Experimental Study on Assessment of Fly Ash and GGBS Based Geopolymer Mortar with Brick Waste Replacement to Fine Aggregates

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Abstract - *This report generally consists of fly ash and GGBS based geopolymer mortar with replacement of sand with brick waste. Fly ash and GGBS percentage was varied as 0:100, 30:70, 50:50, 70:30, 100:0 %. Study was carried on different molarities of sodium hydroxide (NaOH) i.e. 4M, 6M, and 8M. Percentage of replacement of sand with brick waste was kept as 10%, 20% and 30%.*

Construction and demolition waste (CDW) valorization in a new production process has been widely studied. However, up to now, valorization has been limited to use one type of waste. Hence, the environmental and economic benefits remain quite narrow, particularly in countries with high waste production. It is reviewed that during manufacturing 1ton of cement, 1ton of CO2 is released into the atmosphere. Thus, to make up hand with the recent researches in the field of geopolymer concrete a small study has been carried out, which is further stated.

Sodium silicate and sodium hydroxide were used as alkaline activators. Ratio of Sodium silicate to sodium hydroxide was kept 2.5. Initial tests like normal consistency, final setting time, etc. were carried on each mix. Flow test was taken to fix a unique solution to binder ratio. Ambient curing of 70.6 x 70.6 x 70.6 mm cube for 28 days was performed and later tested for compressive strength. 100% of GGBS in geopolymer mortar shown optimum results. Further, an equation was developed to determine the predicated value of compressive strength which was obtained by experimental study. For that regression analysis was performed.

Key Words: Fly Ash, GGBS, Brick Waste, Geopolymer Mortar etc

1. INTRODUCTION

The disposal or recycling of large volumes of waste materials from construction and demolition is one of the most serious environmental issues. Waste clay bricks bonded with cement mortar are one of the most common components found in these leftovers (masonry waste-MW). Only a metropolis like Bogotá, Colombia, produces about 15 million cubic metres of construction debris each year.

Investigations on cement production and its environmental effects have been conducted. It has been determined that a significant amount of Carbon Dioxide (CO2) is released into the atmosphere throughout the manufacturing process. The principal gas responsible for the greenhouse effect is carbon dioxide. Cement production accounts for around 5% of global CO2 emissions. According to research, 1 tonne of cement produced emits 1 tonne of CO2 into the environment (Neville 2012). It has been observed that cement demand is increasing day by day, and that by 2025, it will be close to 500 million tonnes. However, it is estimated that demand and production will lag behind by 230 million people.

Rapid industrialization has resulted in an ever-increasing use of river sand for construction reasons in areas where river beds have become worn out. Several issues have surfaced, including increased river bed depth, decreased water table, increased salinity, and erosion of river embankments. As a result, investigating other materials as a fine aggregate in concrete to replace river sand became a must. Brick waste has emerged as a sensible alternative to meet such standards in this regard.

1.1 What is Geopolymer Concrete?

In 1978, Davidovits used the term "geopolymer" to describe materials defined by chains or networks of inorganic molecules. Amorphous alkali aluminosilicate or alkali-activated cements are two names for it. The reaction of a solid aluminosilicate powder with alkali hydroxide/alkali silicate produces geopolymers. It is mainly made up of a silicate monomer (–Si–O–Al–O–) that repeats itself.

Advantages:

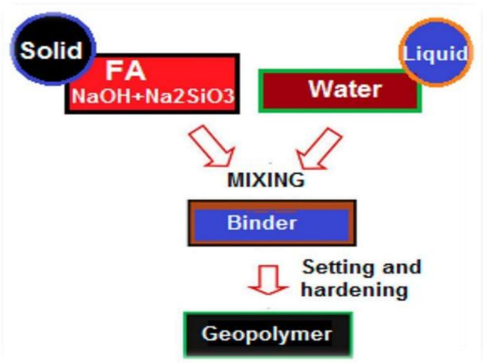
1. Geopolymer concrete has a number of benefits over traditional concrete. It lasts significantly longer than

normal concrete and requires little maintenance, saving a lot of money that would otherwise be spent on repairing and maintaining concrete infrastructure.

2. Geopolymer concretes can survive hundreds of years, but traditional concretes only last tens of years.

3. Geopolymer concrete is more corrosion and fire resistant, has strong compressive and tensile strengths, and quickly reaches full strength (cures fully faster). In addition, it shrinks less than regular concrete.

Figure 1.1 Chemical reactions between fly ash and Alkali solution



Limitations:

1. Geopolymer is more suited to the precast industry due to its sensitivity to composition and curing conditions.
2. Geopolymer production is decentralised with local expertise, as opposed to cement production, which is centralised with embedded knowledge in the bag (you just need to add water thereafter).

