COMPARATIVE STUDY OF HEAT AS WELL AS AMBIENT CURED ALKALI ACTIVATED SLAG CONCRETE

Bavita Bhardwaj[1], Pardeep Kumar[1], Sumit Arora[1]

1. National Institute of Technology, Hamirpur, HP, India

ABSTRACT. The current investigation presents the development of alkali activated slag (AAS) concrete containing industrial by-products such as ground granulated blast furnace slag (GGBS) and waste foundry sand (WFS). Ground granulated blast furnace slag was used as the binder. The natural sand was replaced with waste foundry sand (WFS) in the range of 0% to 60% at an interval of 20%. A number of tests, which include compressive strength, split tensile strength and chloride permeability (RCPT), were conducted to evaluate the strength properties as well as permeability of AAS concrete, at different curing ages. A set of specimens were heat cured at 80°C for 24 hours and later kept in laboratory condition until testing ages. Another set was ambient cured in laboratory till testing ages. Rate of strength gain with curing age was obtained and compared. SEM analysis were also conducted to characterize the respective concrete mixes.

Keywords: Alkali activated slag concrete; GGBS; Waste Foundry Sand; Heated Curing; Strength; durability.

Bavita Bhardwaj is a PhD student in the Department of Civil Engineering of National Institute of Technology Hamirpur, India.

Dr Pardeep Kumar is an Associate Professor of Civil Engineering at National Institute of Technology Hamirpur, India. His research interests are assessment of service life of masonry arch bridges, finite element modelling of reinforced cement concrete structures, retrofitting of columns and strength and durability properties of concrete composites.

Dr Sumit Arora is a Lecturer in the Department of Civil Engineering of National Institute of Technology Hamirpur, India. His research interests include recycling of waste materials in concrete and fatigue properties of concrete.

INTRODUCTION

Environmental concerns and sustainability are the main concerns that are guiding most of the contemporary research. Making construction practices and construction materials satiating these issues is the need of hour. Concrete, which is most widely used construction material in the world is also one of the major contributor to global warming. Each of the primary ingredient of concrete, to a different extent, has an environmental impact and gives rise to different sustainability issues. Besides, most of the concrete structures start deteriorating much before their design life due to different durability issues. In order to address the environmental effects associated with concrete there is need to switch to other environment friendly and sustainable substitutes.

The environmental and durability issues related to conventional OPC concrete have led to search for alternatives to OPC in concrete. Partial to full replacement of OPC with industrial wastes such as fly ash (FA), ground granulated blast furnace slag (GGBS) has been widely studied as well as implemented. Cement free concretes such as alkali activated concretes and geopolymer concrete are the new age concretes. Alkali activated concretes use industrial by products or natural aluminosilicate materials activated by an alkali activator to produce alkali activated binders, which are then combined with fine and coarse aggregates to form alkali activated concretes (AAC) [1]. The production of alkali activated cements produces 50-80% lower CO_2 than OPC [2, 3]. Alkali activated binders are broadly classified into two main subclasses: high-calcium systems and low-calcium or calcium-free systems. As reported by various researchers, the main hydration product of an alkali-activated slag-based binder (AAS), which is a typical high calcium system, is C-S-H gel, which has a lower Ca/Si ratio than traditional OPC [4,5]; in contrast, the main hydration product of low-calcium or calcium-free binders is N-A-S-H gel, which possesses a three-dimensional structure [6–9].

Furthermore, the restriction in the extraction of sand from the river increases the price of sand and has severely affected the stability of the construction industry [10]. As such, finding an alternative material to river sand has become imperative. Waste foundry sand (WFS) is one such promising material which needs to be studied extensively as substitute of sand in concrete. It is a major by-product from the metal alloys casting industry with high silica content [11]. Inclusion of WFS as partial replacement to natural sand by 20-30% has been found to improve the mechanical as well durability properties of conventional as well as special concretes such as SCC and alkali activated concretes [12-15].

