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Assessment of concrete properties with iron slag as a fine aggregate replacement

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Abstract. In an effort to find alternate, environment friendly and sustainable building materials, the scope of possible utilization of iron slag (I-sand), generated as a by-product in iron and steel industries, as fine aggregates in reinforced cement concrete (RCC) made with manufactured sand (M-sand) is examined in this manuscript. Systematic investigations of the physical, mechanical, microstructural and durability properties of I-sand in comparison with RCC made with M-sand have been carried out on various mix designs prepared by the partial/full replacement of I-sand in M-sand. The experimental results clearly indicate the possibility of utilizing iron slag for preparing RCC in constructions without compromising on the property of concrete, durability and performance. This provides an alternate possibility for the effective utilization of industrial waste, which is normally disposed by delivering to landfills, in building materials which can reduce the adverse environmental effects caused by indiscriminate sand mining being carried out to meet the growing demands from construction industry and also provide an economically viable alternative by reducing the cost of concrete production.

Keywords: iron slag; manufactured sand; compressive strength; flexural strength; split-tensile strength; durability

1. Introduction

Ecological imbalance resulting from indiscriminate sand mining for constructions and effective industrial waste disposal are two major issues that demand immediate attention. Hence exploring more environment friendly and sustainable building materials as well as possible ways of recycling and reusing of industrial by-products are of paramount importance (Ouda *et al.* 2017, Prusty *et al.* 2015, Patra *et al.* 2016, Oner *et al.* 2007, Beixing *et al.* 2011). It needs to be noted that several studies have been previously conducted regarding the effective utilization of slag and sludge from steel industries. One such utility is the substitution of natural aggregates of conventional concrete with steel slag (Shailja *et al.* 2018, Ouda *et al.* 2017, Huang *et al.* 2012, Liu *et al.* 2011). Iron slag also proves to be a feasible sand replacement in self-compacting concrete mixtures in terms of filling ability, passing ability, viscosity, segregation and durability characteristics (Mantilla *et al.* 2019, Gurpreet *et al.* 2016, Huang *et al.* 2012, Raharjo *et al.* 2013).

Rising demand of construction sector and worldwide depletion in the availability of good quality river sand along with the environmental pressures to reduce extraction of sand from river beds have led to the usage of manufactured sand (M-sand) as a replacement to natural sand. M-sand is produced in quarries by crushing rocks, stones or larger aggregate pieces. Utilization of M-sand, in place of river sand, is advantageous in terms of having higher concrete strength, consistent gradation, absence of organic or silt materials, lesser probabilities of adulteration and cost effectiveness. But M-sand also comes with its own share of disadvantages especially in terms of workability and presence of micro-fine particles. Since the M-sand particles can be of coarser and angular texture, more water and cement may be required to achieve the expected workability. Also, during the crushing larger amounts of micro-fine particles may be produced which may affect the strength of concrete. Considering this into account, scientists and engineers have been working on the possibilities of utilizing industrial slag wastes as a partial or full replacement for M-sand as fine aggregates in reinforced cement concrete constructions. Since the aggregates typically account for about 70-80% of the concrete volume, the properties of aggregates play a substantial role in determining the concrete properties such as durability, strength and workability. Hence it is important

to understand the properties in detail before putting it to practical usage.

In this manuscript we discuss the possibilities of utilizing iron slag (I-sand), generated as a by-product in iron

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Table 1 Chemical composition of Portland cement used for present research work

Ingredients	CaO	SiO_2	Fe_2O_3	Al_2O_3	SO_3	MgO	K_2O	Na_2O	Loss on ignition
Concentration %	66.67	18.91	4.94	4.51	2.5	0.87	0.43	0.12	1.05

