

Properties of Foundry Sand, Ground Granulated Blast Furnace Slag and Bottom Ash Based Geopolymers under Ambient Conditions

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Abstract

This paper presents a feasibility study on the manufacture of geopolymer concrete at low concentrations of alkaline solutions and lower densities and incorporating waste products like Foundry sand without compensating for the strength properties. Ground Granulated Blast Furnace Slag (GGBFS) and Bottom ash (BA) were used as source materials. From the preliminary studies, the replacement of Foundry sand to Natural sand is taken as 50:50. The density range was taken as 1800 Kg/m³, 2000 Kg/m³, 2200 Kg/m³ and 2400 Kg/m³. Sodium Hydroxide (NaOH) and Sodium Silicate (Na₂SiO₃) were used as alkaline activators and the molarity of NaOH solution was reduced from 8 M upto 4 M. The percentage ratio of BA-GGBFS was selected as 0, 25, 50, 75 and 100. The ratio of Alkaline liquid to Binder content was taken as 0.4 and the molar ratio of NaOH solution was kept as 1. The ratio of Sodium silicate solution to Sodium hydroxide was taken as 2. Ambient curing was adopted for all the mixes. The properties of Geopolymer concrete paver blocks such as Compressive strength, flexural strength and split tensile strength, water absorption, Acid attack and Water absorption were conducted as per IS 15658:2006. Test results show that satisfactory strength properties of geopolymer concrete using Foundry sand can be achieved even with lower concentrations of NaOH solution under ambient curing conditions. This would pave way for creating a greener environment by the efficient use of byproducts and waste materials in concrete.

Keywords

ground bottom ash · curing · molarity · molar ratio · compressive strength

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1 Introduction

With the population increase on the hike and subsequent technological advancements the quantities of consumption and waste production are also mounting. As a result, many researchers and scientists are finding ways to minimize these wastes or as a better alternative to use them as resources with added values. In the recent years, one of the sectors that is experiencing massive increase in the generation of waste, particularly ash, are the hydro-electric power plants generating electricity to cater to the needs of the ever increasing population. In this respect, utilization of Bottom Ash (BA) collected from the boilers for making geopolymer concrete has emerged as an alternative yet a most promising utility in the construction industry [2, 3].

Use of these industrial by products eliminates to a great extent the negative effects associated with the disposal problems and minimization techniques.

Geopolymers invented by Prof. Joseph Davidovits in 1978 and were initially developed to serve as a fire resistant material, but it has now gained momentum as an effective alternate to cementitious binders to limit greenhouse gas emissions. He coined the term Geopolymers for a class of materials rich in Silica (Si) and Alumina (Al) activated by alkaline solutions. Although Fly ash and Bottom ash are obtained from the same source, they have more or less similar chemical compositions [4–7]. But as of now, only Fly ash has found a prominent place in cement replacement when compared to Bottom ash. [8–10]. Of the total ash generated, nearly 80% of Fly ash and only 20% of Bottom ash has been used while the rest of it has been discarded in landfills. Fly ash has been mostly used because of the quality of the end products and also significant environmental benefits derived from reduced CO₂ and energy consumption [11, 12]. Other minor calcined wastes such as bottom ash and pond ash has not received much attention. This is due to the reason that although Fly ash and Bottom ash are obtained from the same source their physical and phase properties are different. Fly ash consists of fine spherical particles whereas Bottom ash as obtained has angular fragments and less spherical particles with less glassy constituent phase [13, 14]. Hence, Bottom ash has cannot be used as such and has to be grinded to increase the surface area and

reactivity. Also bottom ash contains toxic elements which leach out in due course and contaminate the soil [7, 10, 15]. The utilization of bottom ash as replacement to cement has not yet been well acknowledged as itself is porous and increases the water requirement of the mix [10, 16, 17]. In contrast Bottom ash retains the water added and releases it during mixing and the workability of fresh geopolymer mortar is increased with increase in Bottom upto 75% beyond which it decreases due to interparticle friction [18]. Hence an effective utilization of bottom ash as construction material will significantly eliminate the disposal problems as well as environmental pollution.