EXPERIMENTAL PROGRAMME

A range of alkali activated slag (AAS) concrete specimens, prepared with ground granulated blast furnace slag as binder, were cast with varying the mix composition. Concrete mixes were cured in two different curing conditions. Testing included compressive strength, split tensile strength and rapid chloride permeability test. In addition, Scanning electron microscopy (SEM) analysis of the concrete was also undertaken.

Materials

Ground granulated blast furnace slag (GGBS), procured from Astraa chemicals, Chennai, and was used as the binder material. The physical as well as chemical properties are given in

Table 1, confirming to BS-6699 [16]. A combination of sodium silicate (Na_2SiO_3) and Sodium Hydroxide was used as the alkali activator. Sodium hydroxide was procured in pellets form with 98% purity. Whereas, sodium silicate used was a colourless thick viscous solution of alkaline grade with chemical modulus (SiO_2/Na_2O) as 2.1 and water content of 52%. Both were procured from local dealer. The concentration of NaOH solution was kept constant as 14 molar with the mass of NaOH solids per kg of solution was measured as 404g. Sodium silicate to sodium hydroxide ratio by weight was kept as 1.5 for all the concrete mixes.

Table 1 Physical and chemical properties of GGBS

CHARACTERISTIC	TEST RESULT	CONSTITUENT	%
Fineness (m^2/kg)	390	SiO_2	33.06
Specific gravity	2.85	$Al_2O_3+Fe_2O_3$	23.19
Particle size (Cummulative %)	97.10	CaO	35.37
Glass content (%)	91	MgO	7.61
Moisture content (%)	0.10	SO_3	0.38
Chemical Moduli		MnO	0.12
Basicity Coefficient	1.30	Cl	0.009
CaO/SiO_2	1.07	LOI	0.26
$CaO+MgO+SiO_2$	76.03	IR	0.49

Locally available crushed sand (NA) was used as fine aggregate along with waste foundry sand (WFS) as its partial replacement. Waste foundry sand was procured from one local ferrous foundry, manufacturer of automobile parts, shown in Figure 1. The NA lies in zone-2 whereas WFS falls under zone-4 as per IS-383 (1970) [17]. Besides, locally available crushed stone aggregate, angular in shape, with maximum size 12.5 mm was used as coarse aggregate. Physical properties of fine and coarse aggregate are shown in Table 2.

Figure 1 Waste foundry sand as procured from local ferrous foundry.

Methodology

Mix details

For mix design of AAS concrete, the density of concrete was assumed as 2430 kg/m^3. The combined total weight occupied by the coarse and fine aggregates was assumed to be 76%. The alkaline liquid to binder ratio was taken as 0.45. Target strength of 40 N/mm^2 was expected as obtained after conducting trial studies. The mix proportions of the constituents are shown in Table 3. A total of four AAS concrete mixes were planned for the study with four different proportion of foundry sand as replacement of normal sand i.e. 0%, 20%, 40% and 60% named as G1, G2, G3 and G4 respectively.

Activator solutions were premixed 24 hours before casting of concrete. The aggregates were first mixed for 2 minutes in concrete mixer. After that GGBS was added in concrete and mixed for 2 minutes. Activator solutions with extra water and superplasticizer were premixed added slowly in the dry mix. Mixing was continued for 3 minutes after that slump cone test was performed to test the workability of fresh concrete. After that concrete was poured into concrete moulds and table vibrated. After casting one set of specimens was heat cured and other was left to cure in laboratory ambient conditions till testing age. For heat curing, concrete specimens were covered with plastic sheets, to avoid excessive moisture loss, and kept in hot air oven at temperature of 80° for 24 hours. After 24 hours, samples were demoulded and then left in lab ambient conditions till testing ages.

Table 2 Properties of fine and coarse aggregates.