Table 2 Physical properties of Portland cement used for present research work

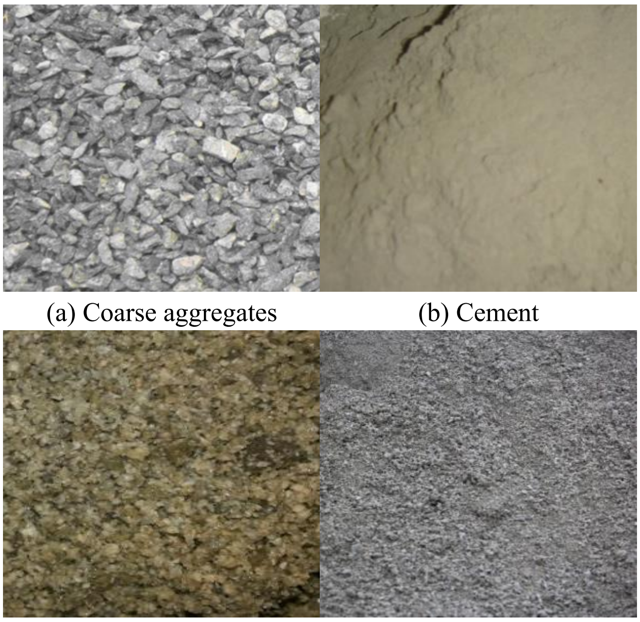
Physical Property	Values obtained	IS: 12269-1987 specifications[7]
Fineness of cement (m^2/kg))	450	225 (minimum)
Soundness of cement (mm)	1.3	10
Specific Gravity	3.15	3.15
Initial Setting time (minutes)	120	30 (minimum)
Final Setting Time (minutes)	275	600 (maximum)
Compressive strength (MPa)		
3 days	35.95	27.0 (minimum)
7 days	47.76	37.0 (minimum)
28 days	58.96	53.0 (minimum)

and steel industries, as a partial or full replacement for M-sand in RCC. In this regard detailed systematic investigations were performed to test the compressive strength, flexural strength and split-tensile strength (cylinders) up to 28 days of age of concrete made with I-sand and compared with those of concrete made with M-sand of various mix proportions (IS: 456-2000) along with their microstructural properties and rapid chloride permeability tests to assess the durability properties. Fineness modulus, specific gravity, moisture content, water absorption, sieve analysis, bulk density, voids ratio, porosity (loose and compact) state for M-sand and I-sand were also studied, thereby examining the possibility of manufacturing cement concrete using I-sand with physical properties similar to those of cement concrete using Manufactured sand as fine aggregate (IS: 2386 (Part III)-1963 (reaffirmed 1997)).

2. Materials and methods

2.1 Properties of materials

Concrete being a proper mixture of cement, sand and aggregate, performance of concrete is greatly influenced by the properties of cement being used. For the experiments discussed in this manuscript, 53 grade cement was used with the chemical composition as given in Table 1. The physical properties of the cement used are summarized in Table 2 (IS: 12269-1987). Details about the Iron slag (I-sand) are discussed elsewhere (Rahmathulla *et al.* 2016). For the present experiments I-sand was procured from JSW



(a) Coarse aggregates (b) Cement

(a) Iron slag (b) M-sand

Fig. 1 Various aggregates used in the present research work

Table 4 Properties of M-sand and I-sand (Iron slag) used for present research work

Particulars	M-sand	I-sand
Bulk density (kg/m^3)	1.766	1.243
Void ratio	0.310	0.818
Porosity	0.237	0.450
Specific gravity	2.315	2.653

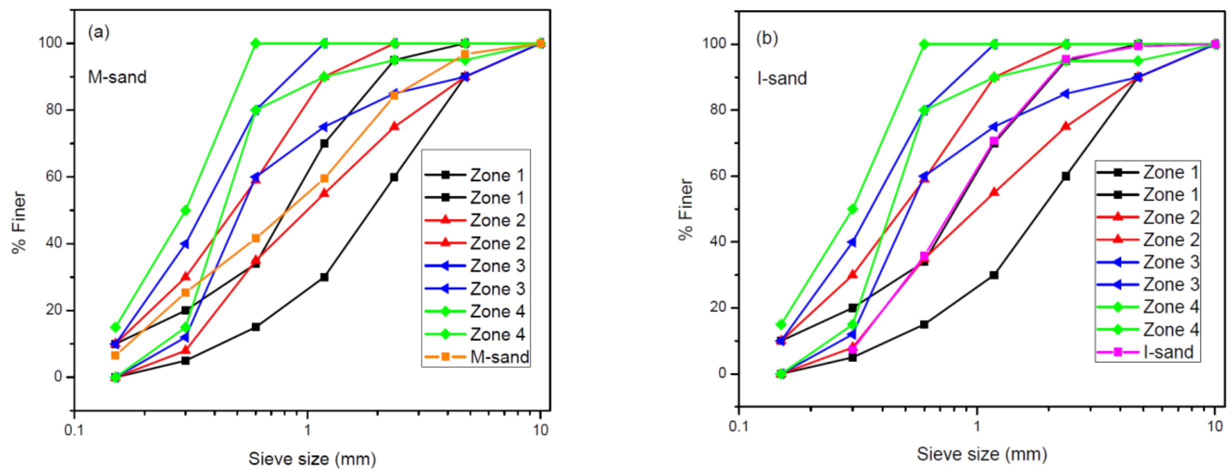
Steel Ltd, Mysore, India and M-sand from Alpha crusher, Mukkom, India. Elemental composition of M-sand used in the experiments are presented in Table 3. Physical properties of the I-sand and M-sand used for the present experiments are summarized in Table 4. From the table it can be seen that the bulk density of I-sand is lesser than that of M-sand even though I-sand possess more specific gravity. This is due to the fact that the bulk density depends on the size distribution, shape of the particle and the void content. M-sand is angular and rougher surface particle whereas iron slag is flaky and cubical particle. Hence M-sand particles will compact more with less air voids in comparison to iron slag resulting in higher bulk density. Pictures of various aggregates used in the present experiments are shown in Fig. 1.

