

Computation of Optimum Proportions of Cotton Textile Effluent in the Development of Geopolymer Concrete

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Abstract: *The growing concern in the Reuse and Recycling of wastes has provoked research interests in exploring ways for the transformation of industrial wastes into useful building materials. This work aims to characterize and study the feasibility of using the Cotton textile effluent from the Mercerizing process for developing Geopolymer concrete blocks. The cotton mercerizing process uses large quantities of caustic soda (NaOH) solution which is then disposed off into agricultural lands, landfills or nearby rivers. This effluent from the mercerizing process is used as a partial replacement of the alkaline activator solution of Geopolymer concrete in the manufacture of blocks. Effluent from various process were collected and were checked for the molar ratio which ranged from 0.015 to 0.751. The effluent from the mercerizing process with molar ratio ($\text{SiO}_2/\text{Na}_2\text{O}$) of 0.54 was chosen and replaced with the alkaline activator solution in varying percentages of 0,25,50,75 and 100. The preliminary investigations were conducted on geopolymer mortar and the optimum replacement of textile effluent was found to be 50% with molarity of 6M with alkaline Liquid to Binder ratio as 0.4 and 0.5. With the optimum parameters geopolymer concrete blocks were manufactured and tested for their mechanical properties. The results show that the cotton mercerizing effluent can be used a partial replacement for the alkaline activator solution of Geopolymer Concrete*

Index Terms: Alkaline activators, Cotton textile Effluent, Geopolymer, Mercerizing,

I. INTRODUCTION

Coimbatore, the Manchester of south India is well known for its cluster of Textile Industries and Foundries. Tiruppur city which is located 55 km from Coimbatore engages about 830 large textile units as per the Tamil Nadu State Pollution Control Board (TNPCB) records. These industries have set up eight Common Effluent treatment plants and many industries have established their individual effluent treatment plants which treat nearly about 75-80 litres of effluent per day generated by the textile industries. Even though strict rules have been enforced regarding discharge of untreated effluent into the water bodies, many treatment plants are still discharging the effluent into nearby streams and water

bodies. On the other hand, the sludge that is retained is disposed in Landfills. This leads to the contamination of groundwater and has socio-economic impacts as well.

The cotton mercerizing process effluent is rich in caustic soda solution. Even though NaOH is considered harmless, it is toxic to wildlife and Environmental Protection Act (EPA) has suggested that the effluent containing NaOH should not be discharged into groundwater. As NaOH falls into a group of salts (chemicals) which are mostly used by the textile industries, it becomes necessary to recognize this sheer volume of this solution. The guidelines for salt concentrations in streams is 230 ppm whereas the salt concentrations in cotton textile effluents is about 2000 to 3000 ppm. Hence treatment of effluent is essential as prevention is the only alternative to encounter the problems associated with this hard to treat waste.

II. LITERATURE REVIEW

Experiments were conducted to identify the maximum percentage of incorporation of Textile sludge in the manufacture of soft-mud bricks. It was evident from the results that Environment friendly and technically sound bricks could be produced, however high concentrations of sludge had negative influence on mechanical properties and absorption characteristics. [Maria et.al, 2011]. Investigations were conducted on the addition of textile mill sludge in the manufacture of burnt clay bricks were performed by Shrikant et.al (2013). Parameters such as mechanical strength, density, water absorption, efflorescence and ringing sound were studied as per BIS (Bureau of Indian Standards) procedures. It was recommended that Textile mill sludge could be added up to 15% in order to get compressive strength more than 3.5 MPa. Balasubramanian et.al (2006) have examined the feasibility of reusing of textile effluent treatment plant (ETP) sludge in the development of building materials. Studies were performed on the physico-chemical and engineering properties for structural and non-structural application with partial replacement of up to 30% of cement. It was recommended that sludge could be replaced to a maximum of 30% for the manufacturing of non-structural building materials. Bricks were manufactured from textile wastewater treatment plant sludge and the results have shown that the proportion of sludge and the firing temperature were the two key factors in determining the quality of bricks. And it was recommended that the bonding strength could be improved by controlling the operating conditions [Mary Lissy and Sreeja, 2014].