Ground Granulated Blast furnace slag, a by product obtained from the steel industries is a glassy, granular, non metallic material consisting essentially of silicates and aluminates of calcium and other bases. Addition of GGBFS is said to enhance geopolymerisation and increase the compressive strength mix [[19–23], Ambily (2011,2012)]. Moreover GGBFS proves to be an effective binder to produce better quality than Ordinary Portland Cement concrete (OPC) [25,26]. Increase in the slag quantity increases the C-S-H [Calcium-Silicate-Hydrate] gel and ultimately the compressive strength [27]. Incorporation of slag in combination with flyash produces structural grade concretes much better than that specified in BIS 456-2000 [23]. On the contrary, utilization of slag in geopolymer poses a major drawback due its high CaO content. Geopolymer paste with high CaO content cured at 60°C showed a compressive strength of 30 MPa [29], whereas geopolymer with less CaO in GGBFS exhibited a compressive strength of 60 MPa [30, 31]. Use of GG-BFS in geopolymer reduced the workability when compared to Fly ash but it attained higher compressive strengths at early ages when compared to Fly ash [22].

At present only limited research activities are in progress in utilizing Bottom ash and GGBFS as cement replacement in geopolymer concrete [8–10, 32]. Owing to its coarser shape and size Bottom ash in combination with GGBFS has been mainly used only after grinding as a replacement for fine aggregates in concrete [[5–7, 33, 35, 36], Siddique (2003)]. But the grinding process is highly energy intensive as the Embodied Energy increases on grinding. Also the embodied energy of Fly ash-GGBFS geopolymer concrete is (1265.73 MJ) 40% less than that of OPC (2083.33 MJ) [37]. Hence an attempt has been made to utilize these by products with minimal processing.

During the last 10 years it has become evident that good quality natural sand has been decreasing at an enormous rate as that of increasing industrialization and urbanization. Also there has been a lot of environmental concerns against indiscriminate mining of natural river sand. The above concerns have led the construction sector to opt for alternative materials in concrete which would reduce the depletion of natural resources without compromising for quality. Recently researchers have found many eco-friendly materials and industrial by products that could be used effectively as aggregate replacement materials of which Foundry sand is taken as a primary concern. There

are more than 5000 foundry units in India with an installed capacity of approximately 7.5 million tons/annum, the majority of which falls under the small scale category. Coimbatore is an important foundry cluster in south india. It caters to the needs of local textile and pump-set industries. There are nearly 600 foundry units in Coimbatore, out of which nearly half are manufacturing castings for pump set industry. Foundries use sand for casting moulds which could be ferrous or non-ferrous. These sands are reused and recycled many times and finally discarded as spent foundry sand. There are many fine aggregate replacement materials like sheet glass powder, crushed granite aggregate, spent fire bricks, CCB's, crushed building and demolition wastes and Foundry sand (FS) which could be incorporated in concrete and masonry works [47]. Out of these Foundry sand contains primarily of silica and can be used in place of natural river sand or as fillers effectively [42,43]. The incorporation of foundry sand in concrete and masonry works reduces the workability which could be improved by adding higher quantities of superplasticizer for the given w/c ratio [42, 44, 46]. The compressive strength increases with the increase in the quantity of foundry sand with maximum strength being achieved for 50% replacement of cement [42, 44, 45]. Also split tensile strength is maximum upto 15% replacement for Washed foundry sand and 70% for spent foundry sand. Also ferrous washed foundry sand gives more strength than non-ferrous washed foundry sand. But ferrous foundry sand can be replaced upto 20% and non ferrous sand upto 10% for maximum strength [45]. Moreover the modulus of elasticity is highest for 30% replacement [42]. The USPV value increases with the increase in the percentage of washed foundry sand and it increases with age which is higher than conventional concrete [45].

Researches show that an increase in alkaline liquid to binder ratio increases the workability and the attained a maximum strength of 52 MPa for a ratio of 0.4. This may be due to larger interparticle distance and lower particle interference [10]. Also the increase in the ratio of Na_2SiO_3 to NaOH beyond 1.5 decreased the strength of geopolymer concrete. This may be due to the fact that Na_2SiO_3 was more viscous than NaOH and the difficulty in compaction [10, 38]. Increase in the concentration of NaOH solution upto 12 M increases the strength proportionally while decreasing the workability. Increase in strength with increasing molarity of NaOH solution may be mainly due to the leaching out of silica and alumina and high $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ ratios [8, 10, 38]. Also higher molarity helps to break the glassy structure of the source materials which aids the Si and Al to enhance Geopolymerisation. Decrease in the molar ratio of SiO_2 to Na_2O of Sodium silicate solution increases the strength as increase in the Na ions concentration were used to balance the charges and form alumino silicate networks [10].

