Durability Properties of Geopolymer Concrete Containing Ground-Granulated Blast Furnace Slag and Black Rice Husk Ash

Tata Sravani and Prasanna Venkatesan Ramani

Abstract Concrete production requires a large amount of Ordinary Portland Cement (OPC) which contributes to enormous carbondioxide emission leading to serious environmental problems. Geopolymer concrete (GPC) is one of the innovative solutions to overcome such environmental issues concerning OPC usage. It is produced by mixing mineral admixtures rich in silica and alumina with alkaline activators resulting in binders due to the polymerization reaction. In this study, GPC was produced using the mineral admixture ground-granulated blast furnace slag (GGBS) as a primary binder which was replaced with black rice husk ash (BRHA) in different proportions of 10, 20 and 30% by weight. A mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) was used as the alkaline activators. After the application of oven curing, the specimens were exposed to acid and seawater resistance tests for 30, 60 and 90 days to evaluate the durability properties of geopolymer concrete. The experimental results showed that the addition of BRHA to geopolymer concrete specimens (GPR1 and GPR2) showed better resistance against acid and seawater as the weight and strength losses were lower for 10 and 20% replacement levels than the control specimens (GP).

Keywords Geopolymer concrete · Ground-granulated blast furnace slag · Black rice husk ash · Acid resistance · Seawater resistance

1 Introduction

Concrete, the widely most used construction material in the world, has gained its popularity because of its several benefits like relatively low cost of production, ease of handling, capacity to be moulded into the desired shape, desired strength ranging from low to very high, serviceability and durability. The principal component of concrete is cement, generally, Ordinary Portland Cement (OPC) which acts as the binder and holds the aggregates intact. However, during the production of OPC, it is found to be

---

T. Sravani (✉) · P. V. Ramani
Assistant Professor (Senior), School of Civil Engineering, Vellore Institute of Technology, Vellore, India
e-mail: tata.sravani2019@vitstudent.ac.in

J. Jayaprakash et al. (eds.), *Advances in Construction Materials and Structures*, Lecture Notes in Civil Engineering 111, https://doi.org/10.1007/978-981-15-9162-4_22

associated with some unfavourable effects to the environment. The manufacturing of OPC is highly energy intensive and produces a high amount of CO_2 into the ambiance which contributes significantly to the 'greenhouse' effect. Bhanumathi das and Mehta [1] have stated that the production of one tonne of cement consumes nearly about 1.5 tonnes of earth minerals, and also one tonne of CO_2 is released into the atmosphere. The raw materials required for cement production are non-renewable and are depleting at a rapid rate. However, at the same time, several industrial and agro-wastes with inherent cementitious properties are produced abundantly. They are mostly disposed into landfills. Employing such by-products as alternates for cement has various benefits including conservation of the environment, the sustainability of resources and solving the disposal problem of by-products. Varadan Vivek et al. [2] pointed out that as per the central statistical organization, there is a drastic change in the increase of industries every year due to the population demand which leads to huge construction and infrastructure projects development. They have highlighted that the manufacturing of cement is a key ingredient in producing the concrete which can be minimized by adding by-products as an admixture to enhance the strength and durability properties of concrete.

Geopolymer concrete, primarily, is introduced by Davidovits [3]. It has recognized that to develop geopolymer concrete, 60% less energy is essential, and it also has 80% less CO_2 emissions than the production of Ordinary Portland Cement Duxson et al.. [4]. Sarath and Ramesh [5], showed the test data of geopolymer concrete achieved by mixing GGBS and metakaolin indicate that on exposure to 5% Na_2SO_4, H_2SO_4 and NaCl, the losses in weight and strength are significantly less than the cement concrete. Several researchers [6], Piyaphanuwat et al. [7] have reported that the addition of BRHA in concrete has improved its durability properties. Naresh Babu et al. [8] have conducted investigation on geopolymer concrete blended with GGBS and phosphogypsum which showed less weight loss in H_2SO_4. Kim et al. [9] have developed the geopolymer concrete based on alkali-activated rice husk ash (RHA) by adding sodium hydroxide with sodium silicate. Durability studies were carried out in acid and sulphate solutions and initiated that geopolymer concrete showed very less weight loss when compared to steam-cured mortar specimens.