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Studies on Geopolymer concrete have been extensively carried out using various source materials like Fly ash, Bottom ash, GGBFS, Red mud, Metakaolin, etc. Of all these Fly ash is the most commonly used as it is easily available. But the applications of bottom ash are not that much widespread as the fly ash. The exploitation of bottom ash and GGBS in the manufacture of geopolymer paver blocks have been studied [Revathi et al, 2014]. The study also describes the current consumption of the fly ash and bottom ash. It was identified that the fly ash utilization is more when compared to bottom ash, the reason being that FA has finer surface area compare to BA. The coarser particle size reduces the strength and other properties of GPC. The authors carried out the utilization of the ground finer BA as the replacement of the cement. The source material for the paver blocks are BA-GGBS in different proportions the alkaline solution used was NaOH and Na₂SiO₃, normal river sand is used as fine aggregate. Thaarrini et al (2015) carried out a feasibility studies on compressive strength of ground coal ash geopolymer mortar. The ground bottom ash with GGBS combination was used as source material. This study carried out analysis of compressive strength of ground coal ash geopolymer mortar with ambient curing and steam curing 60°C with ratio of Na₂SiO₃ has 2, NaOH with molarity of 8M, and the alkaline liquid to binder ratio was 0.4, for different molar ratios of SiO₂ to Na₂O It was also revealed that with proper selection of SiO₂ to Na₂O and Na₂SiO₃to NaOH ratio, best geopolymerization could be achieved even at ambient temperature. It is the positive aspect to use geopolymer technology in cast in situ concrete construction. Attempts were made to study the properties of light weight concrete using incinerator bottom ash. It was concluded that the strength of incinerated bottom ash concrete was appropriate for making light weight concrete blocks [Qiao et al, 2008]. Durability properties of concrete containing non-ground coal bottom ash and non-ground bottom ash were studied. The study concludes that the use of these source materials improve the durability properties when they are used as fine aggregate. In the range of 30% to 50% [TurhanBilir, 2012]. Researches are being carried out to determine the influence of the alkaline activator solution, especially NaOH on the properties of geopolymer mortar under different temperatures. The effect of different NaOH concentrations on the geopolymerization reaction of geopolymer mortars and the curing period were studied and it was observed that the increase in the curing times affected the porosity values while NaOH concentration affected both porosity values and curing process [GokhanGorhan et al, 2014].

III. MATERIALS AND EXPERIMENTAL INVESTIGATION

BOTTOM ASH

The bottom ash was collected from Thermal power station at Mettur. The bottom ash when collected was in wet condition. Hence it was first dried in the oven and then ground to the fineness of less than 45 micron. The grinding of bottom ash increases the surface area similar to fly ash and can be utilized as a binder material. Figures 1 and 2 show Scanning Electron Microscopy and Energy Dispersive Spectroscopy images of ground Bottom ash. Table 1 gives the chemical composition of ground Bottom ash.