Many researchers suggest that higher concentration of sodium hydroxide is essential for achieving high strengths in geopolymer concrete [39]. However due attention is to be paid on the ill effects of higher concentration. Mild to moderate respira-

tory irritation is experienced at a higher concentration of sodium hydroxide [40]. Sodium hydroxide is strongly corrosive and a powerful irritant by all means of exposure (inhalation, ingestion, skin contact and eye contact). When inhaled, mist or dust containing sodium hydroxide will cause irritation and burning of the nasal passages. Furthermore, a large extent of work on geopolymers have revealed that Steam or Heat curing enhances Geopolymerisation.

The rate of increase in compressive strength with the age of concrete is more significant in the case of ambient curing when compared to heat curing at 60°C [37]. Moreover the density of Geopolymer concrete is taken in the range of 2300 to 2400 Kg/m³ as in the case of OPC. Besides, with the selection of suitable Density and Molar ratio of NaOH solution it is feasible to achieve a more user friendly products. The present study is undertaken with the objective of using, low concentrations of NaOH solution from 4 M to 8 M which would be human friendly, utilizing BA, GGBFS and Foundry sand with minimal processing with variation in density and to find the probable mix composition for BA-GGBFS-FS Geopolymer concrete blocks at ambient temperature.

2 Materials and Experimental Details

2.1 Materials

Bottom ash:

Bottom ash used in this study was obtained from Mettur thermal power Station. Mettur thermal power plant has 4 units which are coal based and it has shown 180.21% of fly ash utilization during the year 2011-12 [Annexure – I, Report on Fly ash generation, Central electricity Authority, 2011-12]. Bottom ash was obtained in wet condition and was coarser. Bottom ash particles as received from the boilers possessed a glassy structure and were angular. Its specific gravity was 2.3. Scanning Electron Microscopy(SEM) image of Bottom ash shown in Fig. 1 revealed that it contains spherical shaped particles similar to Fly ash. EDAX of Bottom ash is shown in Fig. 2. It can be seen that the bottom ash is mainly composed of large percentages of Silica and Alumina similar to Fly ash. Table 1 shows the chemical composition of Bottom ash, GGBFS and Foundry sand.

Ground granulated blast furnace slag:

GGBFS was obtained from Agni steel plant, Ingur. The specific gravity of GGBFS was 3.1. The SEM image of GGBFS shown in Fig. 3 reveals that GGBFS particles were crystalline and angular when obtained. It can be seen that GGBFS contains more silica and CaO when compared to Bottom ash (Fig. 4).

River Sand

Locally available river sand conforming to grading zone III as per BIS 383:1970 was used as a fine aggregate in this work. Fineness modulus and specific gravity of river sand in the natural state was found to be 2.26 and 2.63 respectively.

Foundry sand

Fineness modulus and specific gravity of foundry sand in the natural state was found to be 3.36 and 2.61 respectively. Fig. 7 shows the sieve analysis of River sand and Foundry sand.

Coarse aggregate:

6mm chips complying with the requirements of BIS 383:1970 were used as coarse aggregates.

Alkaline activators:

A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. The sodium silicate solution (Na₂O = 13.7%, SiO₂ = 29.4%, and water = 55.9% by mass) and sodium hydroxide (NaOH) in flakes 97% to 98% purity were purchased from a local supplier in bulk. The activator solutions were prepared and mixed at the time of making geopolymer concrete.

Water:

Potable water was used for mixing the alkaline activators. Water used in this study confirmed the requirements of BIS 456:2000.