2.2 Experimental methods

Sieve analysis, also known as the gradation test, was performed on M-sand and I-sand following the standards given in IS: 383-1970 (IS: 383-1970 (reaffirmed 1997)). The mix designs M25, M30 and M40 of concrete mixtures

Table 3 Elemental composition of M-sand

Element	C	O	Na	Mg	Al	Si	K	Ca	Ti	Fe
Weight %	1.74	48.09	2.69	2.45	8.13	18.45	2.84	3.68	1.86	10.06



(a) M-sand (b) I-sand

Fig. 2 Semi log graph showing the sieve analysis

Table 5 Tabulation based on sieve analysis

IS SIEVE diameter	% Passing for			
	Zone 1	Zone 2	Zone 3	Zone 4
10 mm	100	100	100	100
4.75 mm	90 - 100	90 - 100	90 - 100	95-100
2.36 mm	60 - 95	75 - 100	85 - 100	95-100
1.18 mm	30 - 70	55 - 90	75 - 100	90-100
0.6 mm	15 - 34	35 - 59	60 - 80	80-100
0.3 mm	5 - 20	8 - 30	12 - 40	15-50
0.15 mm	0 - 10	0 - 10	0 - 10	0-15

Table 6 Comparison of particle size distribution between M-sand and I-sand

IS SIEVE diameter	M-SAND % of Passing	IRON SLAG % of Passing	% Passing for single sized aggregates of Normal Sand (IS 383 - 1970)[8]Zone 2
4.75 mm	96.8	99.4	90 - 100
2.36 mm	84.3	95.6	75 - 100
1.18 mm	59.5	70.8	55 - 90
600 μm	41.6	35.8	35 - 59
300 μm	25.4	7.4	08 - 30
150 μm	6.5	2.4	0 - 10

were prepared following IS 10262:2009 with different proportions of I-sand, as a partial or full substitute for M-sand as fine aggregate. Various percentage of replacements of I-sand including 10%, 20%, 30%, 40%, 50%, 60%, 80% and 100% were prepared for the present investigations. In the case of M25, the control mix was designed to have a target 28 day characteristic compressive strength of 31.60 N/mm^2 using a water cement ratio of 0.45. The mix ratio for M25 obtained by calculation was 1:2.08:3.283. M30 was designed for a target strength of 38.25 N/mm^2 and a mix ratio of 1:1.63:3.03 with a water cement ratio of 0.43. For M40, the control mix was designed to have a target 28 day characteristic compressive strength of 48.25 N/mm^2 using a water cement ratio of 0.40. The mix ratio for M40 obtained by calculation was 1:1.99:2.669. In all the cases the chemical admixture used was Focerock Conplast SP 430.

Compressive strength for various specimens were evaluated by casting concrete cubes of 15 cm×15 cm×15 cm followed by curing in water for 7 days and 28 days and tested using compression testing machine CTM-200 T, HAICO (IS: 516-1959 (reaffirmed 1997)). Evaluation of split tensile strength for various specimens were carried out by casting concrete cylinders of 15 cm diameter and 30 cm length, cured in water for 28 days, followed by testing using universal testing machine UTM-300 T, HAICO (IS: 5816-1999). Flexural strength of various samples were adjudged by casting concrete beams of size 150 mm×150 mm×700 mm, cured in water for 28 days followed by evaluation in flexural testing machine-100 kN, Lawrence & Mayo (IS: 516-1959 (reaffirmed 1997)). Microstructural analysis was carried out by acquiring Scanning Electron Microscopy images on selected specimen using JEOL JSM-6510 high resolution scanning electron microscope. Energy Dispersive Analysis of X-rays (EDAX) measurements to understand the elemental composition as well as rapid chloride permeability test for assessing the durability of the samples were also carried out.

