BOTTOM ASH BASED GEOPOLYMER CONCRETE PAVER BLOCKS

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Abstract— A study on bottom ash based geopolymer concrete (BAGPC) for paver block was attempted in the present work. Bottom ash was used as the source material. The alkaline liquid was a combination of sodium silicate and sodium hydroxide. Optimum mix design for M30, M35, M40, M50 and M55 grade were arrived based on alkaline liquid to solids ratio, molarity of sodium hydroxide and curing mode. Properties such as compressive strength, split tensile strength, flexural strength, water absorption and abrasion resistance of BAGPC paver block was determined. Further, durability studies on bottom ash geopolymer mortar were carried out against chemical resistance. The results showed that lower grade BAGPC paver block had attained required strength at the age of 3 days under ambient curing mode while higher grade BAGPC paver block achieved at the age of 28 days under heat curing mode. The water absorption of BAGPC paver block was lower for all the grades. It was also found that BAGPC paver block had excellent resistance against abrasion and chemical environment.

Index Terms— bottom ash, geopolymer concrete, paver blocks, abrasion resistance, chemical resistance

I. INTRODUCTION

Cement manufacturing is an energy intensive process and releases a large amount of greenhouse gases into the atmosphere. As per the statistical data, cement industry contributes about 7% weight of the total carbon dioxide emissions [1-2]. Therefore, meticulous attempt is being taken by several researchers to develop alternative cementing materials instead of Portland cement. Geopolymer binder is one such alternative binder to cement which is synthesized by mixing aluminosilicate material and high alkali solutions. It utilizes pozzolanic materials such as fly ash, GGBS, metakaolin etc., as aluminosilicate source to react with high alkali solutions of sodium or potassium based. Geopolymers have many advantages such as good compressive strength and resistance to aggressive environment and long term durability [3-4].

Fly ash and bottom ash produced during the burning of coal in thermal power plant causes severe environment pollution in its disposal. Fortunately, coal fly ash is well acknowledged for several applications in construction industry owing to its beneficial properties.Use of fly ash as a supplementary material in cement concrete and in geopolymer concrete is abundantly available. While fly ash is extensively used by-product in the

construction field, ample utilization of bottom ash is very much limited.

Bottom ash possesses almost similar chemical composition of fly ash especially rich in silica and alumina content However, bottom ash is a porous, glassy, dark gray material with a grain size similar to that of sand (5-12). Being coarser, bottom ash as such cannot be used directly as a source material in geopolymer concrete. Fine bottom ash produces good strength than medium and coarse bottom ash. The strength of bottom ash geopolymer mortar progresses with the addition of small amount of flue gas desulfurization gypsum. Larger particle size reduces the dissolution of bottom ash in activator solution for this reason it does not take part in the reaction [13-16].

The concentration of NaOH solution is directly affecting the dissolution of the aluminosilicate material and thereby it affects the formation of the geopolymer framework. To attain a better dissolving ability in aluminosilicate particulates, a higher concentration of NaOH solution is required [17-19]. Higher concentration of sodium hydroxide seems to favor the corrosion of the glassy membrane and lead to higher compressive strength (20). Longer curing period and higher temperature improves the strength of the geopolymer concrete [21-24]. In contrast, few researchers mentioned that geopolymer concrete cured under ambient temperature is also feasible to produce the desirable compressive strength [25-28].

In the meantime, geopolymer precast concrete products such as culvert, sewer pipes, railway sleepers and wall panels are commercialized]29-33]. Moreover the study on geopolymer concrete paver blocks is very few. Paver blocks are widely used construction material. They are primarily investigated for low traffic volume to heavy volume traffic. A combination of bottom ash -GGBS geopolymer paver blocks for M30 and M35 grade revealed that compressive strength was achieved under ambient mode curing at 3 days [34]. The mixture of red mud - fly ash geopolymer concrete paver blocks

demonstrates good mechanical properties and durability [35]. Aaron Darius Vaz et al carried out a study on M40 grade geopolymer concrete paver blocks using fly ash. It was observed that the mix reached high early strength when the molarity of NaOH was increased from 8M to 12M and cured at 60°C in duration of 24 hours. Meanwhile, GPC paver blocks have better resistance to sulphate attack making them suitable for aggressive soils [36-39].

