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A Prospective Study on Alkali Activated Bottom Ash-GGBS Blend in Paver Blocks

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***Abstract*—**This paper presents a study on use of alkali activated bottom ash (BA) and ground granulated blast furnace slag (GGBS) blend in paver blocks. A preliminary effort on alkali-activated bottom ash, blast furnace slag based geopolymer (BA-GGBS-GP) mortar with river sand was carried out to identify the suitable mix for paver block. Several mixes were proposed based on the combination of BA-GGBS. The percentage ratio of BA: GGBS was selected as 100:0, 75:25, 50:50, 25:75 and 0:100 for the source material. Sodium based alkaline activators were used for activation. The molarity of NaOH was considered as 8M. The molar ratio of SiO_2 to Na_2O was varied from 1 to 4. Two curing mode such as ambient and steam curing 60°C for 24 hours were selected. The properties of paver block such as compressive strength split tensile strength, flexural strength and water absorption were evaluated as per IS15658:2006. Based on the preliminary study on BA-GGBS-GP mortar, the combinations of 25% BA with 75% GGBS mix for M30 and 75% BA with 25% GGBS mix for M35 grade were identified for paver block. Test results shows that the combination of BA-GGBS geopolymer paver blocks attained remarkable compressive strength under steam curing as well as in ambient mode at 3 days. It is noteworthy to know BA-GGBS-GP has promising future in the construction industry.

***Keywords*—**Bottom ash, GGBS, alkali activation, paver block.

I. Introduction

CEMENT has played for many centuries a major role in the construction industry. With the boom of the industrial sectors, the usage of cement showed a tremendous growth favoring significant development in its utilization technology. But as of now, researchers have thrown light on the deleterious effects of cement on the environment mainly because of huge amounts of CO_2 emission during its manufacture process. Accordingly, in order to reduce the CO_2 emission and to reduce the consumption of cement, alternative materials have been developed as binders incorporating industrial by products such as fly ash, GGBS, silica fume etc [1]. In this respect, geopolymers have emerged as a promising alternative to the conventional cement binders [2], [3].

Although, geopolymers were developed initially to serve as a fire resistant material, now it has gained momentum as an alternate to the cementitious binders particularly with a low carbon footprint [4], [5].

Prof. Joseph Davidovits was the first to discover geopolymers in 1978. He coined the term geopolymers for source materials rich in silica and alumina activated by alkaline solutions that could be replaced for the conventional binders. As of now, only fly ash has been found a prominent place as a cement replacement material while less light has been thrown upon on the use of bottom ash in concrete [6]–[8]. Both fly ash (FA) and bottom ash (BA) are obtained from the same thermal plant and have more or less similar compositions of silica and alumina [9]–[12]. Hence use of bottom ash would reduce carbon footprint as well as eliminate the recycling of bottom ash. An effective utilization of BA in construction materials will significantly reduce the accumulation of the by-products in landfills and thus reduce environmental pollution.

Since the particle size distribution of bottom ash is similar to that of sand it can be effectively used as a replacement for fine aggregate [13]–[24]. Being coarser, it should be ground to increase its surface area as well as its reactivity when it is used as binder [25]–[27]. Fine bottom ash produced good strength than medium and coarse bottom ash under heat curing [28]. High strength geopolymer mortar was obtained by ground bottom ash with 3% retained on sieve No 325 and mean particle size of 15.7µm using liquid alkaline /ash ratio of 0.429 – 0.709, the sodium silicate / sodium hydroxide ratio of 0.67 – 1.5 and 7.5M NaOH [8]. The geopolymer mortar made with coal bottom ash under ambient temperature at 20°C and dry curing at 80°C, the 28 days compressive strength of bottom ash geopolymer mortar were 26.23 and 24.4MPa respectively [29].

Bottom ash based geopolymer concrete with sodium hydroxide and sodium silicate activator attained the compressive strength of 52 MPa at 28 days. The mass ratio of the alkali-activator to bottom ash 0.55 provided sufficient chemical components needed for the geopolymerization. Higher concentration of sodium hydroxide 12-15M was seen to favor the corrosion of the glassy membrane of bottom ash and, by the way, lead to higher compressive strength. Besides, lower concentration with larger water content was seen to be advantageous for the flowability. It was recommended to prepare the alkali-activator in advance so as to stabilize [30].