The present investigation aims to study the durability properties of GPC usage as an alternative for conventional concrete. The performance of GGBS and BRHA used in the GPC is assessed. The strength and weight loss of GPC prepared with GGBS and BRHA when immersed in acid and seawater solutions are to be found.

2 Materials and Methods

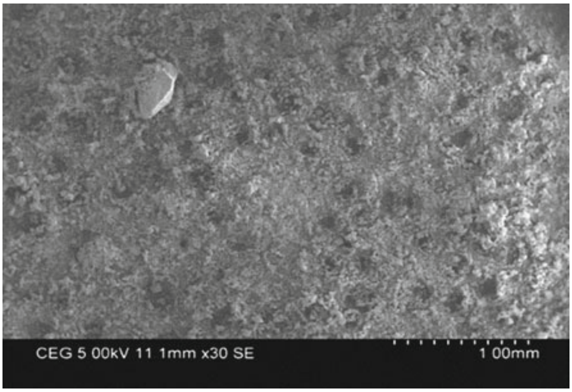
2.1 Ground-Granulated Blast Furnace Slag (GGBS) and Black Rich Husk Ash

GGBS is obtained from JSW Cements Ltd., Bellari, India. GGBS is one of the primary binders to produce geopolymer concrete (GPC) conforming to the specifications of BIS: 12089–1987 [16]. BRHA is obtained from the rice mill near Karaikudi. The BHRA binder was used in percentages of 0, 10, 20 and 30% along with GGBS. The size of the material should pass from 75 μ sieve. The test data (as per ASTM-D: 3682–01) properties are collected from SGS Laboratories, Chennai, and are shown in Table 1. Figures 1 and 2 show the SEM results of the particle distribution of GGBS and BRHA.

Table 1 Results of GGBS and BRHA

Properties	Test results	
	GGBS	BRHA
Silicon dioxide (SiO_2)	31.25%	93.96%
Aluminium trioxide (Al_2O_3)	14.06%	0.56%
Ferric oxide (Fe_2O_3)	2.80%	0.43%
Calcium oxide (CaO)	33.75%	0.55%
Magnesium oxide (MgO)	7.03%	0.40%
Loss on ignition	1.52%	9.79%
Specific gravity	2.61	2.14
Blaine fineness	4550 cm^2/g	5673 cm^2/g

Fig. 1 SEM image of GGBS



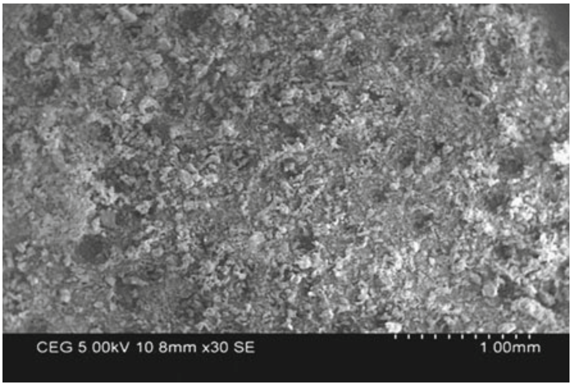


Fig. 2 SEM image of BRHA

Table 2 Experimental results of coarse and fine aggregates

Experiments	Test results	
	Coarse aggregate	Fine aggregate
Fine modulus	6.29	3.54
Specific gravity	2.72	2.61
Zone	I	II
Size of aggregate	20 mm	<4.75 mm
Surface texture	Smooth	Smooth
Particle shape	Angular	Angular

2.2 Aggregates

The tests on physical properties of coarse and fine aggregates were conducted as per BIS: 2386–1963 [17] and BIS: 383–1987 [18]. The test results are given in Table 2. The fineness modulus of aggregates represents the average size of the particles by an index number which is calculated by performing sieve analysis. The specific gravity of aggregates is in the range of 2.5–3.0. The aggregates size, texture and shape are selected as per IS:456–2000, which prescribes that the nominal size of coarse aggregates should be 20 mm and fine aggregates to be chosen <4.75 mm size with a smooth texture and angular shape for bonding purpose.

2.3 Alkaline Solution

The alkaline solution was prepared using sodium hydroxide and sodium silicate. The purity of NaOH is maintained between 97 and 100%, and the composition of Na_2SiO_3 is prepared by adding Na_2O (14.7%), SiO_2 (29.4%) and water (55.6%) by mass. The ratio of alkaline liquid to binder was taken as 0.4. The concentration of sodium hydroxide was taken at 8M, and the ratio of NaOH to Na_2SiO_3 was taken as 2.5.