Of all the different material combinations, geopolymer concrete paver blocks for heavy traffic condition is not explored. Accordingly, the present study on bottom ash geopolymer concrete intends to develop the mix design for all grades from M30 to M55 and to carry out the strength properties and durability properties.

II. MATERIALS AND METHODS

A. Materials

Bottom Ash: Bottom ash was obtained from Mettur thermal power station, India. As the particle size is larger it was ground to finer using ball mill for 8 hours to get particle size of less than 45 micron. The specific surface area and specific gravity of the bottom ash was 3460 cm^2/gm and 2.17. The chemical composition in wt % of bottom ash was: 51.50% SiO2, 32.58% Al2O3, 0.21% MgO, 5.19% SO3, 0.50% CaO, 1.35% Na2O, 0.58% K2O and 1.50% LOI

Alkaline Activators: A combination of sodium silicate solution and sodium hydroxide solution was used as alkaline liquid activators. 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 NaOH flakes were dissolved in water to make the solution.

River Sand: Locally available river sand conforming to grading zone III as per BIS 383-1970 was used as filler for bottom ash geopolymer paver blocks in this research. Fineness modulus and specific gravity of river sand in the natural state was found to be 2.26 and 2.63 respectively.

Coarse aggregate: Coarse aggregate was complied with the requirement of IS 383-1970. Coarse aggregates of size 6 mm was used for the preparation of paver block in the present research.

B. Mix proportioning

Bottom ash geopolymer concrete (BAGPC) comprised of bottom ash, river sand, coarse aggregate and alkaline activators. Alkaline activator contains a solution of sodium silicate and sodium hydroxide. Mix proportioning of BAGPC for M30, M35, M40, M50 and M55 grade paver block was optimized by several trials until the desired compressive strength was achieved. In order to attain the required strength, the density was varied from 2400 to 3000 kg/m^3. The mass of combined aggregate occupied as about 70% and 75% of the mass of concrete. The combined aggregate were comprised of 70% coarse aggregate chips of 6 mm size and river sand as fine aggregate 30%. The molarity of sodium hydroxide is varied from 4M to 12M. The mass of BA and the alkaline liquid were 25 and 30% of the mass of concrete. The ratio of activator solution to binder, by mass, was 0.4 and 0.5. The ratio of sodium silicate solution ($Na_2 SiO_3$) to sodium hydroxide (NaOH) solution by mass was 2 and 2.5. The quantity of mixes proportioned as per these terms are calculated and presented in Table 2.1.

C. Manufacture of Test of Specimens

According to the mixture proportioning of BAGPC, aggregates and bottom ash were mixed dry in a pan mixer for about 2 minutes

Table 2.1. Mix Proportioning of BAGPC for paver block

Materials	Grade of Paver Block				
	M30	M35	M40	M50	M55
Bottom Ash (kg/m³)	400	480	480	560	600
Fine Aggregate (kg/m³)	540	672	672	784	840
Coarse Aggregate (kg/m³)	1260	1008	1008	1176	1260
$Na_2 SiO_3$ Solution (kg/m³)	142.85	171.42	174.8	204.03	234.2
NaOH Solution (kg/m³)	57.15	68.55	99.42	93.33	85.71
Density (kg/m³)	2400	2400	2400	2800	3000
Molarity of NaOH	4M	6M	8M	10M	12M

before adding alkaline activators. The mixture was further mixed for another 3 to 4 minutes, after which it was cast into the moulds. The fresh BAGPC was cast in the moulds. The size of the paver block specimens was considered as per IS 15658:2006. Rectangular size paver block of size 230 mm x 115mm x 50 mm for M30 grade and 230 mm x 115 mm x 60 mm for M35 grade 230 mm x 115 mm x 80 mm for M40 grade; 230 mm x 115 mm x 80 mm for M50 grade and 230 mm x 115 mm x 80 mm for M55 were used for finding the properties of paver block. Immediately after casting, the samples were covered by polyethylene sheet. In accordance with grade of paver block either ambient or steam curing was adopted. Ambient curing was carried out by placing the specimens completely sealed 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 at 60°C temperature, the specimens were demoulded and allowed to cure in room temperature till the day of testing.