3. Results and discussion

3.1 Physical and mechanical properties

Detailed evaluation of the physical and mechanical properties of I-sand and M-sand were carried out. In order to understand the size distribution of aggregate particles sieve analysis was performed and the results obtained for M-sand and I-sand are summarized in Figs. 2(a) and (b), respectively. Table 5 shows the physical properties tested as per IS: 383-1970 (IS: 383-1970 (reaffirmed 1997)). A summary of the comparison of physical and mechanical properties of M-sand and I-sand is presented in Tables 6 and 7, respectively which clearly shows that both M-sand and I-sand falls into the category of Zone 2 which is recommended for mass concrete as per IS:383-1970 (reaffirmed 1997).

M-sand consists of angular and rougher surface texture particles whereas I-sand consists of flaky and cubical

Table 7 Mechanical property evaluation of M-sand versus I-sand

Sl. No.	Property	M-sand	I-sand	Remarks
1	Shape	Angular and rougher surface texture particle	Flaky and cubical particle	Good
2	Gradation	Can be controlled	Can be controlled	Good
3	Specific gravity	2.3-2.7	2.653	May vary
4	Water absorption	1.96 %	1.48 %	Limit 2 %
5	Ability to hold surface moisture	Upto 10%	Up to 10 %	Endurance limit
6	Grading zone (FM)	Zone 2	Zone 2	Recommends Zone 2 for mass concrete

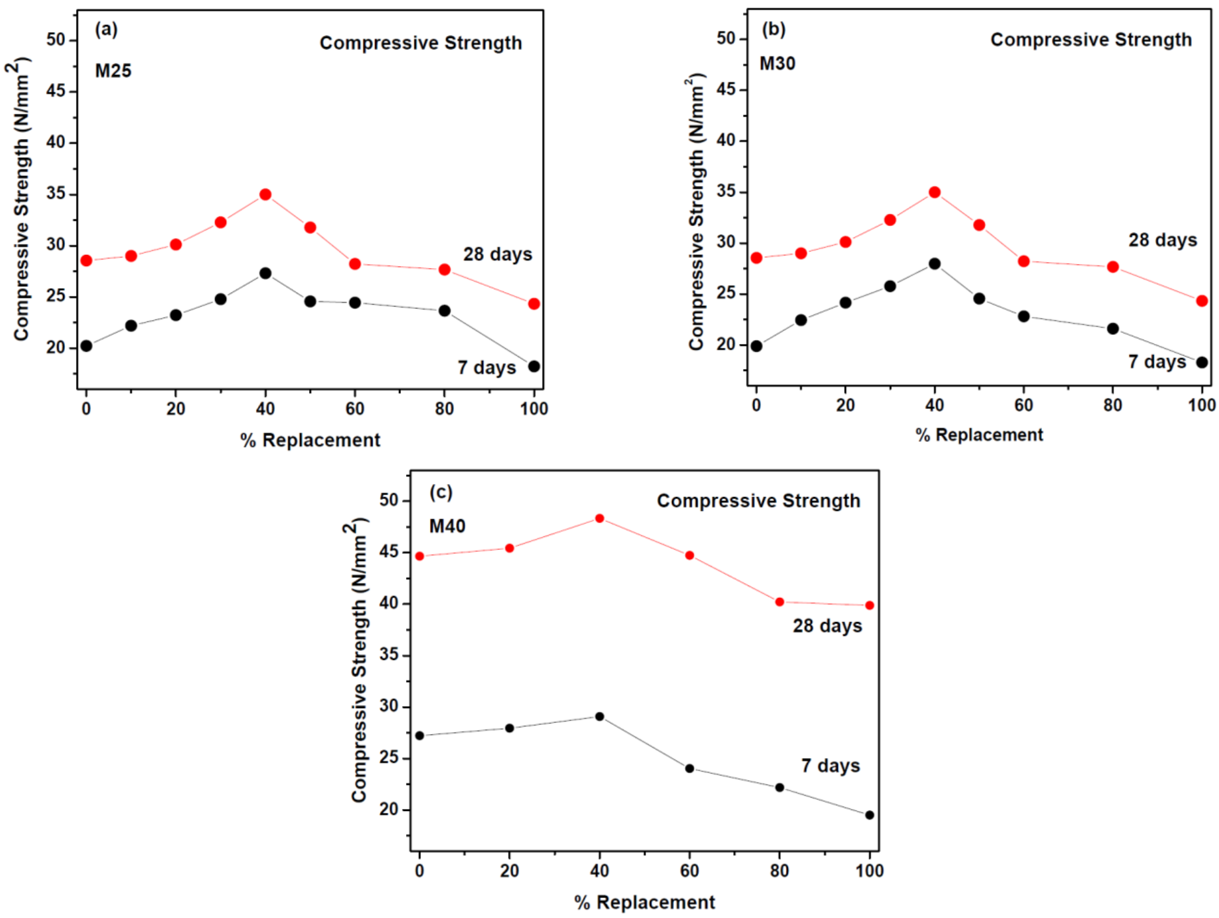


Fig. 3 Compressive strength with percentage replacement of I-sand for M25 (a), M30 (b) and M40 (c) after 7 days and 28 days of curing