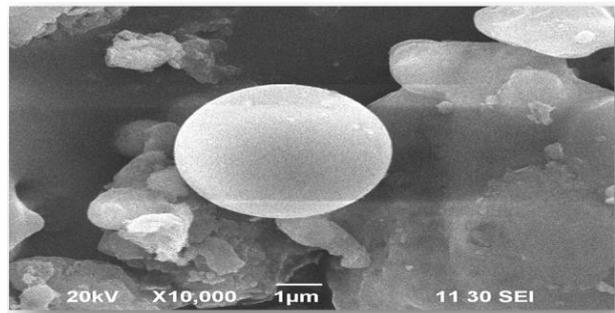


Fig 1. SEM image of ground Bottom ash

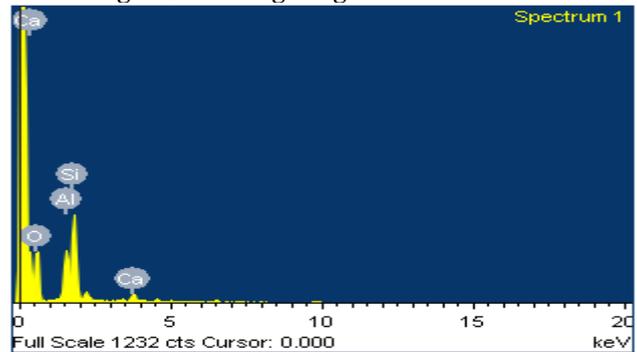


Fig. 2. EDXA image of ground Bottom ash

Table 1 Chemical properties of bottom ash

	Element			
Weight %	O K	Al K	Si K	Ca K
	59.66	13.71	25.10	2.14

GGBFS

GGBS is a by-product of the production of iron and steel and it is composed chiefly of calcium and magnesium silicates and aluminonanosilicates. The GGBFS releases only about 70kg of CO₂ in one ton production of GGBFS. In this study GGBFS was obtained from Agni steels, Ingur. The GGBFS was used in different proportions with bottom ash as source material to attain good strength. Figures 3 and 4 show the Scanning Electron Microscopy and Energy Dispersive Spectroscopy images of GGBFS. The chemical properties of GGBS are enlisted in Table 2

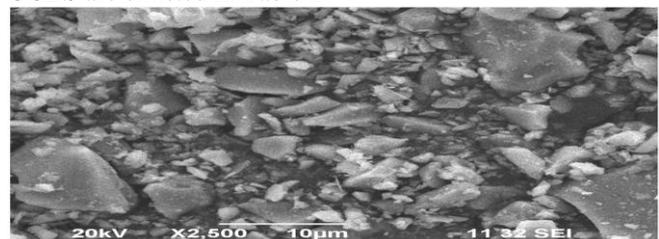


Fig.3 SEM image of GGBFS



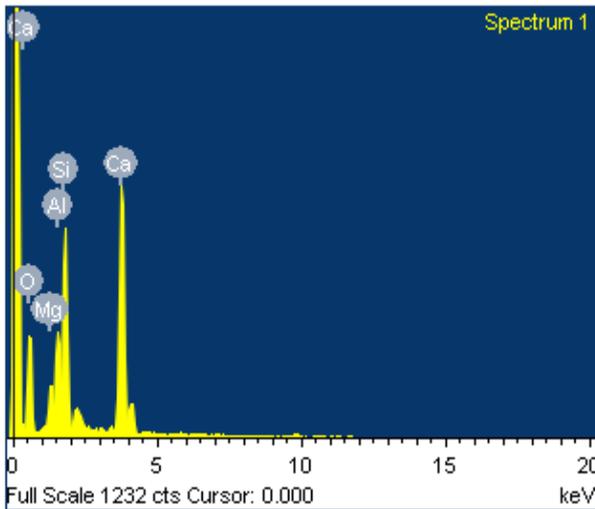


Fig. 4 EDXA image of GGBFS

Table 2 Chemical properties of GGBFS

Weight %	Element				
	O	Mg	Al	Si	Ca
	51.04	3.93	7.46	15.10	22.47

ALKALINE LIQUIDS

Generally in geopolymer concrete the alkaline solutions used are sodium hydroxide and sodium silicate or potassium hydroxide and potassium silicates. But here the sodium based silicates and hydroxides are selected.

a. Sodium Silicate Solution:

The molar ratio of the Na₂SiO₃ solution was found to be 1.5 with a specific gravity of 1.54. The percentage of water is 51.5.

b. Sodium Hydroxide solution :

NaOH solution with an assay of 97%, 1.8% of Na₂CO₃ and traces of other elements like Cl, SO₂, Pb, Fe, K and Zn

TEXTILE EFFLUENT

Effluent is used at different percentage as a replacement for Na₂SiO₃ as 0%, 25%, 50%, 75%, and 100%. The effluent selected for this study should have silicate and alumina content like that of sodium silicates without contamination of coloured particles. The effluent from cotton textile industry at Thenkasi was chosen for this study. The effluent collected from 5 different sources , i.e. Mercerizing 1 &2, Washing, Wetting and Bleaching processes. Proper care is to be taken that the collected effluents should be free from coloured chemical i.e. before the dyeing process. From the molar ratio (SiO₂/Na₂O) ratio, the effluent from Mercerizing process 1 with a ratio of 0.54 was selected as the best one. Table 3 gives the chemical properties of the mercerizing effluent.