A study on the use of bottom ash, fly ash, and flue gas desulfurization gypsum (FGDG) in geopolymer was carried out as in [31]. The particle size of bottom ash, fly ash, gas desulfurization gypsum was 32.2, 63.5, and 10.3µ, respectively. They attempted oven curing at 40°C for 48 hrs and controlled curing with RH of 50%. The compressive strength of bottom ash geopolymer mortar is 25.5 MPa and fly ash geopolymer mortar was 55.5MPa. The strength of 75:25 (BA: FA) with 0%, 5%, and 10% FGDG mortar were 30.5,

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35.0, and 40.0MPa. The strength of bottom ash geopolymer mortar was lower than fly ash geopolymer mortar.

An experimental work on use of fly ash, bottom ash and GGBS in geopolymer concrete with elevated temperature curing at 60ºC for 6 hrs and then 100ºC for 3 hrs was conducted as in [32]. It was found that fly ash-GGBS based concrete attained comparable strengths. Fly ash based geopolymer concrete attained compressive strength of 68MPa while bottom ash based concrete attained only 32MPa. Bottom ash–GGBS based geopolymer concrete gives very low strength probably due to large particle size. Larger particle size reduces the dissolution of bottom ash in activator solution and hence does not take part in the reaction. Concrete cured at ambient temperature attained comparable strength with that of specimens cured at elevated temperatures. Thus curing at elevated temperature doesn't add much to the final strength of coal ash-GGBS based concrete

From the geopolymerisation behavior of fly ash and bottom ash with addition of granulated blast furnace slag, it was observed that fly ash has pozzolanic reactivity as well as reactivity with alkaline solution. However bottom ash mostly behaved as inert aggregate especially during early geopolymerisation reaction [33].

Blast furnace slag is another by product obtained from the steel industries. Blast furnace slag when added with fly ash is said to enhance geopolymerisation and increase the compressive strength [34]–[37]. Also GGBS proves to be an effective binder to produce better quality concrete than OPC [38], [39]. As the quantity of slag is increased the compressive strength also increases and ultimately increases the CSH gel [40].

The potential use of GGBS as geopolymer precursors is presented by slag when used in combination with fly ash are able to produce structural grade concrete which was much more than the minimum grade specified in IS 456-2000 with a maximum replacement of fly ash with slag (28.57%) [41]. In contrast, utilizing slag for geopolymer poses a major drawback due to its high CaO content. When geopolymer paste with high CaO content was cured at 60°C for 24hrs, the compressive strength was 30 MPa [42]. However, geopolymer with less CaO content in slag exhibited compressive strength of 60 MPa [43]–[44].

Researches show that an increase in the alkaline liquid to binder ratio increases the compressive strength as well as workability of geopolymer mortar. Also increase in the sodium silicate to sodium hydroxide ratio decreased the strength beyond certain limit depends on the source material. The increase in sodium silicate solution affects the strength because of the larger interparticle distance [8], [30]. While the molarity of the sodium hydroxide solution increases the strength proportionally, it also decreases the workability [30]. This may be due to the fact that higher molarity breaks the glassy structure of the source material which aids in the internal Si and Al contents to activate the geopolymerisation.

The alkali activation of binder depends on the amorphous content of silica and alumina. The reactivity is higher for higher amorphous content. Some geopolymers are similar to amorphous zeolites in which the crystallization stage is not reached due to the very fast reaction rates during the dissolution and condensation [45], [46]. Aluminum is more reactive than silica for subsequent geopolymer formation. Higher concentration of sodium hydroxide is also suggested to get higher compressive strength of geopolymer concrete by many researchers [47]. However, due attention is also paid on the ill effects of higher concentration. Mild to moderate respiratory irritation is experienced at a higher concentration of sodium hydroxide [48]. If inhaled, mist or dust containing sodium hydroxide will cause irritation and burning of the nasal passages and airways. Sodium hydroxide is strongly corrosive and a powerful irritant by all routes of exposure (inhalation, ingestion, skin contact, and eye contact). Therefore, higher concentration of sodium hydroxide is not preferable in concrete. Further, a large extent of work on geopolymer technology using different industrial by-products reveals that geopolymer reaction is enhanced more under heat curing. Besides, with the proper selection of various parameters such as liquid to solid ratio, sodium silicate to sodium hydroxide, molar ratio of SiO_2 to Na_2O ratio in sodium silicate, it is possible to produce geopolymer concrete as a user friendly material. Moreover, the alkali activation of binder depends on the amorphous content of silica and alumina.

