Fresh properties of self-compacting concrete incorporating electric arc furnace oxidizing slag (EAFOS) as coarse aggregate

P. Murthi¹ · K. Poongodi¹ · P. O. Awoyera² · R. Gobinath¹ · K. T. Raja³ · Oladimeji B. Olalusi⁴

Received: 4 January 2020 / Accepted: 12 March 2020 / Published online: 14 March 2020
© Springer Nature Switzerland AG 2020

Abstract

This study investigates the fresh properties of self-compacting concrete incorporating electric arc furnace oxidizing slag as coarse aggregate. A binary blend of 30% fly ash and cement was utilized as binder to improve the performance of concrete in its fresh state. Concrete grades M20, M30 and M40 were developed by replacing natural coarse aggregate with 50% and 100% electric arc furnace oxidizing slag (EAFOS) aggregate. Thus, fresh properties of SCC; slump flow, T500, U box, V funnel and L-box were determined. From the evaluation of fresh properties, it is shown that the grades of concretes developed passed the set standard limits for SCC. The results showed that 50% EAFOS addition to SCC will not deter its fresh properties in any way, however, when EAFOS was added up to 100%, there was reduction in workability properties of the concrete. The study showcases the significant potential of EAFOS as an alternative aggregate in SCC. Thus, the data provided in this study will be useful for concrete constructors.

Keywords Aggregate · Slag · Self-compacting concrete · Workability · Fly ash

1 Introduction

The challenges of ensuring flow of concrete in congested reinforcement, sloppy site and minimizing energy consumption in vibration, usually encountered during construction and placing of normal weight concrete, are well overcome with self-compacting concrete (SCC) technology. However, over reliance on the natural aggregate sources may affect SCC sustainability in near future. Cement concrete, a widely used construction material, requires good quality aggregates for its production in order to ensure its optimal performance. Aggregates, generally, are considered as volumetric material and occupying 65–75% of concrete volume, it plays a vital role, as it contributes more to the fresh and hardened stated properties of concrete [1–4]. However, studies [5–7] have reported that the increasing use of the natural aggregates

could quicken the depletion of the sources. Thus, in order to preserve the natural aggregate sources, other alternative sources such as wastes are explored. Some of the wastes that have been considered over the years include those emanating from the construction and demolition activities, agricultural and industrial sectors [8–12].

Electric arc furnace oxidizing slag (EAFOS), one of the discarded materials from steel making plants, has been found to be useful for concrete production [13–17]. Apparently, the management of this waste can contribute to the effective management of the steel industry, as it can be used in ecofriendly way, owing to its physical structure. EAFOS is a recycled resource and a viable solution to the fast depletion of natural aggregates. The application of EAFOS as concrete aggregate has been considered for production of different types of concrete.

✉ P. O. Awoyera, paul.awoyera@covenantuniversity.edu.ng | ¹Department of Civil Engineering, S R Engineering College, Warangal, India. ²Department of Civil Engineering, Covenant University, Ota, Nigeria. ³Department of Civil Engineering, SNS College of Technology, Coimbatore, India. ⁴Discipline of Civil Engineering, University of KwaZulu-Natal, Durban, South Africa.

Table 1 Cement and FA—chemical composition

Results (%)	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	LoI
Cement	21.90	5.19	3.78	60.96	1.59	1.34
FA	61.81	20.37	3.19	3.09	1.47	3.37

A study by Lee et al. [18] reported that normal weight concrete produced using EAFOS enhanced the ductile capacity of reinforced concrete columns. According to the authors, the slag provided a strong column development. González-Ortega et al. [19] studied the durability performance of concrete incorporating EAFOS aggregate, and it was established that EAFOS possess limited ability to enhance durability of concrete, as higher carbonation depths, water penetration and expansion were observed. Other studies [20–23] have utilized EAFOS as aggregate in concrete, with somewhat appreciate performance reported. In addition, studies have also reported about the use of different slags in self-compacting concrete (SCC). A few application involved the production of SCC using, stainless slag [24], granular steel slag [25], and granulated blast furnace slag [26–29].