PROPERTY	FINE AGGREGATE		COARSE AGGREGATE
	NA	WFS	
Specific Gravity	2.65	2.18	2.74
Fineness modulus	2.50	1.80	6.93

Tests

The slump test was undertaken in accordance with IS-1199-1959 [18] to assess the workability of fresh AAS concrete. Concrete specimens of size 100mm×100mm×100mm were cast for compressive strength test[19], whereas, cylinders of size 100 mm diameter and 200 mm height were cast for testing split tensile strength as well as for RCPT of concretes. Compressive strength of hardened AAS concrete was tested at the age of 7, 14 and 28 day of ambient curing whereas split tensile strength and RCPT were conducted at the age of 28 days.

RESULTS AND DISCUSSION

Workability and Strength

Workability of fresh concrete was assessed by conducting slump cone test. Sulphonated Naphthalene based superplasticizer was added 2% by weight of GGBS to keep the workability of mixes in the range of 75-100 mm. With increase in the replacement level of foundry sand, decrease in slump of concrete was observed. This is attributed to finer particles of WFS as compared to normal sand.

Compressive strength results of heat as well as ambient cured samples are presented in Table 4. In heat cured samples, most of the strength was achieved in the initial days. There was minor increase in strength after 7 days. Whereas, in ambient cured samples the strength increased gradually. More than 60% of the 28 day strength was achieved in 7 days, whereas, about 80-90% strength was achieved in 14 days. Concrete achieved better strength in case of heated curing. This is attributed to greater dissolution of Si and Al ions in elevated temperature, which leads to formation of stronger polymer chain [20]. Strength achieved by concretes in ambient conditions, at 28 days, is around 70-80% of strength achieved by same concrete mixes in heat curing.

Table 3 Mix design proportions for all constituents of AAS concretes.

CONSTITUENTS OF GPC	(Kg/m^3)
GGBS	400
Fine aggregate	644
Coarse aggregate	1196
NaOH	72
Na_2SiO_3	108
Extra water	11
Super plasticizer	8
Water/ solids ratio	0.24
Slump (mm)	75-100

Table 4 Compressive strength of AAS concrete mixes.

	CURING TYPE	COMPRESSIVE STRENGTH (N/mm^2)		
		7 Days	14 Days	28 Days
G1 HC	Heated	69.2	69.9	72.0
G2 HC	Heated	75.5	75.8	76.9
G3 HC	Heated	59.0	59.6	61.1
G4 HC	Heated	54.0	54.5	55.6
G1 AC	Ambient	35.8	45.9	51.5
G2 AC	Ambient	41.2	48.9	56.2
G3 AC	Ambient	34.1	40.2	48.4
G4 AC	Ambient	27.5	38.7	44.0

With the addition of WFS, compressive strength increased upto a replacement level of 20% but beyond that level strength decreased. This trend was similar in both heat and ambient cured concretes. With addition of 20% WFS, strength of concretes increased by about 7% and 9% in case of ambient and heat cured concretes respectively. On replacement of natural sand by 40% and 60% of WFS also, it was possible to achieve more than 77% of the 28 day strength of reference mix i.e. mix with 0% WFS. Percentage increase/decrease in 28 day compressive strength w.r.t. reference mix i.e. 0% WFS in concretes cured in both conditions is shown in Figure 2.

Split tensile results of concretes were in correlation with compressive strength results. Results of concretes at 28 days age at both heated as well ambient conditions are shown in Figure 3. Tensile strength achieved in ambient cured mixes was about 76-82% of strength achieved in heat curing. Maximum strength was achieved by mix with 20% WFS. Besides, at 40% and 60% replacement of normal sand by WFS, tensile strength more than 85% of strength of reference mix was achievable.