D. Testing

The properties of paver blocks such as compressive strength split tensile strength, flexural strength, water absorption and abrasion resistance were performed in accordance to IS 15658:2006. The specimens were tested for 1, 3, 7 and 28 day compressive strength. The splitting tensile strength of paver blocks were measured at 7 and 28th day. Flexural strength test has been done at 7 and 28 days. The water absorption for paver blocks was conducted by drying a specimen to a constant weight, weighing it, immersing it in water for 24 hours, and weighing it again. The increase in weight as a percentage of the original weight was expressed as its absorption in percent. Water absorption was found at 7 and 28 days. Abrasion resistance of paver blocks was determined at 7 and 28 days with square shaped specimens measuring 71.0 mm using abrasion testing machine. For all tests at each day testing, six specimens were used. A total of 24 specimens for compressive strength, 12 specimens for split tensile strength, 12 specimens for flexural strength, 12 specimens for water absorption and 12 specimens for abrasion testing were used for each grade paver blocks.

In case of sulphate resistance of paver blocks, the test procedure modified by Wallah and rangan (2006) based on ASTM C 1012 (1995) standard was used. The specimens were weighed in surface dry condition over the period of one month. The specimens were immersed in 3% magnesium sulphate solution. After 28 days immersion, specimens were taken out and tested for weight at surface dry condition. For each grade 6 specimens were used for assessing sulphate resistance of paver block specimens.

III. RESULT AND DISCUSSIONS

A. Strength Properties

Compressive strength of BAGPC paver block for the five different grades is illustrated in Fig.3.1. The compressive strength was noticed as 30.54 MPa at 1 day, 35.05 MPa at 3 days, 37.95 MPa at 7 days and 39.46 MPa at 28 days for M30 grade. The compressive strength of M30 grade was about the desirable range at the age of 3 days under ambient curing. This is accomplished when the molarity of sodium hydroxide (NaOH) solution was kept as 4M and density as 2400 kg/m^3. On the other hand M35 grade BAGPC paver block achieved the required compressive strength at 7 days under ambient curing when molarity of sodium hydroxide (NaOH) solution was 6M and density as 2400 kg/m^3. It was observed as 29.66 MPa at 1 day, 32.58 MPa at 3 days, 39.87 MPa at 7 days and 44.76 MPa at 28 days. In case of M40 grade, the specific compressive strength was reached at the age of 7 days under steam curing. Strengths was observed as 33.12 MPa at 1 day, 36.24 MPa at 3 days, 44.38 MPa at 7 days and 47.57 MPa at 28 days when the molarity was kept as 8M and density as 2400 kg/m^3. The mix proportions states that molarity of sodium hydroxide (NaOH) solution as 12M and density as 2800 kg/m^3 is necessary to produce M50 grade compressive strength. Strengths at I day was 43.74 MPa, at 3 days was 48.68 MPa, at 7days was 52.49 MPa, and at 28 days was 55.19 MPa. By increasing the molarity of NaOH and density the compressive strength of paver blocks reached more than 50 MPa even at 7 days. Likewise, M55 grade paver block meets the strength expectations at the age of 28 days under steam curing. When the molarity of sodium hydroxide (NaOH) solution was kept as 12M and density as 3000 kg/m^3, M55 grade exhibited 43.74 MPa at 1 day, 45.67 MPa at 3 days, 54.35 MPa at 7 days and 60.42 MPa at 28 days.