1.2 Brick wastes

The utilisation of recycled clay brick not only solves the problem of disposing of demolished solid waste, but it also helps to mitigate the environmental damage caused by resource overdevelopment. CBP (clay brick powder) has pozzolanic activity and can be used as a cement substitute. Natural coarse aggregate can be replaced with recycled clay brick aggregate (RBA). RBAC (recycled clay brick aggregate concrete) can achieve adequate strength and be used to make medium- and low-strength concrete.

Reason to select brick waste as a replacement

1. Generally many of the studies have been carried on recycled aggregates with replacement of fine aggregates, but limited research has been done in replacing fine aggregates with brick waste.

2. Many researchers had studied the chemical composition of brick waste. It is found that burnt clay brick contains silica and alumina to a maximum amount. This will result in additional formation of C-S-H gel formation, which will further increase the strength of mortar and concrete.

3. Durability is the main aspect in spite of the strength. Limited research has been there on durability of brick waste as replacement in geopolymer mortar.

4. As studied from all reviews, there are limited studies on lower molarity solution of NaOH with brick waste as replacement in geopolymer mortar.

1.3 Reviews on Geopolymer Concrete

Hardjito.D et al (2005): Explained that Geopolymerisation involves a chemical reaction between various aluminosilicate oxides with silicates under highly alkaline conditions, yielding polymeric Si–O–Al–O bonds indicating that any Si–Al materials could become sources of geopolymerization. Geopolymer binders are used together with aggregates to produce geopolymer concrete .

N A Lloyd and B V Rangan (2010): Presented the study of fly ash based geopolymer concrete. The author discussed the properties of geopolymer concrete, design of geopolymer mixtures, use of geopolymer concrete for precast sections.

The economic benefits and contributions of geopolymer concrete to sustainable development have also outlined. This paper showed a great interest on Geopolymer concrete properties and is well-suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after a disaster.

2. PROCESS AND TEST

As stated in the introduction chapter, numerous wastes are generated in our environment that are challenging to recycle. For the past few years, small attempts have been underway to recycle brick waste for long-term development. We conducted an experimental investigation by taking these factors into account. Details of which are depicted in more detail.

2.1 Reviews on Geopolymer Concrete

1. This experiment generally deals with the Fly ash and GGBS based geopolymer mortar.

2. As studied in the reviews, there has been limited research carried on brick waste. Some studies have been carried on replacing the cement with waste clay brick powder partially. This study deals with replacing the fine aggregates with brick waste in limited proportion.

3. From studies, 0%, 10%, 20%, 30% replacement of fine aggregates with brick wastes has been finalized for the experimental work.

4. With variation in the brick waste, there are variations among the fly ash and GGBS content to find the optimum percentage of GGBS and Fly ash in accordance with the previous studies.

5. It was finalized to take 0:100, 30:70, 50:50, 70:30, 100:0 % of GGBS: Fly ash ratio.

6. Alkaline activators are the main constituent in the geopolymer paste, as it is responsible for polymerization.

7. Sodium Silicate and Sodium Hydroxide (NaOH) were considered as the alkaline activators. The ratio of Sodium silicate: Sodium Hydroxide was kept as 2.5 from the study carried out in the reviews section.

8. Considering the molarity aspect, we considered 4M, 6M, 8M solution of sodium hydroxide, as limited research were there at lower molarity.

9. Solution to binder ratio was finalized as 0.55 from initial test carried on different mortars.

10. Initial test were carried out on normal consistency, Initial setting time, final setting time and physical parameters of fine aggregates and brick waste. Solution to binder ratio was determined for each mixes and later unique ratio was maintained among all mixes for comparing the results.

11. Finally, compressive strength was determined for 28 days for each mixes and results were later compared and optimum mix was found out for this experiment.

2.2 Procedure Adopted

As per the above mentioned content initial tests have been carried on fine aggregates and brick waste

2.2. 1 Initial Tests

Under this operations we've concluded with following mentioned four tests (For result perfections)

a. Apparent Specific Gravity

As per IS: 2386 (Part III) - 1963 procedure for determining the specific gravity was adopted for particle size less than 4.75mm.

- Firstly pycnometer bottle was used to determine the specific gravity.
- 500gm of dry sand sample was put into the pycnometer bottle and weight of the bottle was taken (W1).
- Then water should be filled into the jar containing the sand sample. Any trapped air shall be eliminated by rotating the pycnometer on its side, the hole in the apex of the cone being covered with a finger. The pycnometer shall be dried on the outside and weighed (W2).
- Then empty the content from the jar and filling it completely with distilled water. It should be dried from outside and then weight was taken (W3)

Formula,

Specific Gravity = W1 ……….. (3.1)

Hence, W1 = (W2 – W3)

b. Water Absorption

As per IS 2386: 1983 (Part III) water absorption test was carried on fine aggregates and brick wastes.