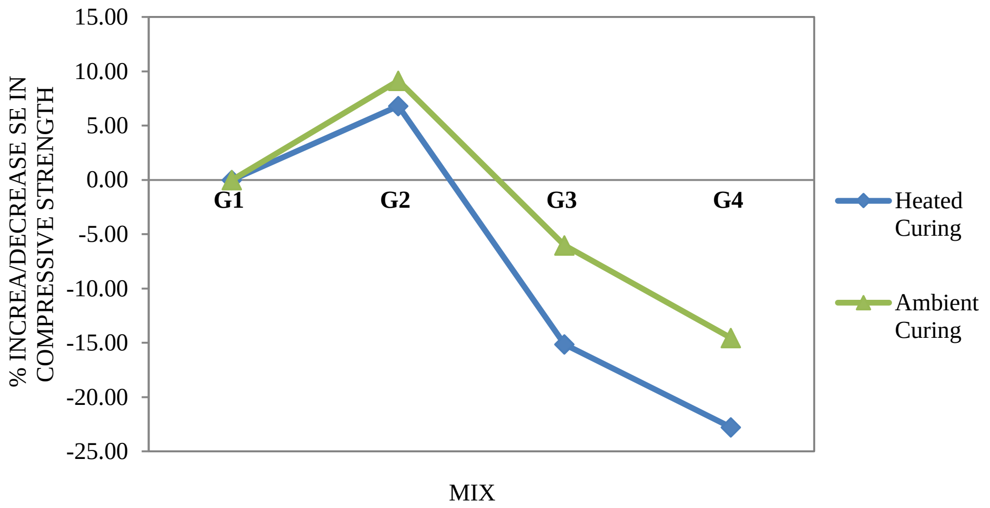


Figure 2 Normalized 28 day compressive strength results of concretes w.r.t. 0% WFS mix in heated as well as ambient cured conditions.

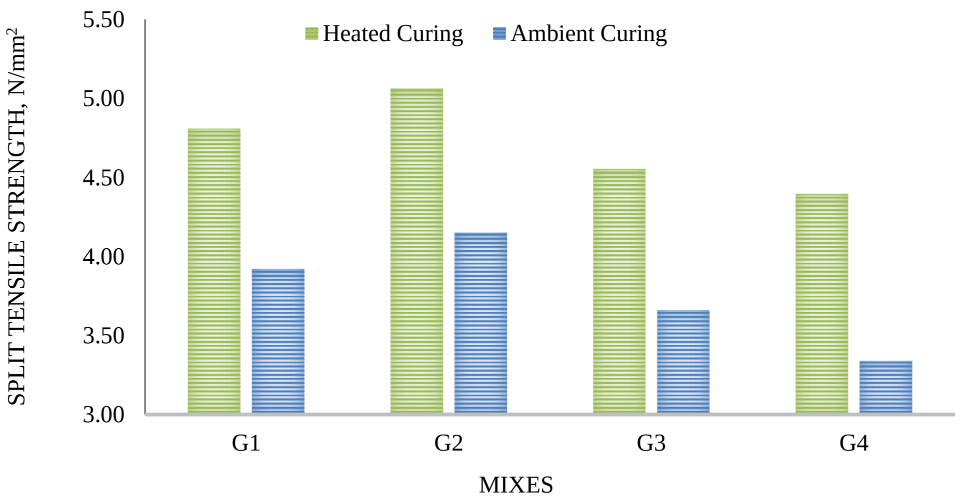


Figure 3 28 day split tensile strength results of concrete mixes.

Rapid Chloride Penetration Test (RCPT)