Therefore the present study is undertaken to produce the geopolymer binder using bottom ash (BA) and ground granulated blast furnace slag (GGBS) with 8M concentration of sodium hydroxide and to find the potential mix composition of BA- GGBS blend for paver block with desirable properties at ambient temperature.

II. Materials and Methods

The materials such as bottom ash (BA), ground granulated blast furnace slag (GGBS), sodium based alkaline activator and river sand as fine aggregate and coarse aggregate were used in the present work**.**

A. Materials

1. Bottom Ash (BA)

Bottom ash was collected from Mettur thermal power plant, Salem. As it was coarser when obtained, it was ground to a particle size of less than 45 micron to increase its surface area as well as reactivity. The particle size distribution is illustrated in Fig. 1. The specific surface area and specific gravity of BA was 3460cm^2/gm and 2.17 respectively. The chemical properties of BA are shown in Table I.

The SEM and EDAX of Bottom ash is shown in Figs. 2 & 3. Bottom ash particles as received from the boilers possessed a glassy structure and were angular. The ground bottom ash particles were spherical in shape similar to the fly ash particles. Fig. 3 shows that the bottom ash is mainly composed of large percentages of silica and alumina similar to fly ash.

2. Ground Granulated Blast Furnace Slag (GGBS)

GGBS was obtained from Agni steel plant, Ingore at Erode. GGBS was also ground to the same fineness as bottom ash. The particle size distribution is illustrated in Fig. 4. The

specific surface area and specific gravity of BA was 1980 cm^2/gm and 3.02 respectively. The chemical property of *GGBS* is presented in Table II. The SEM and EDAX of GGBS are shown in Figs. 5 & 6. The shape of the GGBS grains is crystalline and angular form. From the EDAX, it is observed that GGBS is enriched with silica while compared to other elements.

TABLE I
CHEMICAL PROPERTIES OF BOTTOM ASH

Chemical Compositions	Percentage by weight
SiO_2	29.15
Al_2O_3	26.68
SO_3	0.51
CaO	16.36
MgO	1.51
Na_2O	1.15
LOI, (Loss of Ignition)	1.15
K_2O	0.53
Fe_2O_3	7.28

TABLE II
CHEMICAL PROPERTIES OF GGBS

Chemical Compositions	Percentage by weight
SiO_2	51.50
Al_2O_3	32.58
SO_3	5.19
CaO	0.50
MgO	0.21
Na_2O	1.35
LOI (Loss of Ignition)	1.50
K_2O	0.58