- Initially sand sample was kept in tray with water filled till the top surface. Additional bubbles if there were removed by stirring the sand sample.
- Sample was kept in atmospheric temperature of 27 ± 2 ◦ C for about 24hrs.
- This sample was then stirred and kept for surface drying for half hour. Care was taken that the sample was not kept for long period.
- After that weight of the sample was taken (W1). Then sample was oven dried at 100 – 110 ◦ C for about 24hrs.
- Weight of oven dried sample was taken as (W2).

Formula,

Water absorption (%) = W1-@3/W2 * 100 …….. (3.2)

c. Bulk Density

- Bulk density was carried out as per the procedure given in IS 2386: 1983 (Part III).
- Initially a container of known dimension was taken from the laboratory and was cleaned properly. Then dimensions of the container was measured and volume of the container was calculated (V).

- After calculating the volume of container, it was filled with atmospheric dried sand. 25 no. of blows was given at each interval in three layers. After that weight of the container containing sand was measured (W1). Empty weight of container was also measured (W2)

Formula,
Bulk Density (Kg/m2)= W1-W2/ V …….. (3.3)

d. Flow Test

In this study the flow table used was according to the specifications given by IS: 5512 – 1983.

- As per IS: 4031 (Part 7) – 1988 the test procedure was adopted and performed for geopolymer mortar.
- Sum of % cumulative weight retained 100 & The apparatus was made available in the laboratory as per the specification as per the above IS code. A mould in which paste was to be filled was according to the IS specification.
- After mixing the different proportion of geopolymer paste, 25 no. of blows was given and the diameter of the spreader paste was measured.

Later the flow value was calculated.

Flow value (%)= D1-D0/D0 *100

D1 – Diameter of paste after 25 no. of blows
D0 – Inner diameter of apparatus (12 cm)

e. Compressive Test

As there is no separate code to determine the physical strength of geopolymer mortar, same code of cement mortar was used to determine the compressive strength of geopolymer mortar.

IS 4031 (Part 6): 1988

- For calculating compressive strength cube of dimension 70.6 x 70.6 x 70.6 mm was made of different mixes and was tested after 28 days.
- Mixing of the dry mix with the alkaline solution was done at room temperature of 29 ± 2 ◦ C. As discussed previously, by obtaining solution to binder ratio for each mix, a ratio was fixed which was suitable to all type of mixes to maintain uniformity in comparing the final results.
- Cubes were lubricated with oil from inside and then after mixed paste was filled into it and then vibrated at rate of 400-500 rounds/minute. Extra paste at surface was removed by trowel and surface was made plain.
- Mould was kept at room temperature for about 24 hrs. And then De moulded.
- Some researchers reviewed that 100% fly ash replacement would take more time to react with alkaline solution even after the final setting time was less.
- Purpose moulds with high percentage of fly ash replacement were removed after 36 hrs. As there is no need to cure the geopolymer mortar in water, the moulds were kept in the atmospheric air at ambient temperature.

For each design mix sample three specimens were casted and average of the three results was taken.

- Loading rate of machine was maintained as per IS code, 140 Kg/cm2/min.
- Results in terms of load were noted at failure and then strength was calculated corresponding to it.

2.2.2 Making of Alkaline Solution

- In this study Sodium Hydroxide (NaOH) and sodium silicates were used as alkaline activators for polymerisation reaction.
- Sodium silicate solution was made available from market as specified earlier and sodium hydroxide solution with different molarities was made in the laboratory.
- While making sodium hydroxide solution of specified molarity, some amount of NaOH flakes were taken and dissolved in 1 ltr. of distilled water.
- This leads to decrease in the water content in the solution and hence molarity does not remain same. Hence, extra water is added to the solution after 1 hrs. Of period into the solution to make up it to 1 ltr as marked on the container.
- After doing the above procedure, Sodium silicate is added into it with proper mass proportion (here Sodium silicate: NaOH = 2.5).
- This solution made is then kept for 24 hrs. Prior to its use in the mix.

For example,

- Consider we have to make an alkaline solution with 8M of NaOH and sodium silicate

Molecular weight of sodium hydroxide = 40 gm.

For 8M NaOH = 8 x 40 = 320 gm. / ltr I.e. for 8M NaOH we have to add 320 gm. of NaOH flakes into 1 ltr. Of distilled water.

- After keeping this solution for 1 hr. certain amount of solution gets evaporated.
- Add some amount of water to it to make up the 1 ltr mark on the container. Take 1kg of the solution from that and add 2.5 kg of sodium silicate into it as the alkaline activator ratio is 2.5. And keep the solution for 24hr. at room temperature of 25 ± 2 ◦ C

Figure 3.2 Making of alkaline solution and paste for normal consistency test

Figure 3.3 Making of alkaline solution and paste for normal consistency test

3. RESULTS & DECLARATIONS

Under the result & declaration, First thing first the Life cycle cost analysis was done between the conventional cement mortar and the geopolymer mortar. Which also shown economic statistics of geopolymer mortar as compared to cement mortar.