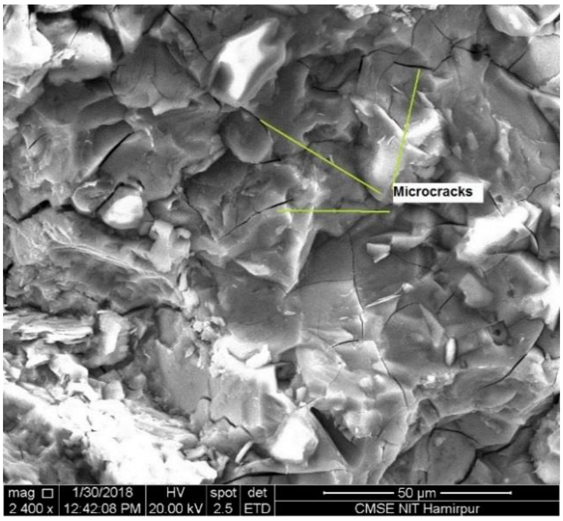
The Rapid Chloride Permeability Test (RCPT) was done in accordance with ASTM C1202-97 [21]. This test is the rapid measurement of the electrical conductance of the concrete with respect to its resistance against chloride ion penetration. Cylindrical discs of size 100 mm diameter and 50 mm thickness were used for this test after attaining 28 days curing age. RCPT results of concrete mixes are shown in Table 5. Inclusion of WFS upto 20% reduced chloride permeability of concretes cured in both conditions. But beyond 20% WFS level, there was rise in permeability of concrete. This is attributable to increase in pores in concrete beyond 20% WFS level due to its unimodal grain size. Besides, all the concretes lied in low to moderate permeability range. This could be due to higher NaOH ratio in the activator which led to increase in ionic concentration, providing more ions to conduct the charge, hence led to increased charge passed. This is dependent on the concentration of NaOH remaining in the pore solution, rather than being absorbed into the C–S–H gel to form N–A–S–H gel [22].

Table 5 Charge passed values of concrete mixes.

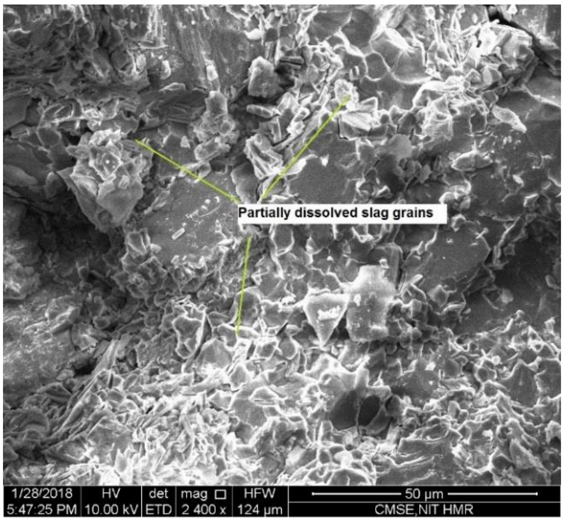
Mix	Charge Passed (Coulombs)	Concrete Permeability
G1 HC	2101	Moderate
G2 HC	1895	Low
G3 HC	2571	Moderate
G4 HC	2995	Moderate
G1 AC	2539	Moderate
G2 AC	2230	Moderate
G3 AC	3135	Moderate
G4 AC	3707	Moderate

SEM Analysis

SEM analysis was undertaken on concrete samples at 28 day age. The SEM imaging was conducted using Field Emission Scanning Electron Microscope, Quanta FEG 450. The visual inspection identified uniformly distributed micro-cracking on the surface of all the concrete samples. The observed micro-cracking is attributed to shrinkage strains [23, 24]. Analysis of SEM images noted that micro-cracks also occurred within the concrete matrix. Law et al. (2012) identified the micro-cracks partially dissolved slag grains, where cracks had formed on the surface of the grains. These micro-cracks are attributed to stress built up as the reaction proceeds [25]. As the reaction follows the microstructure densifies and thus the partially dissolved slag grains become more confined, leading to formation of micro-cracks [25].

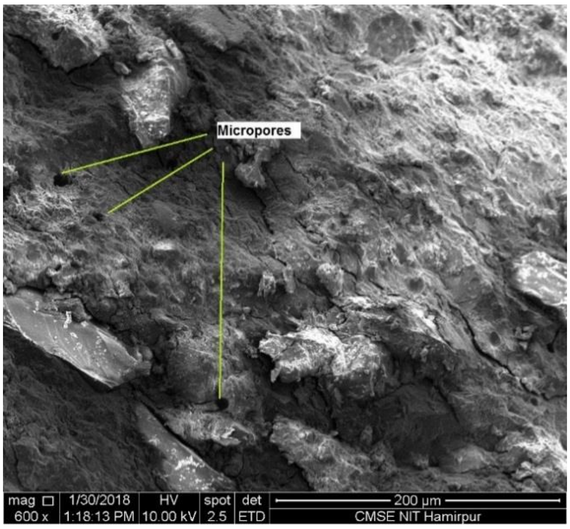


3(a)