Table 3 Chemical properties of effluent from mercerizing- 1 process

Parameters	Chemical composition
pH	7.91
Colour	Yellowish
Specific gravity	1.53 g/cm ³
SiO ₂	95.00 mg/l
Na ₂ O	177.93 mg/l

Fe ₂ O ₃	1.92mg/l
Al ₂ O ₃	BDL [D.L: 0.01]
K ₂ O	2.01mg/l
P ₂ O	36.00 mg/l
MgO	88.04 mg/l

RIVER SAND

Locally available river sand is used as fine aggregate by confirming to grading zone III as per BIS 383-1970 is used as filler for bottom ash geopolymer mortar.

WATER

Potable water which conforms the requirements of IS 456-2000 standards were used for the experimental investigations.

EXPERIMENTAL INVESTIGATION

MIX PROPORTIONS OF GEOPOLYMER MORTAR

From preliminary investigations, the ratio of the source materials i.e. Bottom ash and Ground Granulated Blast Furnace Slag (GGBFS) were determined. The Alkaline liquid/ binder ratio varies from 0.35 to 0.55. In this study the ratios are taken as 0.4 and 0.5 designated by A1 and A2 respectively. The ratio of sodium silicate to sodium hydroxide ranges from 2 to 2.5. In this study the ratio is taken as 2.5. The Molarity of the alkaline activator solution is taken as 4M, 6M and 8M. Mortar cubes of size 70.6 mm are cast using the mentioned mix proportions and the compressive strength was determined. Bottom ash – Sand ratio is 1 :3. Water to Binder ratio was taken as 0.3 and Water to geopolymer solids was taken as 0.2. Geopolymer mortar cubes were cast and tested for their compressive strength to identify the optimum mix compositions of Bottom ash/ GGBFS

The bottom ash and GGBS can be used in different combinations like 0,25,50,75 and 100. Totally there are 60 mixes for both alkaline to binder ratios (0.4 and 0.5) along with different molarity 4M, 6M and 8M concentrations of NaOH, varying proportions of BA and GGBS BG0, BG25, BG50, BG75 and BG100 , effluent to Na₂SiO₃ proportions 0%, 25%, 50%, 75%, 100%. From the test results on Geopolymer mortar the optimum proportions for geopolymer concrete are arrived at.

Table 4 Mix proportions for A1 and A2

	Ingredients			
	Binder	FA	NaOH solution	Na ₂ SiO ₃ solution
Total quantity required in kg/m ³ for Mix A1	455.61	1366.82	50.117	125.293
Total quantity required in kg/m ³ for Mix A2	455.61	1366.82	63.78	162.65



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MIX PROPORTIONS FOR GEOPOLYMER CONCRETE

The parameters for mix proportioning of geopolymer concrete is obtained from previous literatures. The most important parameters which affect the mechanical and durability properties of geopolymer concrete are ratio of (alkaline/ binder), ratio of ($\text{Na}_2\text{SiO}_3 / \text{NaOH}$), molarity, ratio of ($\text{Na}_2\text{SiO}_3 / \text{effluent}$) and curing mode. The designation BG25 denotes that binder contain 75% of bottom ash and 25% of GGBS. Ambient curing was adopted for all cases. Geopolymer concrete cubes were cast and tested for their compressive strength to identify the optimum mix compositions of Bottom ash/ GGBFS

Table 5 The total quantity of materials required for per cubic meter for mix A1 and A2

	Ingredients				
	Binder	CA	FA	NaOH solution	Na_2SiO_3 solution
Total quantity required in kg/m^3 for	442.86	1008	672	50.61	126.53
Total quantity required in kg/m^3 for	413.33	1008	672	59.05	147.63

IV. RESULTS AND DISCUSSION

GEOPOLYMER MORTAR SPECIMENS

Out of 60 mixes 30 mixes have alkalinity to binder ratio 0.4 mix A1 and 30 mixes have alkalinity ratio 0.5 mix A2 to identify the two optimal ratio one from mix A1 and another one from mix A2 by testing compressive strength of 60 mixes by casting mortar cubes. All the geopolymer mortars were designed with sodium hydroxide of molarity 4M, 6M and 8M and sodium silicate replaced by textile effluent from mercerizing process-1 by 0%, 25%, 50%, 75% and 100%, with source materials as finely grounded bottom ash and GGBS in two different combinations bottom ash 75% indicated as BG25 and GGBS 25% then bottom ash 50% and GGBS 50% indicated as BG50. The mortars were casted and cured in ambient temperature. The compressive strength on basis of effluent replacements, molarity variation and bottom ash and GGBS mixes the 60 mixes A1 and A2 were obtained and plotted in graph.