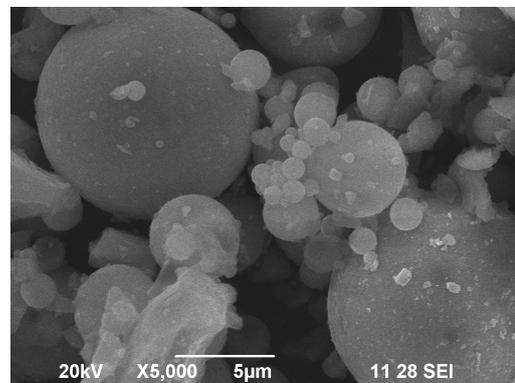


Fig. 1. SEM image of Bottom Ash

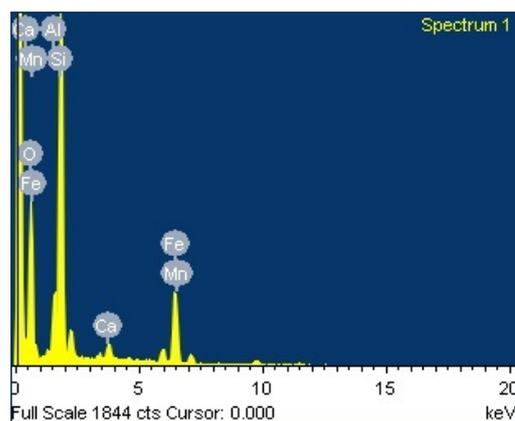


Fig. 2. EDAX of Bottom Ash

2.2 Experimental Details

2.3 Mix proportions of BA-GGBFS paver blocks

The mix design for geopolymer concrete was followed as per BIS codal provisions for ordinary Portland concrete but with some modifications [41]. The ratio of Binder content to Sand was kept as 1:3. BA was varied in percentages ranging from 0, 25, 50, 75 and 100. Density was varied as 1800, 2000, 2200 and

Tab. 1. Chemical composition of Bottom ash, GGBFS and Foundry sand

Chemical Compositions(%)	Bottom ash	GGBFS	Foundry sand
Al ₂ O ₃	26.68	32.58	0.021
SiO ₂	29.15	51.50	83.93
SO ₃	0.51	5.19	0.057
CaO	1.814	40.50	1.03
MgO	1.51	0.21	1.77
Na ₂ O	1.05	1.35	-
LOI	1.15	1.5	2.19
K ₂ O	0.53	0.56	-
Fe ₂ O ₃	7.28	-	0.950

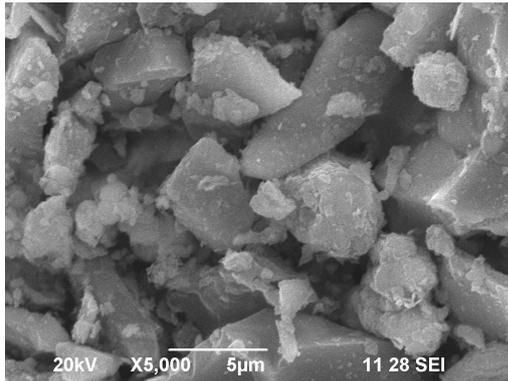


Fig. 3. SEM image of GGBFS

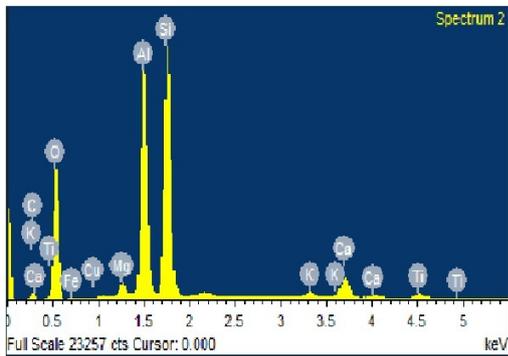


Fig. 4. EDAX of GGBFS



Fig. 5. River Sand



Fig. 6. Foundry Sand

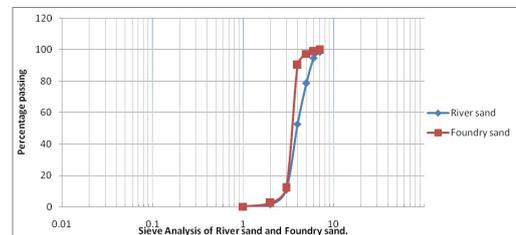


Fig. 7. Sieve Analysis of River sand and Foundry sand

2400 Kg/m³. The alkaline liquid to binder ratio was selected as 0.4 and the ratio of Na₂SiO₃/NaOH was kept as 2. The Molar ratio of Sodium silicate was fixed as 1. The Molarity of the Sodium hydroxide solution was varied as 4 M, 6 M and 8 M. Mix identity for various proportions of BA and GGBFS are shown in Table 2. The mass of combined aggregates was taken as 75% of the mass of concrete, out of which 70% were coarse aggregates consisting of 6 mm chips and 30% fine aggregates. The combined mass of Binder content and alkaline liquids were taken as 25% of mass of concrete. For all the combinations of BA-GGBFS mixes the molar ratio of SiO₂/Na₂O, alkaline liquid to binder ratio and ratio of alkaline liquids were kept constant. Mix proportions for BA-GGBFS paver blocks are presented in Table 3.