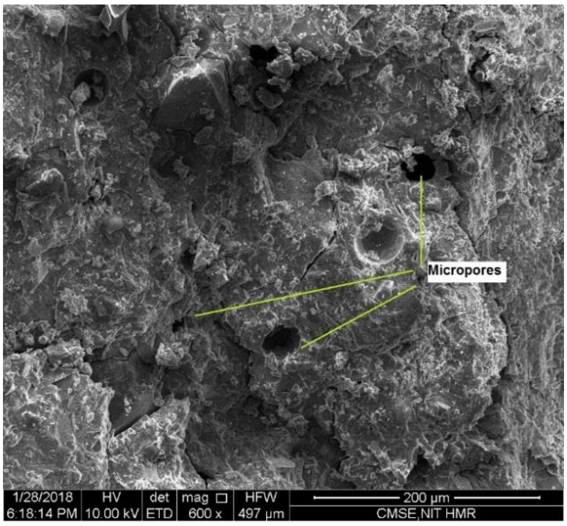


3(b)

Figure 3 SEM images of mix G1 (a) Heat cured (b) Ambient cured



4(a)



4(b)

Figure 4 SEM images of mix G4 (a) Heat cured (b) Ambient cured

The microstructure of heat cured AAS concretes was more refined as compared to ambient cured samples as shown in Figure 3(a) and Figure 3(b). In ambient cured samples a number of partially dissolved slag grains were visible. In both ambient and heat cured samples, with increase in WFS content there was observed increase in micro-pores as shown in Figure 4(a) and Figure 4(b). The increase in micro-pores in the microstructure of concretes, with increased WFS content, correlates with the strength and durability results. Besides, presence of micro-cracks may also have caused increased chloride permeability in all the concretes.

CONCLUSIONS

- Inclusion of WFS as partial replacement to NA lead decreased the workability of concrete due to finer particles of WFS.
- Upto 20% replacement by WFS resulted in superior strength properties in case of both ambient and heat cured samples. Besides, heat cured samples had better strength results than ambient cured samples. Strength achieved in 28 days ambient curing was about 70-80% of strength achieved in heat curing.
- At high replacement levels (40% and 60%) also, more than 85% of the 28 day strength of reference concrete (0% WFS) was achievable. At all replacement levels and at both curing regimes, strength achieved exceeded the target strength of 40 N/mm^2. The split tensile strength results showed a trend similar to compressive strength.
- All the AAS concretes lied in low to moderate chloride permeability range.
- There was visible surface micro-cracking as well as micro-cracks inside the concrete matrix attributable to shrinkage strains.