From the results it was seen that in both the mixes A1 and A2, molarity of 6M showed better results than the other molarities. The results of the combinations BG25 and BG50 for varying proportions of effluent percentages and 6M are shown in Figures 5 and 6.

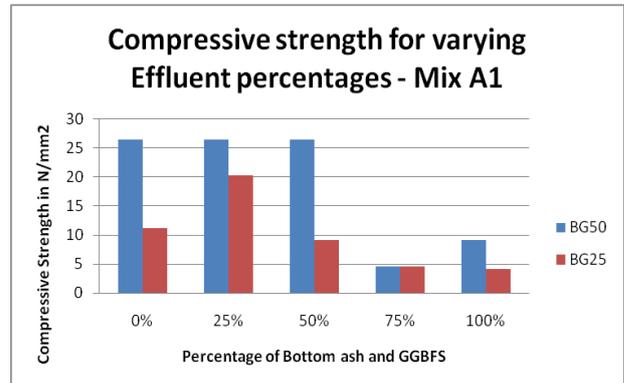


Figure 5 Compressive strength in N/mm^2 for Mix A1

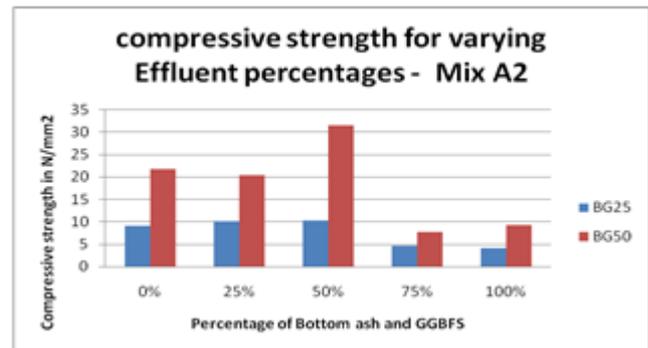


Figure 6 Compressive strength in N/mm^2 for Mix A2

From these two mixes the optimum mix for casting Geopolymer concrete specimens are to be determined by casting the cubes, prisms and cylinders after identifying the mechanical properties of those specimens.

GEOPOLYMER CONCRETE SPECIMENS

The two optimal mixes each from A1 and A2 with Bottom ash 50% and GGBS 50%, alkaline solutions as sodium hydroxide with 6M, sodium silicate 50% and textile replacement 50% with molar ratio $\text{SiO}_2 / \text{Na}_2\text{O}$ as 1.54 were designed, casted and cured at ambient temperature to identify the mechanical properties includes compressive strength, flexural strength and split tensile strength. The mechanical properties were determined at 7th day and 28th day by casting cubes, prisms, and cylinders. The compressive strength for mixes A1 and A2 at 7th and 28th day were represented in Figure 7.

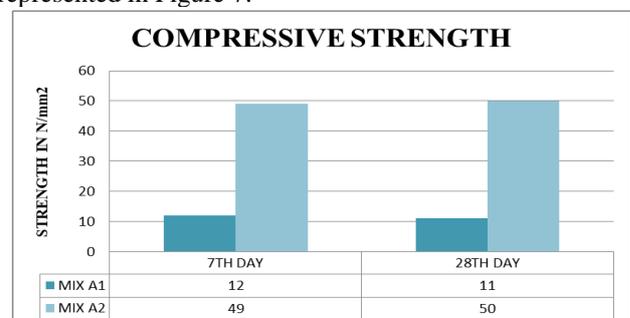


Figure 7 Comparison for mixes A1 and A2 - Cubes

The flexural strength for mixes A1 and A2 at 7th and 28th day are represented in Figure 8.