It can be observed from figure 3.1 that the strength gain in the first day was rapid for all grades from M30 to M55 grade paver blocks. Thereafter, the strength increase pattern was moderate during the period from 3 days to 28 days. The rapid earlier age strength gain is attributed due to the faster rate of dissolution of minerals and glasses to form aluminosilicate glasses. While M30 and M35 grade paver blocks attained the required compressive strength under ambient temperature curing, M40, M50 and M55 grade achieved under heat curing. Moreover, the size of the specimen also has an effect on strength. It is quite evident that the use of smaller moulds resulted in a higher strength compared to the larger moulds. With

this expectation M30, M35 grade and M40 mixes were proportioned with normal density and M50 and M55 at higher density. Further, it can be noted that the molarity of NaOH solution played a vital role to produce the designed strength. The accepted strength was achieved for M30 at 4M, M35 at 6M, M40 at 8M, M50 at 12M and M55 at 12 M. The molarity of NaOH solution, curing mode and mass density of BA GPC are the key factors to get the required grade of paver blocks in order to use it for low traffic to heavy volume traffic.

Split tensile strength of BA GPC paver block for different grades is illustrated in figure 3.2. Split tensile strength of BAGPC paver blocks were 1.79 MPa for M30 grade, 2.34 MPa for M35 grade, 2.84 MPa for M40 grade, 3.04 MPa for M50 grade and 3.23 MPa for M55 grade at the age of 7 days, whereas it was observed as 2.75 MPa for M30 grade, 2.86 MPa for M35 grade, 3.27 MPa for M40 grade, 3.42 MPa for M50 grade and 3.78 MPa for M55 grade at the age of 28 days. It appears that increasing the grade of paver blocks increased the split tensile strength which is clearly deployed in Fig.3.2.

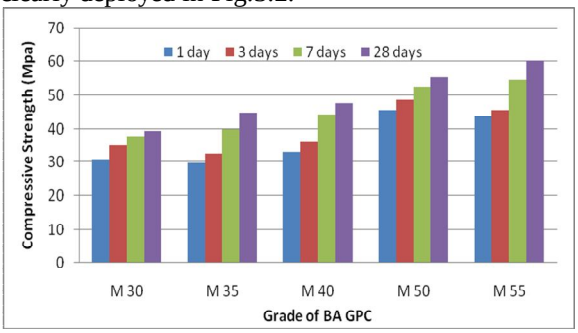


Figure 3.1 Compressive Strength of BA GPC Paver Block

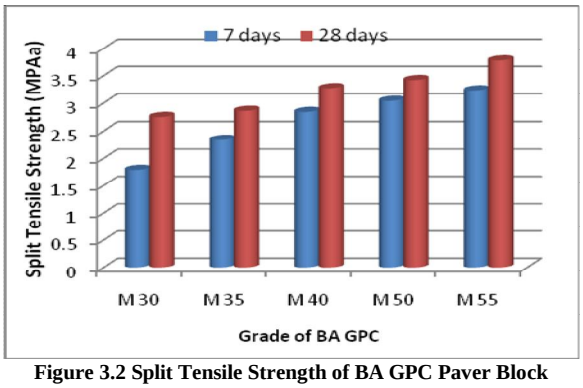


Figure 3.2 Split Tensile Strength of BA GPC Paver Block

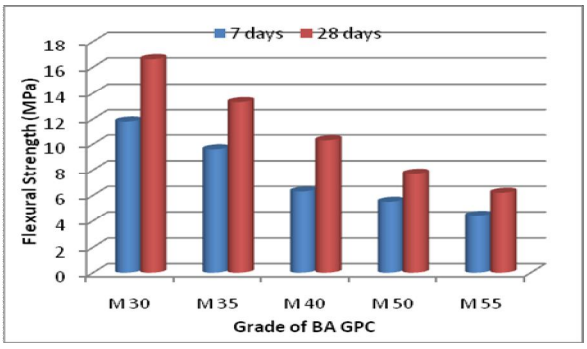


Figure 3.3 Flexural Strength of BA GPC Paver Block

A comparison of flexural strength of BAGPC paver block for different grades is depicted in Fig 3.3. Flexural strength of BAGPC paver block was obtained as 11.8 MPa for M30 grade, 9.6 MPa for M35 grade, 6.3 MPa for M40 grade, 5.5 MPa for M50 grade and 4.4 MPa for M55 grade at the age of 7 days. While it was 16.6 MPa for M30 grade, 13.3 MPa for M35 grade, 10.3 MPa for M40 grade, 7.7 MPa for M50 grade and 6.2 MPa for M55 grade at the age of 28 days. Higher flexural strength was noticed for lower grade paver blocks.