Tab. 2. Mix Identity for various proportions of BA-GGBFS Blocks

Bottom ash: GGBFS (%)	Mix Identity	Density	Mix Identity
100:0	BG0	A	1800 Kg/m ³
75:25	BG25	B	2000 Kg/m ³
50:50	BG50	C	2200 Kg/m ³
25:75	BG75	D	2400 Kg/m ³
0:100	BG100		

Tab. 3. Mix proportions of BA-GGBFS Blocks

Material	Mass Kg/m ³	Weight in Kg /paver block
Bottom ash	225	0.297
GGBS	75	0.09919
Fine aggregate	675	0.89269
Coarse aggregate	675	0.89269
NaOH pellets	20.737	0.02742
Water for NaOH solution	86.41	0.11428
Na ₂ SiO ₃	42.857	0.05668

2.4 Specimen Preparation

The coarse aggregates and fine aggregates (River sand and Foundry sand) were mixed in the pan mixer for 4 to 5 minutes followed by the addition of source materials namely BA and GGBFS. This was followed by the addition of NaOH solution and mixing was continued for another 3 minutes. Finally Na₂SiO₃ solution was added and mixed until a homogeneous mix was achieved. Then the Geopolymer mix was filled in rectangular paver blocks of size 230 mm x 115 mm x t mm and was compacted by vibration in order to expel any air voids. The thickness t was varied as 50 mm, 60 mm, 80 mm, 100 mm and 120 mm for the various grades of M30, M35, M40, M50 and M55 BA-GGBFS paver blocks respectively as mentioned in BIS 15658:2006. The moulds were under ambient conditions until testing as shown in Fig. 8.

**Fig. 8.** Cast BA-GGBFS specimens under Ambient curing

2.5 Curing

Ambient curing was adopted for the BA-GGBFS paver blocks. The cast specimens were kept in the moulds completely sealed in room temperature for 24 hrs. After 24 hrs it was demoulded and left in room temperature till the day of testing at 3,7 and 28 days.

2.6 Testing

Mechanical properties such as Compressive strength, Split tensile strength, Flexural strength, and Durability properties like water absorption, chloride attack and sulphate attack were evaluated on BA-GGBFS paver blocks.

3 Results and Discussions

3.1 Compressive Strength

Compressive strength results of geopolymer concrete made with BA and GGBFS for various Molarities, Densities and Mixes for grades M30 and M50 are shown in Fig. 9 to Fig. 16. It can be seen that for M30 grade, maximum strengths of 58.78 MPa, 61.43 MPa, 65.80 MPa and 69.20 MPa which were more than the targeted strength of 30 MPa were attained for densities of 1800, 2000, 2200 and 2400 Kg/m³ respectively. For lower grades of concrete up to M40, a strength higher than the targeted strength was achieved even at a lower density of 1800 Kg/m³ whereas for higher grades of concrete (M50, M55) the required strength was achieved only at a higher density of 2400 Kg/m³. For M50 grade, maximum strengths of 44.26 MPa & 49.18 MPa which were lesser than the required strength of 50 MPa were attained for densities of 1800 and 2000 Kg/m³ respectively whereas the required strength of 50.01 MPa and 52.49 MPa were attained only at higher densities of 2200 and 2400 Kg/m³. But irrespective of the grades of geopolymer concrete blocks, the compressive strength was found to increase with the increase in density, the maximum strength being attained for a density of 2400 Kg/m³. This may be due to the fact that as the density is increased, the microstructure becomes dense. The proportion of the coarse aggregates varies proportionally to the increase in density. For lower grades of geopolymer concretes (M30, M35 & M40), the difference in the thickness of the blocks are very nominal in the range of 50 mm, 55 mm and 60 mm. Hence the increase in density upto M40 grade makes the microstructure more dense which ultimately increase the strength. But beyond M40 grade there is a drastic increase in the thickness of the geopolymer concrete blocks (100 mm and 120 mm) which increases the coarse aggregate content. The reduction in strength in higher grades may be due to the increase in coarse aggregate content and that the coarse aggregates were weaker than the geopolymer matrix and ma-

trix aggregate interface. Also as the coarse aggregate content is increased, for a constant alkaline liquid to binder ratio of 0.4, the binder content is reduced which automatically reduces the strength of geopolymer concrete.