Following the survey of literatures on the production and development of concrete using EAFOS, it can be seen that numerous applications of the material was more common in the aspect of normal weight concrete, than in SCC. While a number of investigations have been carried out using slags in SCC, however, not so much have been reported on the use of EAFOS for SCC production. Whereas, it is necessary to evaluate EAFOS application in SCC, because various slags certainly vary in properties according to their production condition. Therefore, in this study, the fresh properties of self-compacting concrete produced using electric arc furnace oxidizing slag as coarse aggregate is investigated. Various properties of the fresh SCC mixtures are considered for three grades of SCC, M20, M30 and M40. The study aims to provide useful data for concrete constructors in the built environment, thereby contributing to the sustainability process in the field.

2 Materials and methods

2.1 Materials

In this study, ordinary Portland cement (OPC) conforming to IS: 12269 [30] was utilised. The fineness and specific gravity of the cement was determined as 298 m²/kg and 3.14, respectively. The chemical composition of cement is shown in Table 1. Scanning electron microscopy (SEM) image and energy-dispersive X-ray spectroscopy (EDS) spectrum of cement are shown in Figs. 1 and 2, respectively. Finely ground low calcium fly ash (FA) obtained

Fig. 1 SEM image of cement particle **Fig. 2** EDS spectrum for cement particle

from Mettur (Tamil Nadu, India) thermal power plant was recycled as a secondary binder. The fineness and specific gravity of FA was determined as 294 m²/kg and 2.67, respectively. The chemical composition of FA is provided in Table 1. SEM image and EDS spectrum of FA are shown in Figs. 3 and 4, respectively. The obtained river sand was tested as per IS: 383 [31] and found as grade zone II. The specific gravity fineness modulus of river sand was 2.68 and 2.68, respectively. Crushed rock (granite) of 20 mm maximum size was utilized as coarse aggregate in normal strength concrete, and while 12 mm size was used for self-compacting concrete. The natural coarse aggregate (20 mm size) and crushed EAFOS (20 mm size) are presented in Figs. 5 and 6, respectively. The obtained coarse aggregate was tested as per British code [32], IS: 383 [31],

Fig. 3 SEM image of FA particle

Fig. 4 EDS spectrum for FA particle

Fig. 5 Coarse aggregate 20 mm size

IS: 2386 [33]. The relative density of the 20 mm size coarse aggregate is 2.75 and its fineness modulus is 7.08. The EAFOS used in the present investigation was obtained from Salem Steel Plant (SSP), India. The EAFOS was not used as concrete ingredient in its raw form, as it is known

Fig. 6 Crushed 20 mm EAFOS

Table 2 EAFOS—chemical compositions

Results (%)	CaO	Fe ₂ O ₃	SiO ₂	Al ₂ O ₃	MgO
EAFOS	26.74	21.53	17.57	12.63	5.36

to swear overtime because it contains unrestricted calcium oxide (CaO) and silica (SiO₂) contents [34]. The presence of the oxides causes the concrete to expand [35]. Thus, following the approach reported in a study [36], the slag was exposed to outdoor atmosphere for 24 months so as to reduce the concentration of CaO and SiO₂ considerably. The aggregate crushing values for granite and EAFOS were 20 and 26, respectively. The surface of the slag is rough and hard (Fig. 6), which could largely contribute to the compactness of aggregate—paste interphase. Slag size less than 20 mm was selected in normal strength, and while 12 mm was used for self-compacting concrete. The specific gravity and water absorption values of EAFOS were 3.67 and 2.07%, respectively. The chemical properties of EAFOS is presented in Table 2. The particle size distribution curves of coarse aggregate used for normal weight concrete and EAFOS can be seen in Fig. 7.