2.4 Superplasticizer

The superplasticizer of 2% (Naphthalene) was added to reduce the usage of water, attaining early strength and enhancing the workability of fresh properties of geopolymer concrete.

2.5 Water

Water also plays an important role in the preparation of GPC. 15% of extra water was also added to the binder content to amplify the workability of the geopolymer concrete.

3 Methodology

To produce the GPC mix, it is essential that it requires careful selection and proportioning of the ingredients which are almost the same as the conventional concrete. The GPC mix design process is developed for low calcium-activated geopolymers using alkaline activator solutions. The density of geopolymer concrete was assumed as 2400 kg/m^3, and 30 MPa was assumed as a minimum targeted strength due to the lack of availability of codal provisions. The calculations were made based on the density of concrete as per the mix design given by Lloyd and Rangan [10]. Based on that method, by withholding the total aggregates content from the density, the total mass of GGBS and alkaline activator solution was attained. The combined total volume occupied by the coarse and fine aggregates was assumed to be 77%. The alkaline liquid to binder ratio was taken as 0.40. The targeted compressive strength and workability were determined using water to geopolymer solid ratios. In this investigation, GGBS was used as the control specimen for preparing geopolymer concrete (GPC), and the BRHA was varied in terms of GPR1-10%, GPR2-20% and GPR3-30%. Table 3 shows the mix proportions in terms of quantities.

4 Preparation of Test Specimens

All the ingredients, in dry condition, were weighed and mixed thoroughly in pan mixer up to 3–4 min. The alkaline solution was prepared by combining the sodium

Table 3 Mix proportions of GPC

Raw materials	Proportions (kg/m^3)			
	GP	GPR1	GPR2	GPR3
GGBS	394	355	315	276
BRHA	0	39	79	118
Coarse aggregate	1201	1201	1201	1201
Fine aggregate	647	647	647	647
Sodium hydroxide	45	45	45	45
Sodium silicate	113	113	113	113
Superplasticizer	8	8	8	8
Water	59	59	59	59

hydroxide and sodium silicate solutions in the ratio of 1:2.5. Subsequently, this solution was added to the dry mix. For improving the workability, 15% of extra water was added by the weight of the binder in addition to 2% of superplasticizer. For each test, nine specimen samples of each mix were prepared and cured at a temperature of 60 °C constant temperature for 24 h to sustain the rate of polymerization and setting of GPC. After de-moulding, the cubes were again placed in the oven with the same temperature for another 24 h. The specimens were then allowed to room temperature until the day of testing.

5 Results and Discussion

5.1 Acid Resistance Test

The GPC cubes of 100 mm × 100 mm × 100 mm were cast and tested for acid resistance after 28 days. At the outset, the weight of each specimen was measured, and for assessing the loss in compressive strength, the initial characteristic compressive strengths of the respective mixes were measured. Then the specimens were immersed separately in 3% hydrochloric acid (HCl) and 3% sulphuric acid (H_2SO_4) solutions for a period of 30, 60 and 90 days from the day of immersion. On the day of the testing, the specimens were taken out, cleaned and measured the weight. Subsequently, the specimens were tested using the compression testing machine of 2000 kN capacity at a uniform rate of loading of 140 kg/cm^2/min as per BIS: 516-1959 [19] test procedure. The losses in weight and the compressive strength of the GPC were then determined. The results of strength and weight losses of H_2SO_4 and HCl are shown in Tables 4 and 5. Figures 3 and 4 show the performance of weight loss and % compressive strength loss of GP and GPR specimens exposed to H2SO$_4$ and HCl for a period of 30, 60 and 90 days.