particles but gradation can be controlled in both the cases. Physical properties of I-sand helps in the workability of concrete. Also, fineness modulus, specific gravity and water absorption coefficients of I-sand and M-sand are within the permissible limits making them suitable for mass concrete in substitution of river sand. The water absorption of iron slag is less compared to the M sand. Hence when the replacement percentage of M-sand with iron slag increases with the same water to cement ratio, excess water will be there in the mix which decreases the strength of the concrete because of the pores present in concrete due to the excess water.

3.2 Mix design-Replacement of M-sand by I-sand

Compressive strength, split-tensile strength and flexural strength were evaluated for mix designs prepared by partial /full replacement of M-sand by I-sand in varying proportions (IS: 10262-2009, IS: 516-1959 (reaffirmed 1997), IS: 5816-1999 and IS: 1199-1959 (reaffirmed 1999)). For M25 the mix proportion of the cement, fine aggregate and coarse aggregate followed were 1:2.08:3.283 with the water cement ratio being 0.45. The mix proportion of 1:1.63:3.03 with a water cement ratio of 0.43 and 1:1.99:2.669 with the water cement ratio of 0.4 was used for M30 and M40, respectively. Maximum size of the aggregate used was 20 mm. Results of the compressive strength evaluated after 7 and 28 days of curing for all the mix designs are tabulated in Tables 8 and 9 and shown in Figs.

Table 8 Results of compressive strength test for mix designation M25 and M30

% Replacement of M-sand by I-sand	Compressive strength (MPa)			
	M25		M30	
	7 days	28 days	7 days	28 days
0 %	20.22	28.55	19.88	31.55
10 %	22.19	29.00	22.44	33.23
20 %	23.22	30.11	24.15	34.23
30 %	24.78	32.28	25.77	35.11
40 %	27.31	35.00	27.98	39.95
50 %	24.56	31.78	24.55	36.67
60 %	24.44	28.22	22.81	34.99
80 %	23.65	27.67	21.60	32.48
100 %	18.22	24.33	18.28	29.44

Table 9 Results of compressive strength test for mix designation M40

% Replacement of M-sand by I-sand	Compressive strength (MPa)	
	M40	
	7 days	28 days
0 %	27.22	44.66
20 %	27.95	45.44
40 %	29.08	48.34
60 %	24.03	44.74
80 %	22.18	40.22
100 %	19.5	39.88

3(a), 3(b) and 3(c), respectively. It can be inferred from the results that the best compressive strength for all the mix designs are observed for 40% replacement of M-sand by I-sand. As reported in our previous studies (Rahmathulla *et al.* 2016), the improvement in the compressive strength of the mixture with the percentage replacement of iron slag can be attributed primarily due to the pozzolanic reaction and the improved particle packing behaviour. M-sand particle will compact more with less air voids compared to iron slag. Hence when M-sand is replaced by iron slag the particle packing increases and the optimum value of packing and compaction reaches up to 40% replacement. However, excessive slag added beyond 40% remain unreacted and acts only as a filler leading to a reduction in compressive strength.

Split tensile strength evaluation of the mix designs M25 and M30 for various compositions were carried out after 28 days of curing (IS: 5816-1999) and the results are summarized in Table 10 and Fig. 4. For the present experiments also the mix proportion of cement, fine aggregate and coarse aggregate ratio used were 1:2.08:3.283 with the water cement ratio being 0.45 for M25 and 1:1.63:3.03 with a water cement ratio of 0.43 for M30, respectively. Here again it can be clearly observed that the best results were obtained for 40% replacement of I-sand in M-sand. Flexural strength test (IS: 516-1959 (reaffirmed 1997)) was also performed for the mix designs M25 and M30 for various percentage replacements of I-sand after casting concrete beams and curing for 28 days and the corresponding results are summarized in Table 11 and Fig. 5.