2.2 Experimental procedure

The study explored the fresh properties of SCC using slump-flow, time of spread of concrete to 500 mm diameter (T500), L-box, U-box test and V-funnel tests, following the procedures described in specification and guidelines for selfcompacting concrete (EFNARC) [37].

Two series of concrete mixtures were considered. In Series-I, four mix combinations were considered, mix A consists of conventional concrete called normal concrete and mix B consists of 30% fly ash for making binary blended normal concrete with conventional granite

Fig. 7 Particle size distribution curves of coarse aggregate and EAFOS

aggregate. The concrete mixture proportions of control concrete were obtained as per the guidelines of BIS code IS: 10262 [38]. The mixture C and mixture D consist of 50% and 100% EAFOS aggregate, respectively in the binary blended concrete. The summary of concrete mix proportion for ordinary concrete prepared in this investigation is presented in Table 3. In series-II, the suitability of EAFOS in SCC was evaluated by comparing the results with ordinary concrete and SCC made with conventional granite aggregate. The aggregate and superplasticizer (polycarboxylate based) contents were slightly adjusted in order to maintain the required workability of the concrete. After several trials, the final mix proportion for SCC investigated in this study was developed as shown in Table 4.

Table 3 Mix proportioning of ordinary concrete

Concrete grade	Mix ID	Binder				20 mm CA					w/b	Water (kg/m ³)	Superplasti- cizer (kg/m ³)
		Cement		Fly ash		Granite		EAFOS		Sand			
		%	kg/m ³	%	kg/m ³	%	kg/m ³	%	kg/m ³				
M20 (1:2.4:4.57)	AN20	100	280	0	0	100	1280	0	0	673	0.50	142.8	2.80
	BN20	70	196	30	84	100	1280	0	0	673	0.50	142.8	1.96
	CN20	70	196	30	84	50	640	50	675	673	0.50	142.8	1.96
	DN20	70	196	30	84	0	0	100	1350	673	0.50	142.8	2.15
M30 (1:2.3:4.16)	AN30	100	300	0	0	100	1250	0	0	690	0.45	135	3.00
	BN30	70	210	30	90	100	1250	0	0	690	0.45	135	2.10
	CN30	70	210	30	90	50	625	50	657	690	0.45	135	2.10
	DN30	70	210	30	90	0	0	100	1314	690	0.45	135	2.25
M40 (1:2.08:3.56)	AN40	100	340	0	0	100	1210	0	–	710	0.40	136	2.95
	BN40	70	240	30	100	100	1210	0	–	710	0.40	136	2.25
	CN40	70	240	30	100	50	605	50	636	710	0.40	136	2.25
	DN40	70	240	30	100	0	00	100	1272	710	0.40	136	2.45

Table 4 Mix proportioning of SCC

Concrete grade	Mix ID	Binder				12 mm CA				Sand (kg/m ³)	w/b	Water (kg/m ³)	Superplasti- cizer (kg/m ³)
		Cement		Fly ash		Granite		EAFOS					
		%	kg/m ³	%	kg/m ³	%	kg/m ³	%	kg/m ³				
M20 (1:3.28:3.82)	BS20	70	196	30	84	100	1070	0	0	920	0.50	140	2.95
	CS20	70	196	30	84	50	535	50	560	920	0.50	140	2.95
	DS20	70	196	30	84	0	0	100	1120	920	0.50	140	3.35
M30 (1:3.13:3.43)	BS30	70	210	30	90	100	1030	0	0	940	0.45	135	2.30
	CS30	70	210	30	90	50	515	50	530	940	0.45	135	2.30
	DS30	70	210	30	90	0	0	100	1060	940	0.45	135	2.65
M40 (1:2.85:2.91)	BS40	70	240	30	100	100	990	0	0	970	0.40	132	2.45
	CS40	70	240	30	100	50	495	50	515	970	0.40	132	2.45
	DS40	70	240	30	100	0	0	100	1030	970	0.40	132	2.85