Table 4 Weight and compressive strength loss of GPC specimens exposed to H2SO$_4$

(a)

Mix	Initial Weight at 28 days (kg)	Weight loss after immersion (%)		
		30 days	60 days	90 days
GP	2.53	0.25	3.45	6.1
GPR1	2.51	0.1	2.85	4.9
GPR2	2.48	0.1	3.1	5.2
GPR3	2.44	0.4	5.6	10.8

(b)

Mix	Initial Characteristic Compressive Strength at 28 days (kg)	% Compressive strength loss after immersion		
		30 days	60 days	90 days
GP	69.3	3.3	10.25	15.2
GPR1	70.7	2.9	9.6	13.4
GPR2	51.5	3.2	10	13.9
GPR3	24.5	9.8	24	39.5

Table 5 Weight and compressive strength loss of GPC specimens exposed to HCl

(a)

Mix	Initial Weight at 28 days (kg)	Weight loss after immersion (%)		
		30 days	60 days	90 days
GP	2.53	0	1.8	4
GPR1	2.51	0	1.15	3.1
GPR2	2.48	0	1.4	3.5
GPR3	2.44	0.2	3.8	8.6

(b)

Mix	Initial Characteristic Compressive Strength at 28 days (kg)	% Compressive strength loss after immersion		
		30 days	60 days	90 days
GP	69.3	2.1	8.8	12.4
GPR1	70.7	1.8	8.5	11.5
GPR2	51.5	1.9	9.1	12.1
GPR3	24.5	7.1	16.3	24.6

The exposure of GPC specimens to 3% H_2SO_4 solution reveals that, in terms of both weight and strength losses at 30, 60 and 90 days, the control specimens showed higher losses at all three testing periods. GPR1 and GPR2 specimens showed lower losses than the control specimen GP, which indicates that the addition of BRHA had a positive effect on the acid resistance of GPC. For instance, at 90 days of exposure to H_2SO_4, there was a 12% lesser weight loss for GPR1 specimens and 9% for GPR2 specimens while comparing the control GPC specimens. The strength

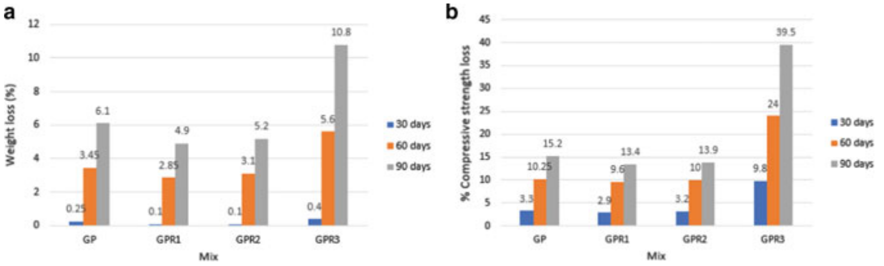


Fig. 3 **a** Weight loss of GPC on exposure to H_2SO_4. **b** Strength loss of GPC on exposure to H2SO4

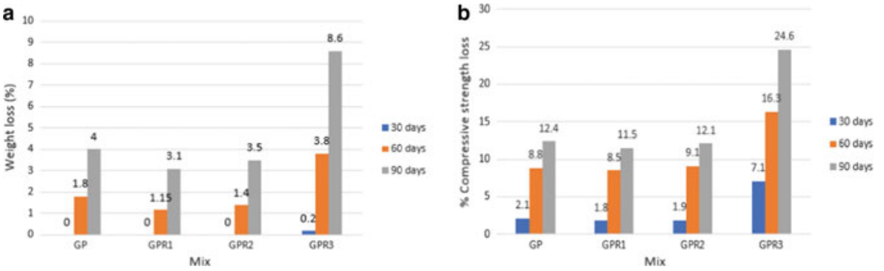


Fig. 4 **a** Weight loss of GPC on exposure to HCl. **b** Strength loss of GPC on exposure to HCl

losses are 18 and 13% lower for GPR1 and GPR2 against the control specimens at 90 days of exposure. The finer BRHA particles enhanced the dissolution of silica and alumina ions to form a stronger geopolymer matrix resulting in more resistive passive layer against the attack of sulphate ions. However, when the BRHA addition was increased to 30%, the losses suddenly amplified. This effect can be possibly due to the irregular silica–alumina ratio resulting with excess BRHA [11], which can also be inferred from the material property of BRHA where the silica content is as high as 93.96% while the alumina content is only 0.56%. The results are comparable with Rajamane et al. [12] *where the GGBS-based GPC specimens showed compressive strength losses of* 3.7, 10 and 11.1 *after exposure to* 2% H_2SO_4 at 30, 60 and 90 days, *respectively.* Exposure to HCl also showed a similar trend with addition of BRHA lowering the weight and strength losses. But the losses are less severe than that of H_2SO_4 which seemed to have cause more aggressive attack on concrete than HCl. The action of $H2SO_4$ on concrete is more aggressive due to the combination of acid and sulphate attack Barbhuiya and Kumala, [13].