B. Durability Properties

i) Water Absorption

Water absorption of BAGPC paver blocks was obtained as 4.8 % for M30 grade, 2.7 % for M35 grade, 2.5 % for M40 grade, 2.3 % for M35 grade and 1.7 % for M55 grade at the age of 7 days. At the age of 28 days water absorption was decreased in comparison with 7 days. It was noticed as 3.1 % for M30 grade, 2.6 % for M35 grade, 2.3 % for M40 grade, 1.9 % for M35 grade and 1.5 % for M55 grade at the age of 7 days. When the days increased water absorption seems to be decreased. This is possible due to denser alumino silicate polymer structure. Besides, lower grade paver block yielded high and higher grade resulted low water absorption. According to IS 15658: 2006, water absorption shall not be more than 6 percent by mass in individual samples; the water absorption should be restricted to 7 percent. It can be emphasized that all the five grades satisfy the norms recommended.

ii) Abrasion Resistance

Abrasion resistance of BAGPC paver block was obtained as 0.03mm^3 for M30 grade, 0.03 mm^3 for M35 grade, 0.02 mm^3 for M40 grade, 0.03 mm^3 for M35 grade and 0.02 mm^3 for M55 grade at the age of 7 days. Similarly it was noticed as 0.02 mm^3 constant value at the age of 28 days for all the grades paver block. Irrespective of grades abrasion resistance of paver blocks seems to be insignificant. Aaron Darius Vaz et al mentioned that abrasion resistance of geopolymer paver blocks showed excellent performance. Same trend was observed in the present study on abrasion resistance of BAGPC.

iii) Sulphate Resistance

After one month period of exposure to sulphate solution, no deposits were found on the surface of specimens. However, minor weight variations were observed in the paver block specimens. Sulphate resistance of BAGPC paver block was noticed as 0.78% for M30 grade, 0.72% for M35 grade, 0.64% for M40 grade, 0.58% for M35 grade and 0.55% for M55 grade. It can be stated from the results that all the grade of paver blocks showed excellent sulphate resistance. In conventional cement concrete sulphate

attack leads to the formation of ettringite and gypsum and this in turn resulted into expansion and spalling of concrete. However, geopolymer do not produce either ettringite or gypsum to cause expansion. Many studies on geopolymer concrete had very good stability when immersed in sulphate solution (35-37).

Similar behaviour was noticed in the present study on BAGPC. In addition to that no noteworthy differences were observed on loss in weight among different grades of paver block.

CONCLUSION

A study on bottom ash in geopolymer paver blocks was attempted under ambient curing and steam curing for its use in light traffic to heavy traffic. From the result the following conclusions are drawn.

i) By selecting appropriate NaOH concentration, curing temperature and density, geopolymer paver blocks can be produced from bottom ash to meet the IS IS15658:2006 requirements.
ii) The geopolymer paver blocks specimens prepared at 4 M NaOH concentration is feasible to produce M30 and 6 M NaOH concentration M35 grade. However, M40 grade required 8 M NaOH and 12 M is necessary for M50 and M55 grade. This earmarked that larger concentration of NaOH increases the strength of geopolymer paver blocks.
iii) Similarly curing mode is also a significant factor affecting the geopolymerization and thus the strength of geopolymer paver blocks specimens. The target strength achieved for M30 and M35 grade is under ambient temperature curing mode while M40, M50 and M55 attained at heat curing temperature at 60°C.
iv) Moreover, the density of geopolymer paver blocks is associated with the grade. The density of geopolymer paver blocks is ranged from 2400 to 3000 kg/m³. The more the denser, more the strength is evidenced in this study.
v) Water absorption of geopolymer paver block satisfied IS IS15658:2006 requirements. Further, abrasion resistance and chemical resistance of all the grades have shown excellent resistance.
vi) From various tests conducted, the authors recommended that BA GPC paver blocks can be used for domestic paving, commercial areas, industrial areas and all traffic roads according to the required grade of paver. However, long term strength assessment including durability studies such as freezing resistance and skid resistance need to be assessed.

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