Fig. 8 Slump value of ordinary concrete **Fig. 9** V-funnel flow time (s)**Table 5** Slump-flow and T_{500} results of SCC

Mix designation	Replacement level of CA by EAFOS (%)	Average slump-flow (mm)		T_{500} (s)
		0 min	30 min	
BS20	0	745	707	3.7
CS20	50	723	688	4.3
DS20	100	704	662	4.8
BS30	0	767	727	3.4
CS30	50	746	695	4.0
DS30	100	724	679	4.3
BS40	0	779	746	3.1
CS40	50	758	732	3.7
DS40	100	743	707	4.1

3 Results and discussion

3.1 Effect of slag on slump value of normal concrete

The slump value for normal weight concrete is shown in Fig. 8. It was shown that the addition of FA caused marginal increase in slump value. However, there was insignificant reduction of slump value of concrete specimens with 50% and 100% EAFOS, which may be attributed to the rough textural characteristics of EAFOS. Also, wide surface area of the aggregate contributed to the workability. Generally, the required slump value (75–100 mm), according to British standard [39] and IS code [40], of all the mixtures was obtained by slightly modifying the superplasticizer dosage level (Fig. 9).

3.2 Effects of EAFOS on fresh SCC

3.2.1 Slump flow test

One of the important specification for SCC is its homogeneity and ability to flow under own weight, which is measured using flow test. In order to examine the

flow of SCC with time after mixing, the flow value was determined after 30 min of mixing. Table 5 presents the results of slump flow. For the three grades of concretes produced M20, M30 and M40, the flow values of the mixtures fell with specified limits of 650–800 mm [37]. The same was the case, for slump flow measured at 0 min and that of 30 min. A significant drop in slump flow occurred as EAFOS content increased from 50 to 100%, which is attributable to the rough textural appearances of EAFOS.

The result of T_{500} are also presented in Table 5. The T_{500} values for the concrete mixtures considered in the investigation satisfied the standard requirement for SCC [37].

3.2.2 V-funnel test

The flow time of the SCC mixtures through a V-funnel apparatus was calculated, so as to measure the passing ability of the mixture. The standard range of the V-funnel time is between 11 and 15 s [37]. The addition of EAFOS instead of natural aggregate caused reduction in the flow time of M20 grade SCC. A similar trend of reduction in flow time was observed in M30 and M40 grade SCC as well. Though there was reduction in flow time, overall, the mixtures satisfied the standard limits. From this results, it can be stated that the EAFOS is suitable for preparing SCC. A

comparison between the T_{500} and V-flow time of the designated mixtures is presented graphically in Fig. 10. Thus, both the T_{500} and V-flow time were within the required limits, which suggests that the viscosity and segregation resistance of the mixtures is satisfactory.

3.2.3 U-box test

The U-box test was conducted according to EFNARC criteria [37], which requires that the difference of levels in two chambers (Δh) should be smaller than 30 mm. The average U-box result of M20 grade SCC without EAFOS was observed as 12 mm. The values of height difference (Δh) of the SCC were 15 mm and 17 mm for 50% and 100% EAFOS in M20 grade SCC, respectively. There was increase in the difference of levels (Δh) between the two chamber in an insignificant manner, especially where EAFOS was used instead of natural aggregate in the M20 grade SCC. A similar trend of reduction was found in U-box data for M30 and M40 grade of SCC. The decreased U-box results with EAFOS aggregate could be attributed to the surface properties of EAFOS. The relationship between V-flow time and difference in levels of U-box (Δh) for all the designated mixtures is shown in Fig. 11. The results of V-flow time and Δh are within the target limit of $11 \leq T_v \leq 15$ s and $0 \leq \Delta h \leq 30$ mm (26) which established that mixtures have acceptable filling ability. From the observations, it is evidence that the EAFOS can be suitable for preparing SCC.