Table 10 Results of split tensile strength test for mix designation M25 and M30

% Replacement of M-sand by I-sand	M25		M30	
	Maximum load, P (kN)	Split tensile strength (MPa) 28 days	Maximum load, P (kN)	Split tensile strength (MPa) 28 days
0 %	279.9	3.96	278.5	3.94
20 %	309.9	4.38	316.6	4.48
40 %	337.9	4.78	342.8	4.85
60 %	275.8	3.9	282.0	3.99
80 %	225.1	3.19	234.6	3.32
100 %	164.0	2.32	204.3	2.89

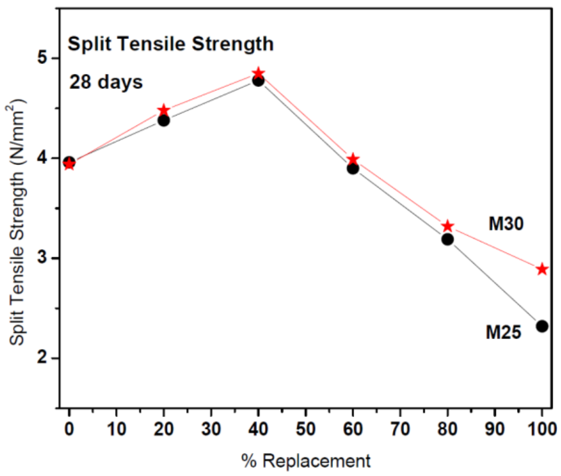


Fig. 4 Split tensile strength with percentage replacement of I-sand for M25 and M30 after 28 days of curing

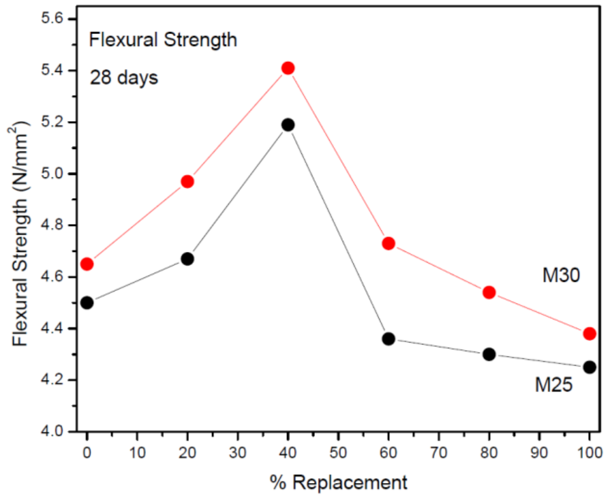


Fig. 5 Variation in flexural strength with percentage replacement of I-sand for M25 and M30 after 28 days of curing

Again the optimum values were arrived at for the 40% replacement. The above behaviour may again be attributed to the pozzolanic reaction and slag being finer than M-sand, the resulting particle packing behavior. Beyond 40% replacement, the excessive slag remain unreacted and acts as a filler leading to a reduction in the split tensile strength