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REFERENCES

1. DAVIDOVITS J, Geopolymers: Inorganic Polymeric New Materials. Journal of Thermal Analysis, Vol. 37 (8), 1991, pp 1633–1656.
2. DUXSON P, PROVIS J L, LUKEY G C, VAN DEVENTER J S, The role of inorganic polymer technology in the development of 'green concrete'. Cement and Concrete Research, Vol.37 (12), 2007, pp 1590–1597.
3. PROVIS J L, VAN DEVENTER J S J, (Eds.), Geopolymers: Structures, processing, properties and industrial applications, CRC Press, 2009.
4. WANG S D, SCRIVENER K L, Hydration products of alkali activated slag cement. Cement and Concrete Research, Vol. 25 (3), 1995, pp 561–571.
5. SHI C, DAY R L, Selectivity of alkaline activators for the activation of slags. Cement Concrete and Aggregates, Vol. 18 (1), 1996, pp 8–14.
6. FERNÁNDEZ-JIMÉNEZ A, PALOMO A, Composition and microstructure of alkali activated fly ash binder: effect of the activator. Cement and Concrete Research, Vol. 35 (10), 2005, pp 1984–1992.
7. PALOMO A, GRUTZECK M W, BLANCO M T, Alkali-activated fly ashes: a cement for the future. Cement and Concrete Research, Vol. 29 (8), 1999, pp 1323–1329.
8. CRIADO M, APERADOR W, SOBRADOS I, Microstructural and mechanical properties of alkali activated Colombian raw materials. Materials, Vol. 9 (3), 2016, pp 158.
9. C. Tennakoon, K. Sagoe-Crentsil, R. San Nicolas, J.G. Sanjayan, Characteristics of Australian brown coal fly ash blended geopolymers, Constr. Build. Mater. 101 (2015) 396–409.
10. DOLAGE D A R, DIAS M G S, AND ARIYAWANSA C T, British Journal of Applied Science and Technology, Vol. 3(4), 2013, pp 813–825.
11. BHARDWAJ B AND KUMAR P, Waste foundry sand in concrete: A review Construction and Building Materials, Vol. 156, 2017, pp 661-674.
12. SIDDIQUE R, SINGH G, Utilization of waste foundry sand (WFS) in concrete manufacturing. Resources, Conservation and Recycling, Vol.55, 2011, 885.
13. SIDDIQUE R, AGGARWAL Y, AGGARWAL P, KADRI E H, AND BENNACER B, (2011). Strength, Durability and Microstructure of concrete made with used-foundry sand (UFS)." Construction and Building Materials, Vol.25, 2011, pp 1916-1925.
14. JOY J S, MATHEW M, Experimental study on geopolymer concrete with partial replacement of fine aggregate with foundry sand. International Journal of Advances in Technology and Engineering Sciences, Vol. 3, 2015, pp 559–569.
15. SIDDIQUE R, SANDHU R K, Properties of Self-Compacting Concrete Incorporating Waste Foundry Sand. Leonardo Journal of Sciences, Vol. 23, 2013, pp 105–124.
16. BRITISH STANDARDS INSTITUTION. BS 6699, Specification for ground

granulated blastfurnace slag for use with Portland cement. BSI London, 1992. Replaced By : BS EN 15167-1:2006, BS EN 15167-2:2006.

17. BUREAU OF INDIAN STANDARDS. IS 383:1970 Specification for Coarse and Fine Aggregates for Concrete. BIS New Delhi, 1970, p19.
18. BUREAU OF INDIAN STANDARDS. IS 1199:1959 Methods of Sampling and Analysis of Concrete. BIS New Delhi, 1959, p45. Reaffirmed 2004.
19. BUREAU OF INDIAN STANDARD. IS 516:1959 Methods of Tests for Strength of Concrete. BIS New Delhi, 1959, p24. Reaffirmed 1999, Edition 1.2 (1991-07).
20. KUSBIANTORO A, NURUDDIN M F, SHAFIQ N AND QAZI S A, The effect of microwave incinerated rice husk ash on the compressive and bond strength of fly ash based geopolymer concrete. Construction and Building Materials, Vol. 36, 2012, pp 695-703.
21. ASTM C1202, Electrical indication of concrete's ability to resist chloride ion penetration, Annual Book of American Society for Testing Materials Standards C04.02 2000.
22. PROVIS J L AND VAN DEVENTER S J, .Material Science, Vol. 42, 2007, pp 2974–2981.
23. COLLINS F AND SANJAYAN J G, Cracking tendency of alkali-activated slag concrete subjected to restrained shrinkage Cement and Concrete Research, Vol. 30(5), 2000, pp 791–798.
24. KUTTI T, BERNTSSON L AND CHANDRA S, Shrinkage of cements with high content blast furnace slag. In Proc: Fly ash, silica fume, slag and natural pozzolans in concrete. Istanbul, 1992, pp 615–25 (supplementary papers).
25. DAVID W L , ADAM A A, THOMAS K M AND PATNAIKUNI I, Durability assessment of alkali activated slag (AAS) concrete Materials and Structures, Vol.45, 2012, pp 1425–1437.