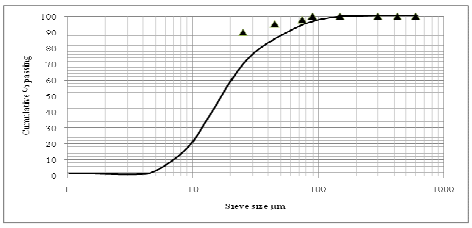


Fig. 1 Particle Size Distribution of bottom ash

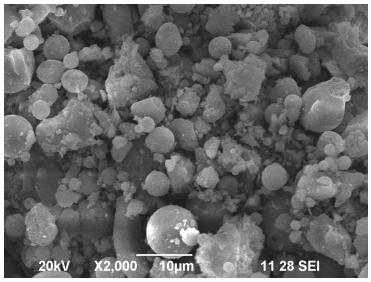


Fig. 2 SEM of Ground Bottom Ash

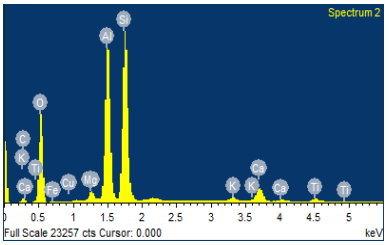


Fig. 3 EDAX of Ground Bottom Ash

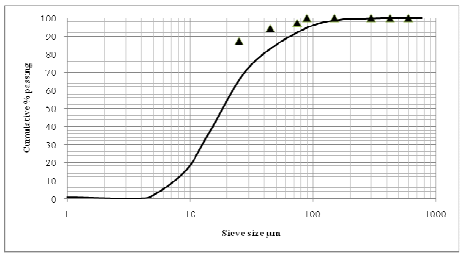


Fig. 4 Particle Size Distribution of GGBS

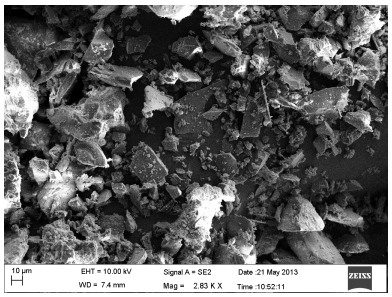


Fig. 5 SEM Image of GGBS

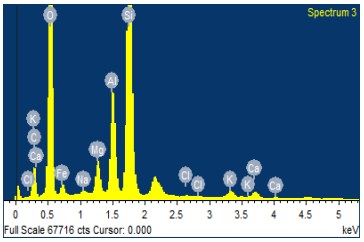


Fig. 6 EDAX of GGBS

3. Alkaline Activators

The alkaline liquid used in this study was a combination of sodium hydroxide (NaOH) and sodium silicate. The sodium silicate solution (Na_2=13.7%, SiO_2=29.4%, and water=55.9% by mass) was purchased from a local supplier in bulk. The sodium hydroxide (NaOH) in flakes 97% to 98% purity was also purchased from local supplier in bulk. The NaOH flakes were dissolved in water to make the solution.

4. Fine Aggregate

Locally available river sand was used as fine aggregate in this work. The physical properties of river sand were determined in accordance with BIS 2386-1963. Fineness modulus and specific gravity of river sand in the natural state

was found as 2.26 and 2.63 respectively. River sand is conforming to Grading Zone III as per BIS 383-1970.

5. Coarse Aggregate

Coarse aggregate complied with the requirement of IS 383. Coarse aggregates of size 6mm was used for the preparation of paver block in the present study.

6. Water

The water used in this study was conformed the requirements specified in IS 456:2000. Potable water was used throughout the work.

B. Methods

In this study, a preliminary work on alkali-activated bottom ash, blast furnace slag based geopolymer (BA-GGBS-GP) mortar with river sand was carried out. Based on the compressive strength of BA-GGBS-GP mortar suitable combinations were selected for finding the properties of M30 and M35 grade paver blocks.

1. Mix Proportions BA-GGBS-GP Mortar

Five mixes were proposed according to the ratio of BA-GGBS. The percentage ratio of BA: GGBS was selected as 100:0, 75:25, 50:50, 25:75 and 0:100 for the source material. The ratio of source material to river sand was fixed as 1:3. The liquid to solids ratio was selected as 0.5. The ratio of sodium silicate to sodium hydroxide was kept as 2.5. The molar ratio of Si_2O to NaO_2 was varied from 1 to 4. The molarity of alkaline activator is chosen as 8M.

Mix identity used in this work is shown in Table III. Letter B represent bottom ash; G represents GGBS; and the suffix numerical indicates the amount GGBS in the total quantity of BA + GGBA.

TABLE III
MIX IDENTITY FOR VARIOUS MIXES

Bottom Ash (BA)% : GGBS%	Mix Identity
100:0	BG_0
75:25	BG_{25}
50:50	BG_{50}
25:75	BG_{75}
0:100	BG_{100}

2. Specimen Preparation

The raw materials BA with GGBS and river sand were thoroughly mixed for few minutes in the pan mixer. This was followed by the addition of the alkaline liquid and the mixing was continued for another 4-5 minutes. The preparation of the solution of alkaline liquid was immediate to the mixing with the source material. The fresh geopolymer paste was filled in moulds and was compacted by vibration to expel the air voids. Then the moulds were sealed to avoid any water loss in evaporation.