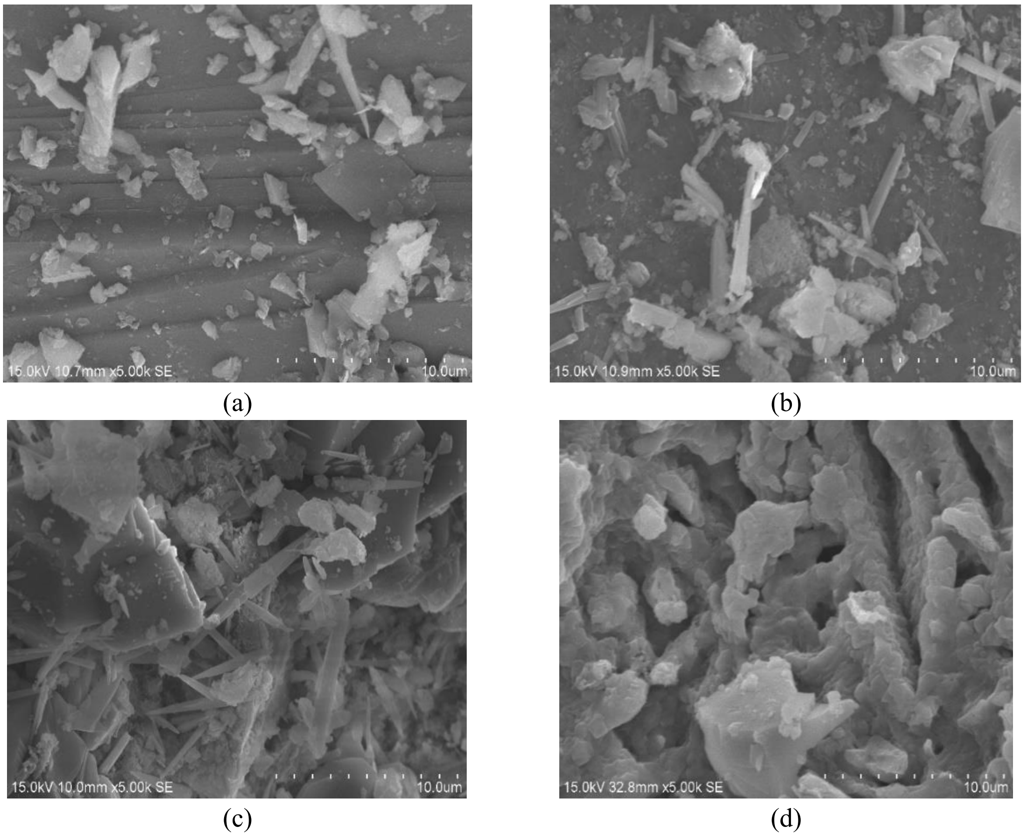


Fig. 6 Scanning Electron Microscopy images acquired from I-sand (a) and (b), M-sand (c) and 40% replacement of I-sand in M-sand (d)

Table 11 Results of flexural strength test for mix designation M25 and M30

% Replacement of M-sand by I-sand	M25			M30		
	Maximum load, *P* (kN)	Crack length, *a* (mm)	Flexural strength (MPa) 28 days	Maximum load, *P* (kN)	Crack length, a (mm)	Flexural strength (MPa) 28 days
0 %	21.9	267	4.50	22.4	271	4.65
20 %	22.5	240	4.67	23.9	240	4.97
40 %	25.0	215	5.19	26.1	220	5.41
60 %	21.0	255	4.36	22.8	262	4.73
80 %	20.73	245	4.30	21.9	266	4.54
100 %	20.5	256	4.25	21.1	261	4.38

as well as flexural strength. Hence pozzolanic reaction as well as the particle packing behavior, in combination, affects the above properties (Rahmathulla *et al.* 2016).

Previously we have also performed detailed investigations of the electronic structure and thermal conductivity properties of I-sand in detail (Rahmathulla *et al.* 2016) on another batch of iron slag samples. Our results showed that the iron slag is predominantly composed of Si and the Fe content is smaller. Also, the room temperature thermal conductivity value of I-sand was found to be about 1.9 W/K-m which falls very well under the range of required values of concrete i.e., 1.28-2.5 W/K-m at 293 K (Han *et. al* 2003).

SEM images were acquired to examine the microstructure of selected specimen. Figs. 6 (a) and (b) correspond to the SEM images from I-sand and Figs. 6 (c) and (d) correspond to the images from M-sand and the optimal composition namely 40% replacement of I-sand in M-sand, respectively. Micro structural analysis suggests that M-sand consists of more loosely bonded particles, while after the substitution with I-sand, possibly the voids decreases and the particles gets bonded better, thereby increasing the overall strength. An elemental analysis has also been carried out on the Iron slag sample and the resulting percentages are summarized in Fig. 7 which suggests that the main content of the slag is Si possibly in the oxide form. Our previous compositional analysis results on the different batch of iron slag samples also shows that the slag is mainly composed of Si (Rahmathulla 2016).

It is also important to assess the durability of concrete prepared using partial/full replacement of M-sand with I-slag. In order to estimate this, rapid chloride permeability tests were performed on various samples of M25 and M30 and the corresponding results are summarized in Table 12. The results suggest that the control mix with 0 % I-slag comes under the category of moderate permeability whereas