5.2 Seawater Resistance Test

For evaluating the seawater resistance, the test procedure was similar to that of the acid resistance test. The prepared specimens were cured for 28 days and immersed in the seawater mediate obtained from the shore of the Bay of Bengal near Thiruvanmiyur, Chennai, for periods of 30, 60 and 90 days. Prior to immersion in seawater, the weight of specimens and the characteristic compressive strength were measured. After 30, 60 and 90 days of immersion in seawater, the specimens were taken out, and the surfaces were cleaned, weighed, and subjected to axial load at a rate of 140 kg/cm^2/min. The weight loss and compressive strength loss measurements were calculated for each period of immersion. The results of strength and weight losses of GPC exposed to seawater are shown in Table 6. Figure 5 shows the variation in weight loss and % compressive strength loss of GP and GPR specimens exposed to seawater for periods of 30, 60 and 90 days.

From the obtained results, no significant weight losses were observed in all mixes at 30 days of exposure. With continued exposure to seawater, the specimens suffered significant weight loss at 60 and 90 days. The weight and compressive strength losses of GPR1 were, respectively, 12 and 32% lower than that of a control specimen GP

Table 6 Weight and compressive strength loss of GPC specimens exposed to seawater

(a)

Mix	Initial Weight at 28 days (kg)	Weight loss after immersion (%)		
		30 days	60 days	90 days
GP	2.53	0.2	4.7	8.8
GPR1	2.51	0.15	4.1	7.6
GPR2	2.48	0.2	5.2	9.3
GPR3	2.44	0.3	8.8	17.1

(b)

Mix	Initial Compressive Strength at 28 days (kg)	% Compressive strength loss after immersion		
		30 days	60 days	90 days
GP	69.3	6.5	13.4	22.7
GPR1	70.7	5.9	11.3	19.4
GPR2	51.5	6.8	14.6	25.6
GPR3	24.5	9.2	26.5	42.6

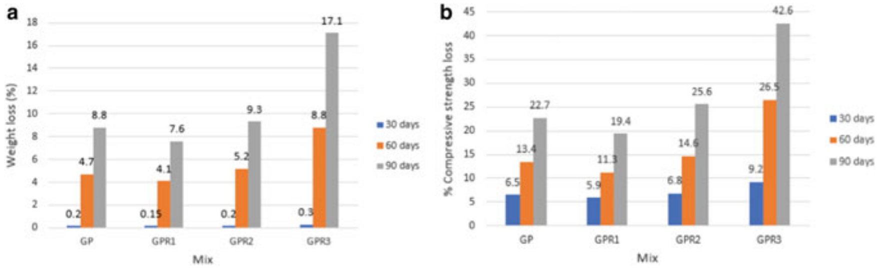


Fig. 5 **a** Weight loss of GPC on exposure to Sea water. **b** Strength loss of GPC on exposure to seawater

at 90 days of immersion. But the weight losses were slightly higher (around 5%) for GPR2, in comparison with control GP specimens at 60 and 90 days. Strength losses too exhibited a similar increasing trend for the GPR2 mix against GP control mix. GPR3 specimens showed maximum losses in weight and compressive strength at all the three different exposure periods. This was due to the interconnectivity of the increased pores allowed rapid chloride ion movements from the outer to the inner side of concrete resulting in deterioration and weight loss [14]. The surface of the GPC specimens showed visible stains at 30 days and continued to deteriorate with time. Significant surface erosion was observed after 90 days of exposure to seawater. Similar results were reported by Omer et al. [15]. By comparing the acid resistance test, the reduction in compressive strength of GPC was relatively greater at 60 days and 90 days. Under the action of seawater, the higher leaching of alkalis in the specimens altered the integrity of the geopolymer alumino-silicate network which contributed to the higher losses Olivia and Nikraz, [14].