3. Curing

Two curing modes were attempted, ambient curing and steam curing. Ambient curing was achieved by placing the specimens completely sealed or covered for 24 hours under room temperature. The specimens were then demoulded and left at room temperature till the day of testing. Steam curing was achieved by placing the sealed specimens in a steam curing chamber provided with an electrical boiler. Water was supplied continuously and the temperature inside the steam curing chamber was maintained at 60°C for 24 hours. Upon curing, the specimens were demoulded and allowed to cure in room temperature till the period of testing.

4. Compressive Strength of BA-GGBS Geopolymer Mortar

The compressive strength of BA-GGBS geopolymer mortar cubes 70.6x70.6x70.6mm was taken for each mix proportion and the strength at 3 and 7 days were evaluated for the two curing modes, ambient curing and steam curing at 60˚C.

5. Mix Proportioning of BA-GGBS-GP Paver Block

Based on the preliminary study on BA-GGBS-GP mortar, mixes were selected in such a way to get the desired strength at ambient temperature for paver block of M30 grade and M35 grade. In such a way, BG_{75} for M30 and BG_{25} for M35 grade were used in the present study. For mix proportioning of BA-GGBS-GP paver block concrete, the density of was chosen as 2400kg/m^3. The mass of combined aggregate was selected as 75% of the mass of concrete. The combined aggregate were comprised of 70% coarse aggregate chips of 6 mm size and fine aggregate 30%. The mass of BA-GGBS and the alkaline liquid were 25% of the mass of concrete. In the selected combination of BA and GGBS, the ratio of sodium silicate to sodium hydroxide, molar ratio of Na_2O to SiO_2, and molarity of alkaline activator were used similar to the corresponding mortar mix. The quantity of mixes proportioned as per this terms are calculated and presented in Table IV.

6. Properties of BA-GGBS-GP Paver Block

As per IS15658:2006 for paver block, the size of the specimens was considered and properties were determined. Rectangular size paver block of size 230mm x 115mm x 50mm for M30 grade and 230mm x 115mm x 60mm for M35 grade were used for finding the properties of paver block. The properties such as compressive strength split tensile strength, flexural strength and water absorption were evaluated.

TABLE IV
MIX PROPORTION FOR BA-GGBS-GP PAVER BLOCKS

Materials	Mass (kg/m^3)	
	BG_{25}	BG_{75}
Bottom ash	360	100
GGBS	120	300
Sodium silicate solution	171.425	142.85
Sodium hydroxide solution	32.85	27.3
Fine aggregate	672	540
Coarse aggregate	1008	1260
Water	35.70	29.85

III. RESULTS AND DISCUSSION

The compressive strength of BA-GGBS-GP mortar mixes for various molar ratios from 1 to 4 for ambient and steam

curing at 60°C is presented in Tables V to VIII and shown in Fig. 7.

A. Compressive Strength of BA-GGBS-GP Mortar

1. BG-GP Mortar with Molar Ratio 1

The compressive strength of BG-GP with molar ratio 1 for ambient and steam curing at 60°C is presented in Table V and shown in Fig. 7 (a). The compressive strength of ambient curing 1BG-GP varies from 10.82 to 36.71 MPa at 7 days for 0 to 100% GGBS, whereas steam curing is in the range of 15.32 to 58.2MPa. The mix $1BG_{25}$ gained a maximum compressive strength of 58.2MPa at 7 days under steam curing. The mix except $1BG_0$ & BG_{100} achieved significant compressive strength even at ambient curing. The mix $1BG_{25}$ and $1BG_{75}$ attained maximum compressive strength of 28.68 and 24.27 MPa even at 3 days ambient curing. It is obvious that steam curing achieves more strength than ambient curing.

TABLE V
COMPRESSIVE STRENGTH OF BA-GGBS-GP MORTAR WITH MOLAR RATIO 1

Sl. No	Sample Identity	Compressive Strength MPa (Ambient Curing)		Compressive Strength MPa (Steam Curing at 60°C)	
		3 days	7 days	3 days	7 days
1	$1BG_0$	5.41	10.82	15.05	22.82
2	$1BG_{25}$	28.68	36.71	40.52	58.20
3	$1BG_{50}$	18.25	34.60	40.52	54.54
4	$1BG_{75}$	24.27	30.09	33.30	49.01
5	$1BG_{100}$	9.02	12.27	13.82	15.32