3.2.4 L-box test

The passing capacity of SCC between re-bars was examined using L-box, which is also known as blocking ratio. The L-box for the mixtures is shown in Fig. 12. The dashed line denotes the boundary of blocking ratio (H_2/H_1) and should be more than 0.8 [37]. The average ratio (H_2/H_1) of M20 grade SCC (BS20) without EAFOS was identified as 0.95. The values of blocking ratio of the SCC were 0.93

Fig. 10 V-funnel time versus T_{500}

Fig. 11 Comparison between V-funnel flow and Δh of U-box

and 0.92 for 50% and 100% EAFOS based M20 grade SCC, respectively. A decrease in blocking ratio of concrete occurred when EAFOS was added to SCC in place of natural aggregate in M20 grade SCC. The same was also the case in L-box test result observed in M30 and M40 grade SCC. However, the L-box test results of all the designated SCC specimens considered in this investigation with EAFOS were within the self-flow zone as shown in Fig. 12, thus, it is evidence that the EAFOS can be suitable for preparing SCC.

4 Conclusions

In this study, the fresh properties of self-compacting concrete incorporating electric arc furnace oxidizing slag (EAFOS) as coarse aggregate was determined. The following conclusions were drawn from the study:

In the normal weight concrete, significant reduction in slump value occurred, which is attributable to the rough

Fig. 12 Blocking ratio of SCC and EAFOS substitution level (%)

textural characteristics of the aggregate, which increased the total surface area of the aggregate. Slump value after 30 min was found to reduce from 15 to 20%, which was an indication that the workability of normal concrete was not affected by addition of EAFOS aggregate.

Also, the addition of EAFOS as partial replacement of natural aggregate caused decrease in slump flow value of the SCC. However, the flow values of EAFOS SCC mixture was between the limit (650–800 mm). The results of T_{500} of all the concrete mixtures considered in this investigation satisfied the requirements for SCC. The use of EAFOS as partial replacement of natural aggregate caused a reduction in the V-flow of SCC, but overall, the values were within the acceptable limits between of 11–15 s. Hence, this study shows that EAFOS can be suitable for production of SCC. The U-box results was smaller than the self flow zone value of 30 mm. A decrease in the blocking ratio of concrete was observed when EAFOS was utilized as a replacement of natural aggregate in SCC. Generally, this study has established the suitability of EAFOS for SCC mixtures based on fresh state properties, however, in the next phase of this research, both the mechanical properties in terms and strength thermal behavior, and durability properties in terms resistance to acid, chloride ingress and corrosion of steel will be reported.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

