Fig. 3.

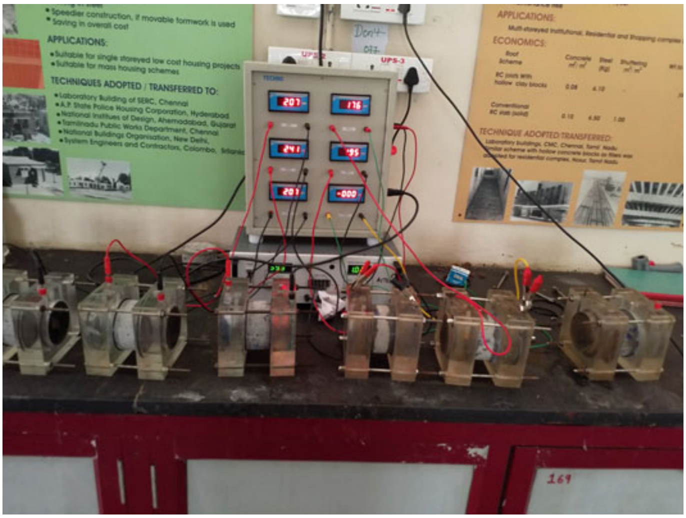

Fig. 3 RCPT setup

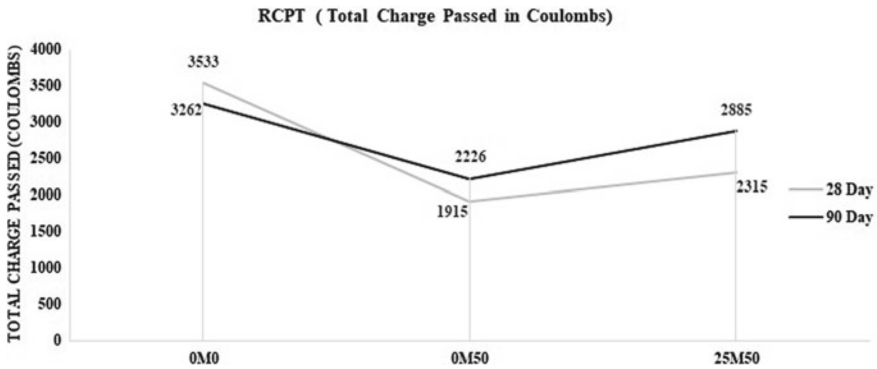

Fig. 4 Results of RCPT

Table 6 Chloride ion permeability based on charge passed

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

The RCPT results obtained are represented in Fig. 4. Across the mix, value changes considerably and the performance looks improved, with partial replacement of slag aggregates. As per ASTM C1202, the interpretation of the total charge passed to the permeability is given in Table 6.

The specimens of control mix $({}_0M^0)$ showed higher permeability compared to the other 2 mixes. Thus, it could be concluded that with steel slag aggregates the pore structure seems to get densified under same water–cement ratio.

5 Conclusion

An experimental investigation was carried out to investigate the performance of slag aggregate as a partial replacement for river sand. From the tests conducted, the following conclusions are drawn:

With 50% replacement of river sand with steel slag aggregates,

- compression strength, split-tensile strength and flexural strength were comparatively equal to that of the control mix.
- steel slag aggregates with PPC or fly ash substituted mix is a matter of question because of the relatively lower strength performance in this study.
- the pore structure seems to improve, as shown by the RCPT results.

It can be concluded that steel slag aggregates shall be used as a 50% replacement for river sand and get the same performance as of 100% river sand along with the added environmental benefits.

However, more study is required to understand the reason for reduced strength in mixes with fly ash replacement for cement.

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