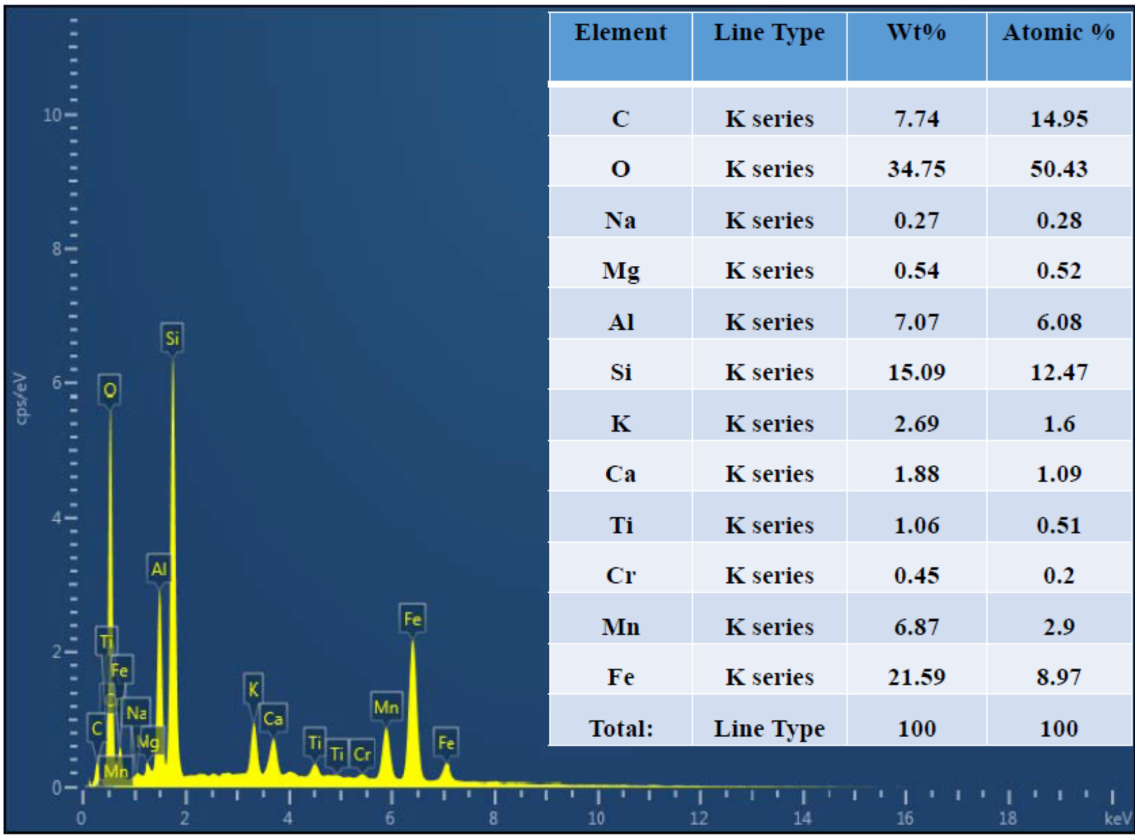


Fig. 7 Elemental analysis carried out on Iron slag using EDAX, along with the summary of the composition

Table 12 Results of rapid chloride permeability test for mix designation M25 and M30

Sl. No.	% Replacement of M sand by I-sand	M25		M30	
		Total charge passed (C)	Chloride ion permeability	Total charge passed (C)	Chloride ion permeability
1	0	2125	Moderate	2015	Moderate
2	20	1600	Low	1550	Low
3	40	1310	Low	1240	Low
4	60	1095	Low	1030	Low
5	80	950	Very low	825	Very Low
6	100	875	Very low	760	Very Low

mixes with 10%, 20%, 30%, 40%, 60%, 80% and 100% replacements of I- slag come under the category of low and very low permeability as per ASTM C1202-94. The rate of ingress of chloride into concrete depends on the pore structure of concrete (Patra *et al.* 2017). Hence reduction in permeability with increase in I-slag content indicates an improvement in the microstructure of concrete with increasing I-sand replacement which is also observed from the SEM images shown in Fig. 6.

4. Conclusions

In this manuscript we discuss the scope of possible utilization of iron slag as a replacement of manufactured sand as fine aggregates in RCC constructions. A detailed investigation of the physical, mechanical and microstructural properties of I-sand, M-sand and various mix designs M25, M30 and M40 prepared by the partial/full replacement of I-sand in M-sand have been carried out. Physical properties of I-sand helps in the workability of concrete. Also, fineness modulus, specific gravity and water absorption coefficients of I-sand and M-sand are within the permissible limits making them suitable for mass concrete in substitution of river sand. Evaluation of compressive strength, split tensile strength and flexural strength of various specimens indicated that the best results were obtained for an optimal replacement of 40% of M-sand by I-sand. This could be attributed to the pozzolanic reaction and the particle packing behavior. Beyond 40% replacement, the excessive slag remains unreacted and acts only as a filler leading to a reduction in the compressive strength split tensile strength as well as flexural strength. Rapid chloride permeability tests also indicate a reduction in chloride ion permeability with increase in I-slag content indicating an improvement in the microstructure of concrete with increasing I-sand replacement which is also observed from the SEM images. Hence effective utilization of iron slag, which is an industrial waste product, in reinforced concrete may be possible without compromising on the quality of the building materials. This could help in effectively disposing the industrial wastes as well as aid in the conservation of natural resources, like river sand which is indiscriminately being exploited for construction industries. Such effective utilization of environment friendly alternate substitutes for sustainable building materials in construction industry is the need of the hour.

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