2. BG-GP Mortar with Molar Ratio 2

The compressive strength of BG-GP with molar ratio 2 for ambient and steam curing at 60°C is presented in Table VI and shown in Fig. 7 (b). The compressive strength of ambient curing 2BG-GP varies from 2.56 to 20.16MPa at 7 days for 0, 25, 50, 75 and 100% GGBS, whereas steam curing resulted from17.05 to 47.04MPa. The mix $2BG_{25}$ gained a maximum compressive strength of 47.04MPa at 7 days. The compressive strength of 2 molar ratio did not show strength improvement under ambient curing. However, the mix $2BG_0$ attained a compressive strength of 20.16MPa at 7 days. Also, the mix only with GGBS attained a very low strength in comparison with other combinations. Similar to molar ratio 1 mixes, steam curing achieves more strength than ambient curing for molar ratio 2.

TABLE VI
COMPRESSIVE STRENGTH OF BA-GGBS-GP MORTAR WITH MOLAR RATIO 2

Sl. No	Sample Identity	Compressive Strength MPa (Ambient Curing)		Compressive Strength MPa (Steam Curing at 60°C)	
		3 days	7 days	3 days	7 days
1	$2BG_0$	7.42	20.16	22.13	35.87
2	$2BG_{25}$	4.9	9.86	28.6	47.04
3	$2BG_{50}$	4.9	5.36	17.42	23.04
4	$2BG_{75}$	3.62	4.89	14.6	26.04
5	$2BG_{100}$	1	2.56	11.2	17.05

3. BG-GP Mortar with Molar Ratio 3

The compressive strength of BG-GP with molar ratio 3 for ambient and steam curing at 60°C is furnished in Table VII and illustrated in Fig. 7 (c). The compressive strength of ambient curing 3BG-GP ranges from 2.23to 17.34 MPa at 7 days for 0, 25. 50, 75 and 100% GGBS. Whereas steam curing resulted from 11 to 58 MPa. The mix $3BG_0$ and $3BG_{25}$ attained a maximum compressive strength of 58 and 47 MPa at 7 days. Similar to 2 molar ratio mixes, compressive strength of 3 molar ratio did not show strength improvement under ambient curing. The mix $3BG_0$ attained a compressive strength of 12.38 at 3 days 17.34 MPa at 7 days under ambient curing achieved significant compressive strength of 37.35at 3 days 58 MPa at 7 days under steam curing. Similarly, the mix only with GGBS attained a very low strength in comparison with other combinations in both ambient as well as steam curing. The compressive strength of 3 molar ratio at various ages under ambient and steam curing is also illustrated in Fig. 7 (c).

TABLE VII
COMPRESSIVE STRENGTH OF BA-GGBS-GP MORTAR WITH MOLAR RATIO 3

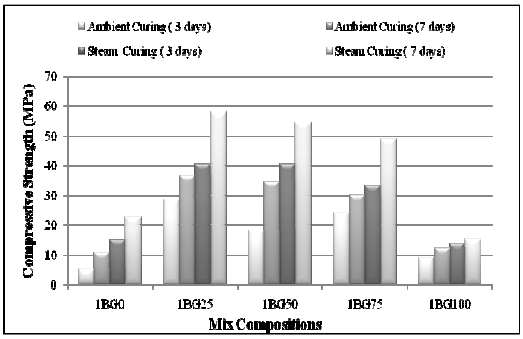
Sl. No	Sample Identity	Compressive Strength MPa (Ambient Curing)		Compressive Strength MPa (Steam Curing at 60°C)	
		3 days	7 days	3 days	7 days
1	$3BG_0$	12.38	17.34	37.35	58
2	$3BG_{25}$	5.9	10.52	37.12	47
3	$3BG_{50}$	4.32	8.36	24.19	37
4	$3BG_{75}$	3.44	4.23	18.29	22
5	$3BG_{100}$	1.23	2.23	9.05	11