BA-GGBFS concrete blocks of grades M30 and M35 show similar trends in the attainment of compressive strengths at 28 days. For higher grades of M40, M50 and M55, there is a decrease in strength in proportion to the thickness of the geopolymer concrete blocks. For all the mixes there is an increase in strength with the increase in Molarity, the maximum strength being attained at 8 M. From Fig. 13 it can be seen that none of the mixes irrespective of the molarity have achieved the targeted compressive strength of 50 N/mm². But the increase in molarity increases the compressive strength and the maximum strength of 44 MPa and 49 MPa were achieved only at 8 M for densities of 1800 and 2200 Kg/m³. Whereas for higher densities, the required strength of 50 MPa was attained only for a higher molarity of 8 M. From the results it can be seen that the compressive strength increased with the increase in NaOH concentration. This is due to the reason that higher concentrations of NaOH enhance the dissolution of Si and Al from Bottom ash and GGBFS leading to the formation of aluminosilicate gel thereby increasing the strength. Moreover the presence of substantial quantities of Ca ions in slag lead to the formation of C-S-H gel. At the same time higher concentrations of NaOH solution cause leaching of Si and Alumina from the source materials and result in increased geopolymerization forming NASH gel. The coexistence of these C-S-H and NASH gel are responsible for the increase in strength. Also the interrelation of various oxides contained in the mixture compositions affects the strength variably.

Out of all the mixes for various grades M30 to M55, mixes containing 100% BA alone (BG0) showed only a maximum strength of 35 N/mm². But with the addition of GGBFS there was an increase in compressive strength upto 50% replacement. The strength increment with time is mainly due to the formation of C-S-H gel with the increase in the addition of slag which is found to be effective after 25% addition. Slag is rich in CaO which combination with Si undergoes dissolution in the presence of high concentrations of NaOH solution to form C-S-H gel which enhances the strength of geopolymer concrete by the conversion of amorphous gel into more stable crystalline phases [12]. But beyond 50%, the strength decrease may be attributed to insufficient activation of Si and Al in the source materials for geopolymerization. Also activation of geopolymer concrete with slag showed an increase in the compressive strength when compared to mixes without slag (BG0) even at lower concentrations of NaOH solution (4 M and 6 M). This shows that the activator concentration has less influence when GGBFS is added as a source material. The decrease in strength beyond 50% may be attributed to insufficient activation of Si and Al in the source materials for geopolymerization.

Hence it is evident from the compressive strength results that for lower grades of geopolymer concrete blocks (M30 and

M35), the targeted strength is achieved even at lower molarity of 4 M and lesser density of 1800 Kg/m³. But as the grade of concrete is increased (M40 - M55), the targeted strength is achieved only at higher molarities (6 M & 8 M). The reason may be that the increase in the thickness of the geopolymer concrete blocks increases the quantity of binder and for lower molarities, there may not be sufficient quantities of alkaline activator solution for binding. Hence higher strengths are achieved only with higher molarities for higher grades of geopolymer concrete blocks.

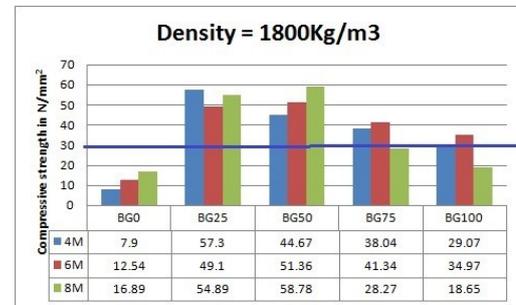


Fig. 9. Compressive strength of M30 grade for density 1800 Kg/m³ at 28 days in N/mm²

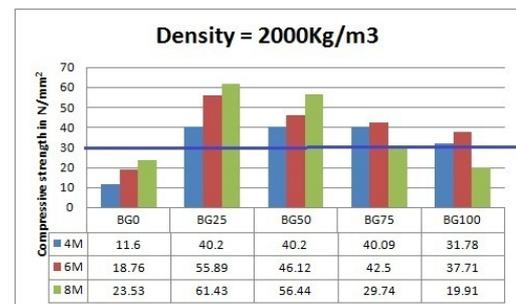


Fig. 10. Compressive strength of M30 grade for density 2000 Kg/m³ at 28 days in N/mm²