References

- Hashemi M, Shafigh P, Bin Karim MR, Atis CD (2018) The effect of coarse to fine aggregate ratio on the fresh and hardened properties of roller-compacted concrete pavement. *Constr Build Mater* 169:553–566. <https://doi.org/10.1016/j.conbuildmat.2018.02.216>
- Güçlüer K (2020) Investigation of the effects of aggregate textural properties on compressive strength (CS) and ultrasonic pulse velocity (UPV) of concrete. *J Build Eng* 27:100949. <https://doi.org/10.1016/j.jobbe.2019.100949>
- Murthi P, Awoyera P, Selvaraj P, Dharsana D, Gobinath R (2018) Using silica mineral waste as aggregate in a green high strength concrete: workability, strength, failure mode, and morphology assessment. *Aust J Civ Eng*. <https://doi.org/10.1080/14488353.2018.1472539>
- Selvaraj KP, Murthi P, Gobinath R, Awoyera PO (2018) Eco-friendly high strength concrete production using silica mineral waste as fine aggregate—an ecological approach. *Ecol Environ Conserv* 24:909–915
- Pradhan S, Tiwari BR, Kumar S, Barai SV (2019) Comparative LCA of recycled and natural aggregate concrete using particle packing method and conventional method of design mix. *J Clean Prod* 228:679–691. <https://doi.org/10.1016/j.jclepro.2019.04.328>
- Zhang LW, Sojobi AO, Kodur VKR, Liew KM (2019) Effective utilization and recycling of mixed recycled aggregates for a greener environment. *J Clean Prod* 236:117600. <https://doi.org/10.1016/j.jclepro.2019.07.075>
- Ben Fraj A, Idir R (2017) Concrete based on recycled aggregates—recycling and environmental analysis: a case study of paris' region. *Constr Build Mater* 157:952–964. <https://doi.org/10.1016/j.conbuildmat.2017.09.059>
- Lu J-X, Yan X, He P, Poon CS (2019) Sustainable design of pervious concrete using waste glass and recycled concrete aggregate. *J Clean Prod* 234:1102–1112. <https://doi.org/10.1016/j.jclepro.2019.06.260>
- Capasso I, Lirer S, Flora A, Ferone C, Cioffi R, Caputo D, Liguori B (2019) Reuse of mining waste as aggregates in fly ash-based geopolymers. *J Clean Prod* 220:65–73. <https://doi.org/10.1016/j.jclepro.2019.02.164>
- Mahdikhani M, Khanban M (2019) Utilization of industrial waste residue containing heavy metals as a substitute for fine aggregates. *Constr Build Mater* 221:772–786. <https://doi.org/10.1016/j.conbuildmat.2019.06.061>
- Shafigh P, Bin Mahmud H, Jumaat MZ, Zargar M (2014) Agricultural wastes as aggregate in concrete mixtures—a review. *Constr Build Mater* 53:110–117. <https://doi.org/10.1016/j.conbuildmat.2013.11.074>
- Awoyera PO, Adesina A, Gobinath R (2019) Role of recycling fine materials as filler for improving performance of concrete—a review. *Aust J Civ Eng*. <https://doi.org/10.1080/14488353.2019.1626692>
- Roslan NH, Ismail M, Khalid NHA, Muhammad B (2020) Properties of concrete containing electric arc furnace steel slag and steel sludge. *J Build Eng* 28:101060. <https://doi.org/10.1016/j.jobbe.2019.101060>
- Qasrawi H (2018) Towards sustainable self-compacting concrete: effect of recycled slag coarse aggregate on the fresh properties of SCC. *Adv Civ Eng* 2018:7450943. <https://doi.org/10.1155/2018/7450943>
- Stefania T, Matteo F (2010) EAF slag in self-compacting concretes. *Facta Univ Ser Archit Civ Eng* 8:13–21
- Awoyera PO, Adekeye AW, Babalola OE (2015) Influence of electric arc furnace (EAF) slag aggregate sizes on the workability and durability of concrete. *Int J Eng Technol* 7:1049–1056
- Awoyera P (2018) Predictive models for determination of compressive and split-tensile strengths of steel slag aggregate concrete. *Mater Res Innov* 22:287–293. <https://doi.org/10.1080/14328917.2017.1317394>
- Lee J-M, Lee Y-J, Jung Y-J, Park J-H, Lee B-S, Kim K-H (2018) Ductile capacity of reinforced concrete columns with electric arc furnace oxidizing slag aggregate. *Constr Build Mater* 162:781–793. <https://doi.org/10.1016/j.conbuildmat.2017.12.045>
- González-Ortega MA, Cavalaro SHP, Rodríguez de Sensale G, Aguado A (2019) Durability of concrete with electric arc furnace slag aggregate. *Constr Build Mater* 217:543–556. <https://doi.org/10.1016/j.conbuildmat.2019.05.082>
- Ortega-López V, Fuente-Alonso JA, Santamaría A, San-José JT, Aragón Á (2018) Durability studies on fiber-reinforced EAF slag concrete for pavements. *Constr Build Mater* 163:471–481. <https://doi.org/10.1016/j.conbuildmat.2017.12.121>
- Autelitano F, Giuliani F (2016) Electric arc furnace slags in cement-treated materials for road construction: mechanical and durability properties. *Constr Build Mater* 113:280–289. <https://doi.org/10.1016/j.conbuildmat.2016.03.054>
- Roy S, Miura T, Nakamura H, Yamamoto Y (2018) Investigation on applicability of spherical shaped EAF slag fine aggregate in pavement concrete—fundamental and durability properties. *Constr Build Mater* 192:555–568. <https://doi.org/10.1016/j.conbuildmat.2018.10.157>