4. BG-GP Mortar with Molar Ratio 4

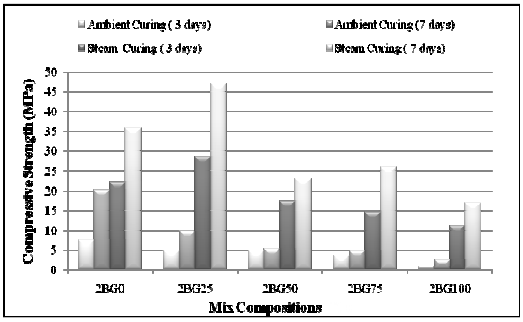
The compressive strength of BG-GP for liquid/solid ratio 0.5 with molar ratio 4 for ambient and steam curing at 60°C is presented in Table VIII and shown in Fig. 7 (d). The compressive strength of ambient curing 4BG-GP varies from 3.23 to 16.54 MPa at 7 days for 0, 25, 50, 75 and 100% GGBS; whereas steam curing is in the range of 9.34 to 56 MPa. The mix $4BG_0$ gained a maximum compressive strength of 56 MPa at 7 days. The same mix achieved a compressive strength of 16.54 MPa at 7 days under ambient curing. Like other molar ratios 1, 2 and 3 the mix only with GGBS gained very low strength.

TABLE VIII
COMPRESSIVE STRENGTH OF BA-GGBS-GP MORTAR WITH MOLAR RATIO 4

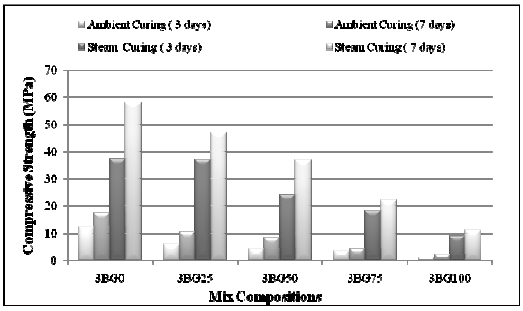
Sl. No	Sample Identity	Compressive Strength MPa (Ambient Curing)		Compressive Strength MPa (Steam Curing at 60°C)	
		3 days	7 days	3 days	7 days
1	$4BG_0$	11.28	16.54	41	56
2	$4BG_{25}$	4.9	9.52	32	48.2
3	$4BG_{50}$	3.31	7.36	28	39.01
4	$4BG_{75}$	3.56	5.87	21	28.6
5	$4BG_{100}$	2.23	3.23	8.8	9.34



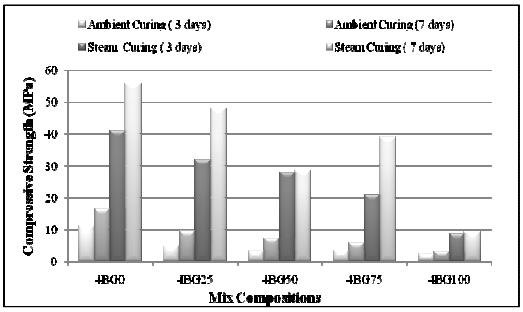
(a) Molar Ratio



(b) Molar Ratio 2



(c) Molar Ratio 3



(d) Molar ratio 4

Fig. 7 Compressive Strength of BA-GGBS-GP

5. Summary

It has been previously stated that amorphous material is more reactive than crystalline material [46]. The ground BA used in this study was in amorphous phase. Therefore, the mix only with BA exhibited higher compressive strength under steam curing except $1BG_0$ mix. The reason for $1BG_0$ mix less in strength in comparison with other mixes only with BA could be the slower rate of dissolution of silica and alumina to form aluminosilicate glasses. Further, the mix only with GGBS such as $1BG_{100}$, $2BG_{100}$, $3BG_{100}$ and $4BG_{100}$ showed very less compressive strength even at steam curing. This is in contrast that GGBS provides a good source of highly reactive material [34], [35]. Though it is reactive, the cost is high similar to OPC in many places [38], [39]. Therefore, the present study undertakes the locally available discarded low quality slag for geopolymer binder whose specific surface area is almost half of BA material after grinding. Moreover, the available aluminum is also less in comparison with BA. These points may be the reason for getting low strength for the mixes only with GGBS. Remarkably, the mix with molar ratio 1 showed good compressive strength in case of $1BG_{25}$, $1BG_{50}$ and $1BG_{75}$ mixes under ambient temperature. Therefore, under ambient temperature the above combinations are the potential mixes.