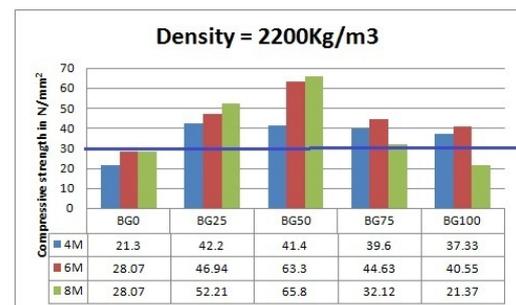


Fig. 11. Compressive strength of M30 grade for density 2200 Kg/m³ at 28 days in N/mm²

3.2 Split tensile strength, flexural strength

The Split tensile strength and Flexural strength results for the selected combinations are presented in Table. 5. The split tensile testing setup is shown in Fig. 17 and Flexural strength test set up is shown in Fig. 18.

The Split tensile and Flexural strength results shows that the geopolymer concrete blocks are much better when compared to the ordinary concrete for the corresponding grades.

Tab. 4. Recommended mix proportions for various grades of BA-GGBFS blocks

GRADE	RECOMMENDED MIX
M30	A4BG50
M35	A4BG25
M40	B4BG50
M50	D6BG50
M55	D8BG50

Tab. 5. Split Tensile and Flexural strengths of various grades BA-GGBFS blocks in N/mm²

Grade	Mix Composition	Split Tensile strength in N/mm ²	Flexural strength in N/mm ²
M30	A4BG25	2.55	6.20
M35	A4BG50	2.76	6.47
M40	B4BG50	2.97	6.60
M50	D6BG50	3.15	7.05
M55	D6BG50	3.54	7.14

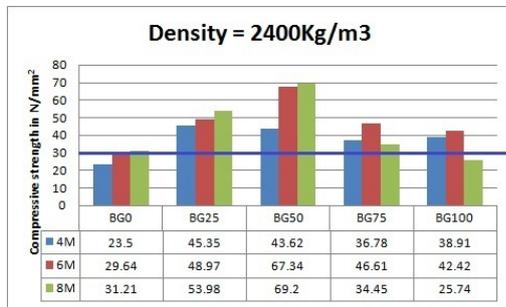


Fig. 12. Compressive strength of M30 grade for density 2400 Kg/m³ at 28 days in N/mm²

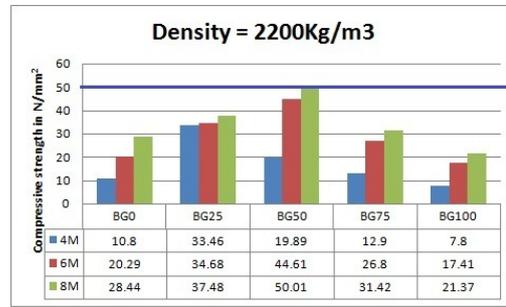


Fig. 15. Compressive strength of M50 grade for density 2200 Kg/m³ at 28 days in N/mm²

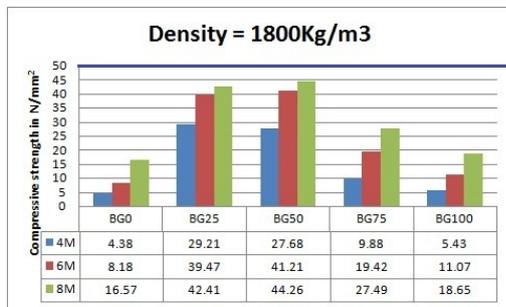


Fig. 13. Compressive strength of M50 grade for density 1800 Kg/m³ at 28 days in N/mm²

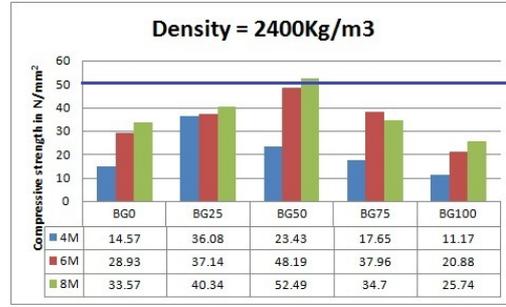


Fig. 16. Compressive strength of M50 grade for density 2400 Kg/m³ at 28 days in N/mm²