6 Conclusions

Based on the experimental investigation, it can be concluded that GPC made with GGBS and BRHA could perform remarkably well in the durability criteria. The addition of BRHA improves the durability of GPC. After 90 days of exposure to H2SO$_4$, the weight and strength losses of GPR1 and GPR2 were 12 and 9% lesser than control GP specimens, respectively. Similar behaviour was observed for the specimens exposed to HCl, where the addition of BRHA in proportions of 10 and 20% showed better resistance than the control GP specimens in terms of strength and weight losses. Against the action of seawater, the addition of BRHA upto 10% exhibited beneficial effect of minimizing the strength and weight losses in GPC. However, beyond 20% BRHA proportion, the specimens performed poorly in all the tests owing to poor structural compatibility from inappropriate silica–alumina ratio. It can be concluded that GPC can be highly useful as an alternative durable construction material. Besides minimizing the CO$_2$ emission, GPC production utilizes industrial wastes like GGBS and BRHA for generating the binding system in concrete, which will also alleviate their disposal problem.

References

1. Bhanumathidas N, Mehta PK (2001) Concrete mixtures made with ternary blended cements containing fly ash and rice-husk ash. In: 7th CANMET/ACI international conference on fly ash, silica fume, slag and natural Pozzolans in concrete. Chennai, India, pp 22–27
2. Vardhan Vivek CM, Anitha A, Sravani T (2015) Use of partially treated wastewater of battery industry in cement mortars. J Environ Res Develop 9(3A):933–943
3. Davidovits J (1999) Chemistry of geopolymeric systems, terminology. Geopolymere ’99 conference. Saint-Quentin, France, pp 9–22

4. Duxson P, Provis JL, Lucky GC, Van Deventer IS (2007) The role of inorganic polymer technology in the development of green concrete. Cem Concr Res 37(12):1590–1597
5. Sarath CKB, Ramesh (2017) Durability studies of GGBS and metakaolin based geopolymer concrete. Int J Civil Eng Technol 8(1):17–28
6. Chatveera B, Lertwattanaruk P (2009) Evaluation of surface resistance of cement mortars containing black rice husk ash. J Environ Manage 9(3):1435–1441
7. Piyaphanuwat R, Asavapisit S, Buddhawong S (2005) Effects of elevated temperature curing on strength and leachability of the solidified wastes using lime and BHA as solidification binder. Suranaree J Sci Technol 91–97
8. Naresh Babu Y, Sudarsana Rao H, Ghorpade VG (2017) Strength and durability studies on geopolymer concrete blended with GGBS and phosphogypsum. Int J Chem Tech Res 10(6):987–994
9. Kim YY, Lee BJ, Saraswathy V, Kwon SJ (2014) Strength and durability performance of alkali-activated rice husk ash geopolymer mortar. Hindawi Publishing Corporation, The Scientific World Journal, pp 1–10
10. Lloyd NA, Rangan BV (2010) Geopolymer concrete with fly ash. In: Second international conference on sustainable construction materials and technologies. Ancona, Italy
11. Rajesh M, Chachithanantham S, Ramaswamy A (2016) Performance and behaviour of GGBS imparted to geoploymer concrete structural elements and analysed with ANSYS. Adv Mater Sci Eng 7023897:1–9
12. Rajamane NP, Nataraja MC, Dattatreya JK, Lakshmanan N, Sabitha D (2012) Sulphate resistance and eco-friendliness of geopolymer concretes. Indian Concr J 86:13–21
13. Barbhuiya S, Kumala D (2017) Behaviour of a sustainable concrete in acidic environment. Sustainability 9:1556–1568
14. Olivia M, Nikraz H (2013) Properties of fly ash geopolymer concrete in seawater environment. In: Proceedings of the 13th east asia-pacific conference on structural engineering and construction. Sapporo, Japan
15. Omer SA, Demirboga R, Khushefati WH (2015) GGBFS based geopolymer mortars immersed in sodium and magnesium sulphate solutions and sea water. Int J Eng Res Technol 4:377–384
16. BIS 12089–1987 Specification for granulated slag for the manufacture Portland slag cement. Bureau of Indian Standard, New Delhi
17. BIS 2386–1963 Methods of testing for aggregates for concrete, specific gravity, Density, absorption and organic impurities. Bureau of Indian Standard, New Delhi
18. BIS: 383–1987, Specification for coarse and fine aggregate from natural sources for concrete. Bureau of Indian Standard, New Delhi
19. BIS: 516–1959 Methods of test for strength of concrete. Bureau of Indian Standard, New Delhi