B. Properties of BA-GGBS-GP Paver Block

1. Compressive Strength

The compressive strength of above said mixes were carried out at 3 and 7 days and it is reported in Table IX. The desired compressive strength was achieved for both M30 and M35 grades. The mix BG_{75} mix offered 36.22 MPa at 3 days and 42.09 MPa at 7 days compressive strength. Another mix $3BG_{25}$ attained a compressive strength of 32.51 MPa at 3 days and 39.34 MPa at 7 days. Further, M35 grade trial mix $1BG_{25}$ was observed with a compressive strength of 37.65 MPa and 37.05 at 3 days; whereas at 7 days 44.29 MPa were obtained.

TABLE IX
COMPRESSIVE STRENGTH OF BA-GGBS-GP PAVER BLOCK

Mix Identity	Grade	Compressive Strength, MPa		
		3 days	7 days	28 days
BG_{75}	M30	36.22	42.49	57.34
$1BG_{25}$	M35	37.65	44.29	59.58

2. Split Tensile Strength

The split tensile strength of the mixes was carried out at 7 days and it is furnished in Table X. The split tensile strength of $1BG_{75}$ mix was obtained as 0.847 MPa. Further, split tensile strength of M35 grade mix BG_{25} were obtained as 1.301MPa and 1.023 at 7 days.

TABLE X
SPLIT TENSILE STRENGTH OF BA-GGBS-GP PAVER BLOCK

Mix Identity	Grade	Split Tensile Strength at 7 days, MPa
$1BG_{75}$	M30	0.847
$1BG_{25}$	M35	1.023

3. Flexural Strength

The flexural strength of BA-GGBS-GP is furnished in Table XI. The flexural strength of the mix BG_{75} gained the flexural strength as 9.76 MPa at 7 days. In the same way, flexural strength of M35 grade attained flexural strength 8.31

MPa for BG_{25} mixes at 7 days. The flexural strength of BA-GGBS-GP selected trail mixes achieved the suggested characteristic breaking load according Annexure G-7 IS15658:2006.

TABLE XI
FLEXURAL STRENGTH OF BA-GGBS-GP PAVER BLOCK

Mix Identity	Grade	Flexural Strength at 7 days N/mm^2
$1BG_{75}$	M30	9.79
$1BG_{25}$	M35	8.31

4. Water Absorption

The water absorption of the mixes was carried out and it is presented in Table XII. The water absorption of BG_{75} mix was obtained as 0.76%. Further, the water absorption of M35 grade $1BG_{25}$ was obtained as 0.28%. As per IS: 15658:2006, the water absorption shall not be more than 6 percent by mass and in individual samples and it should be restricted to 7 percent.

TABLE XII
WATER ABSORPTION OF BA-GGBS-GP PAVER BLOCK

Mix Identity	Grade	Water Absorption %
$1BG_{75}$	M30	0.76
$1BG_{25}$	M35	0.28

IV. CONCLUSION

A study on BA–GGBS Blend in geopolymer was attempted with two curing mode such as ambient and steam curing 60°C for 24 hours. From the preliminary work on BA-GGBS blend geopolymer, promising mix compositions were selected for paver block. From the test results of BA-GGBS blend geopolymer mortar and paver block the following conclusions is made.

The blend of BA-GGBS geopolymer mortar attained significant compressive strength under steam curing. The combinations $1BG_{25}$, $1BG_{50}$ and $1BG_{75}$ with molar ratio gained tremendous improvement over mixes only with BA and GGBS. The mix $1BG_{25}$ and $1BG_{75}$ achieved maximum compressive strength of 28.68 and 24.27 MPa even at 3 days ambient curing. The mix $1BG_{25}$ gained a maximum compressive strength of 58.2 MPa at 7 days under steam curing. In these combinations compressive strength was increased rapidly under steam and ambient curing. This is because of the good synthesis between BA and GGBS.

The combinations $1BG_{25}$ for M30 grade, and $1BG_{75}$ for M35 grade were selected for paver block. The compressive strength of M30 grade paver blocks achieved 36.22 MPa and M35 grade attained 37.65 MPa at 3 days under ambient curing. In fact, the selected combinations achieved the desired properties according to the requirements of IS15658: 2006 under ambient temperature at early age. This is encouraging on BA-GGBS blend geopolymer which will have a promising future in construction industry.

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