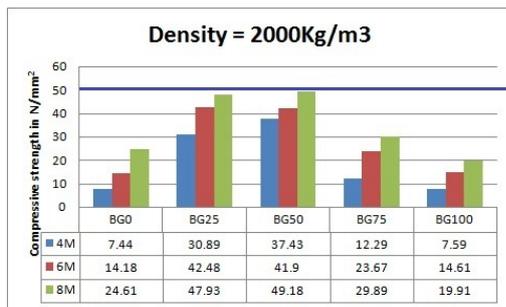


Fig. 14. Compressive strength of M50 grade for density 2000 Kg/m³ at 28 days in N/mm²



Fig. 17. Split Tensile test set up of BA-GGBFS blocks

Tab. 6. Comparison of Water absorption, Weight loss in percentage for various Grades soaked in HCl & H₂SO₄

MIX	Water Absorption	Weight Loss for Sulphate attack	Weight Loss for Chloride attack
UNIT	%	%	%
M30	2.617	1.58	1.168
M35	2.530	1.295	1.032
M40	2.236	0.652	0.7138
M50	2.017	0.564	0.689
M55	1.652	0.432	0.564



Fig. 18. Flexural strength test set up of BA-GGBFS blocks

3.3 Water absorption, sulphate attack and chloride attack

The water absorption test for the geopolymer blocks were carried out in accordance with IS: 15658:2006. The water absorption as per Annex C, Shall not be more than 6 percent by mass and in individual samples, the water absorption should be restricted to 7 percent.

From these results (Table 5) it can be seen that the absorption values of geopolymer concretes at all the strength levels were lower than the limit of 3% specified for good concrete. All the geopolymer mixes show lower absorption rates and reduces with the increase in the grade of concrete. The reason for low water absorption may be attributed to the dense and less porous microstructure of the geopolymer matrix due to the addition of GGBFS which increases upto 50% replacement.

The Geopolymer specimens are immersed in sulphuric acid and HCl solution to test its resistance to sulphate attack and chloride attack. Loss in weight percentage should be minimum at range around 1% for better resistance to the surrounding medium.

From the Fig. 19 it can be seen that the higher percentage of weight loss is seen for lower grades of paver blocks. The reason for minimum loss of weight in higher grades may be due to higher cross section area than the corresponding lower grades of geopolymer concrete blocks.

4 Conclusions

The following concluding remarks are presented on the study of Ternary blended geopolymer concrete using foundry sand:

- BA-GGBFS-FS geopolymer blocks attain sufficient strength even at lower molarities of 4 M NaOH solution under ambient

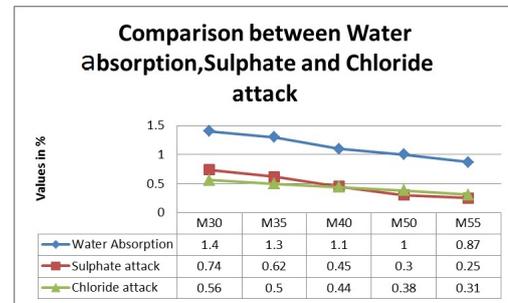


Fig. 19. Durability properties of BA-GGBFS blocks when immersed in Water, HCl and H₂SO₄ solutions

curing conditions which is an encouraging outcome of this work.

- As the density of the geopolymer concrete increases, the strength also increases variably. But the difference in compressive strength for various densities is very nominal, the maximum strength being achieved for the highest density of 2400 Kg/m³
- The addition of slag enhances the geopolymerisation reaction. As the quantity of slag increases, the compressive strength increases upto a 50% replacement beyond which it decreases
- The addition of Foundry sand upto 50% replacement for river sand does not affect the strength of geopolymer concrete
- Geopolymer concrete absorbs less water when compared to normal concrete and shows better resistance against chloride and sulphate attack.
- Geopolymer concrete specimens with lower concentrations of alkaline liquids can be satisfactorily used for structural grade concretes even with lower densities. Geopolymer concrete incorporating Bottom ash and GGBFS using Foundry sand as partial replacement for river sand emerge as a sustainable and eco-friendly building material in the years to come.

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