23. Pellegrino C, Gaddo V (2009) Mechanical and durability characteristics of concrete containing EAF slag as aggregate. *Cem Concr Compos* 31:663–671. <https://doi.org/10.1016/j.cemconcomp.2009.05.006>
24. Sheen Y, Huang L-J, Sun T-H, Le D-H (2016) Engineering properties of self-compacting concrete containing stainless steel slags. *Procedia Eng* 142:79–86. <https://doi.org/10.1016/j.proeng.2016.02.016>
25. Rehman S, Iqbal S, Ali A (2018) Combined influence of glass powder and granular steel slag on fresh and mechanical properties of self-compacting concrete. *Constr Build Mater* 178:153–160. <https://doi.org/10.1016/j.conbuildmat.2018.05.148>
26. Huseien GF, Shah KW (2020) Durability and life cycle evaluation of self-compacting concrete containing fly ash as GBFS replacement with alkali activation. *Constr Build Mater* 235:117458. <https://doi.org/10.1016/j.conbuildmat.2019.117458>
27. Guo Z, Jiang T, Zhang J, Kong X, Chen C, Lehman DE (2020) Mechanical and durability properties of sustainable self-compacting concrete with recycled concrete aggregate and fly ash, slag and silica fume. *Constr Build Mater* 231:117115. <https://doi.org/10.1016/j.conbuildmat.2019.117115>
28. Adesina A, Awoyera P (2019) Overview of trends in the application of waste materials in self-compacting concrete production. *SN Appl Sci* 1:962. <https://doi.org/10.1007/s42452-019-1012-4>
29. Qasrawi H (2018) Fresh properties of green SCC made with recycled steel slag coarse aggregate under normal and hot weather. *J Clean Prod* 204:980–991. <https://doi.org/10.1016/j.jclepro.2018.09.075>
30. IS 12269 (1987) Specification for 53 grade ordinary Portland cement, Bureau of Indian Standards, New Delhi
31. IS 383 (1970) Specification for coarse and fine aggregates from the natural source for concrete. Bureau of Indian Standards, New Delhi
32. BS 882 (1992) Aggregates from natural sources. Br. Stand. London, UK
33. IS 2386, part 5 (2002) Method of test for aggregate for concrete: bulk density, sieve analysis. Bureau of Indian Standards, New Delhi
34. Wang GC (2016) Case studies on slag utilization. In: Wang GC (ed) *The utilization of slag in civil infrastructure construction*. Woodhead Publishing, Duxford, pp 339–370. <https://doi.org/10.1016/B978-0-08-100381-7.00014-8>
35. Akinwumi I (2014) Soil modification by the application of steel slag. *Period Polytech Civ Eng* 58:371–377
36. Pellegrino C, Cavagnis P, Faleschini F, Brunelli K (2013) Properties of concretes with black/oxidizing electric arc furnace slag aggregate. *Cem Concr Compos* 37:232–240. <https://doi.org/10.1016/j.cemconcomp.2012.09.001>
37. EFNARC (2002) *Specification and Guidelines for Self-Compacting Concrete*. Association House, Farnham. www.efnarc.org
38. IS 10262 (2009) Guidelines for concrete mix design proportioning. Bureau of Indian Standards, New Delhi
39. BS EN 12350-2 (2009) Testing fresh concrete. Slump-test. Br. Stand, London, UK
40. IS: 516 (1959) Methods of test for strength of concrete. Bureau of Indian Standards, New Delhi

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.