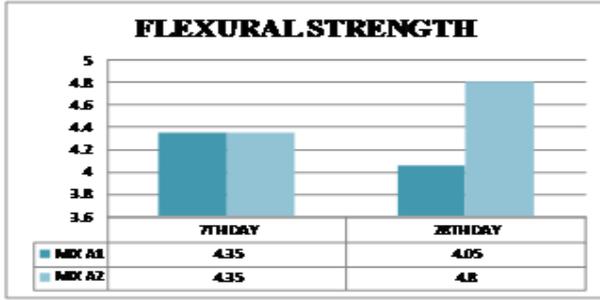


Figure 8 Comparison for mixes A1 and A2 - Prisms

The split tensile strength for mixes A1 and A2 at 7th and 28th day are represented in Figure 9.

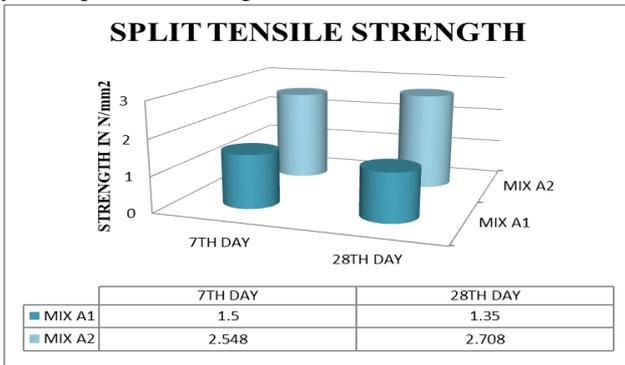


Figure 9 Comparison for mixes A1 and A2- cylinders

From these results the mix A2 with alkalinity to binder ratio 0.5, BG50, with alkaline solutions as sodium hydroxide with 6M and effluent replacement for Na₂SiO₃ 50% with molar ratio SiO₂ to Na₂O 1.54 were chosen as an optimum mix .

V. CONCLUSION

From the test results the following conclusions are drawn. In case of Geopolymer mortar specimens,

- ⊙The compressive strength is good upto 50% replacement of effluent; this is due to the increase in molar ratio from 1 to 1.54.
- ⊙And also the setting time of geopolymer concrete increases with increase of molar ratio, the compressive strength increase with the increase in molar ratio
- ⊙From the various compressive strength results it came to known that the molar ratio is high when 50% of Na₂SiO₃ and 50% of effluent were used. And the strength is optimum at 50% of effluent replacement. Beyond that the molar ratio decreases with decreases in molar ratio.
- ⊙At the same time the workability of geopolymer concrete is high when effluent content is more. This is due to less density of effluent when compare to Na₂SiO₃ (1540 kg/m³ > 1500 kg/m³).
- ⊙From the compressive strength results the two mixes one from mix A1 and another one from mix A2 were chosen as optimal one.
- ⊙In A1 the mix with BG50, effluent replacement 50% for Na₂SiO₃ with 6M and in A2 the mix with BG50, effluent replacement 50% for Na₂SiO₃ with 6M were chosen.

In case of Geopolymer concrete specimens

- ⊙The mix A2 with binder to alkaline liquid ratio 0.5 gives high compressive strength of 49 N/mm² and 50 N/mm² at 7th and 28th day respectively when compare to that of mix A1 with alkalinity to binder ratio 0.4 were the compressive strength is 12 N/mm² and 11 N/mm² at 7th and 28th day respectively.
- ⊙The mix A2 with binder to alkaline liquid ratio 0.5 gives high flexural strength of 4.35 N/mm² and 4.80 N/mm² at 7th and 28th day respectively when compare to that of mix A1 with alkalinity to binder ratio 0.4 were the flexural strength is 4.35 N/mm² and 4.05 N/mm² at 7th and 28th day respectively.
- ⊙The mix A2 with binder to alkaline liquid ratio 0.5 gives high split tensile strength of 2.548 N/mm² and 2.708 N/mm² at 7th and 28th day respectively when compare to that of mix A1 with alkalinity to binder ratio 0.4 were the split tensile strength is 1.5 N/mm² and 1.35 N/mm² at 7th and 28th day respectively
- ⊙The mix A2 with Alkaline liquid to binder ratio of 0.5, Ratio of source materials as 50%, with Molarity of alkaline solution as 6M, molar ratio SiO₂ to Na₂O 1.54 and Effluent replacement with alkaline liquid as 50% were chosen as an optimum proportion for Geopolymer concrete.

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