Further regression analysis was carried out to determine an equation which will give predicted values of compressive strength by using the experimental data. Curvilinear (non- linear) nature was adopted to formulate the equation which was known as multivariable power equation.

3.1 Compressive strength of Different mixes

Table 3.0.1 28days compressive strength of 0% fly ash and 100% GGBS

Binder/ Aggregate	Proportion of Fly Ash and GGBS (%)		Molarity (M)	Replacement of Fine Aggregate (%)	Compressive Strength (MPa)
	Fly Ash	GGBS			28 days
1 : 1	70	30	4	0	42
				10	38
				20	39
				30	35
			6	0	49
				10	46
				20	47
				30	43
			8	0	53
				10	48
				20	49
				30	44

Table 3.0.2 28days compressive strength of 50% fly ash and 50% GGBS

Binder/ Aggregate	Proportion of Fly Ash and GGBS (%)		Molarity (M)	Replacement of Fine Aggregate (%)	Compressive Strength (MPa)
	Fly Ash	GGBS			28 days
1 : 1	0	100	4	0	55
				10	49
				20	52
				30	47
			6	0	59
				10	54
				20	57
				30	49
			8	0	62
				10	55
				20	58
				30	49

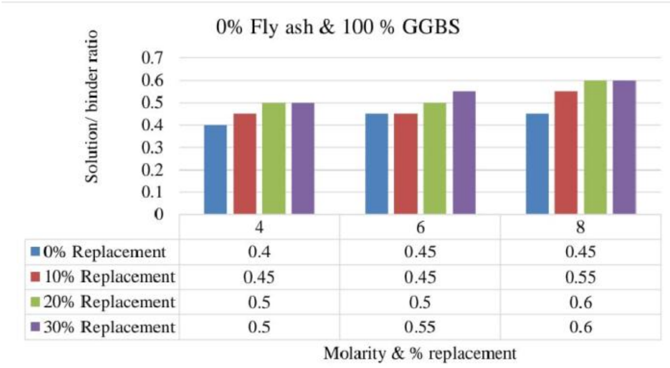
3.2 Flow Test

IS: 5512 – 1983 gives the specification for flow table. As per IS: 4031 (Part 7) – 1988 the test procedure was adopted and performed for geopolymer mortar.

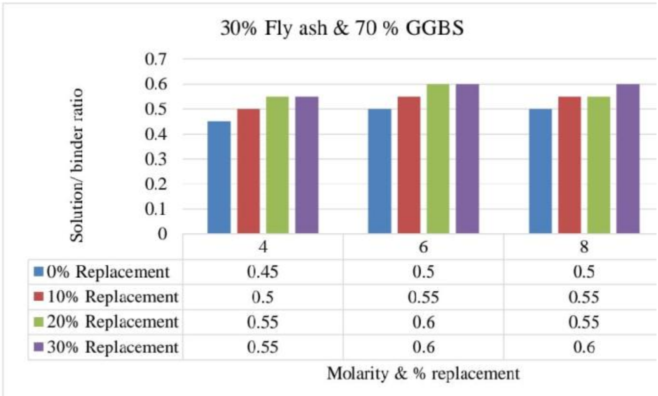
In this study, flow test was conducted to finalise the solution to binder ratio. A fix flow value of 10% was taken and the alkaline solution was mixed with the dry mix and test was carried.

The main purpose of this test was to calculate the Solution to Binder ratio. Following is the Table which gives the values of solution to binder ratio for each mix.

0% Fly Ash & 100% GGBS



30% Fly Ash & 70% GGBS



This study is generally based on sustainable development and making ecofriendly concrete in the field of geopolymer concrete. Certain factors, here Fly Ash: GGBS ratio, molarity and % replacement by brick waste are considered for the study.

Fly ash: GGBS ratio 0: 100, 30: 70, 50: 50, 70: 30 and 100: 0 percentages are considered, whereas molarities of NaOH are 4M, 6M and 8M. % replacement of sand with brick waste is 10%, 20% and 30%

4. CONCLUSIONS

The fresh and mechanical properties of a fly ash and GGBS geopolymer mortar with replacement of sand with brick waste showed encouraging results and led to pointing out

interesting aspects to use as a possible solution in building industries. Following are some of the conclusion made by studying different research papers and correlating it with the experimental results.

From the results, normal consistency of the solution is affected by the content of fly ash and GGBS. It is seen that as fly ash content increases normal consistency decrease i.e. requirement of alkaline solution decreases.

This is due to the microscopic structure of fly ash being spherical shape (i.e., curved, cubic shape with rounded angularity) with smooth surface texture, making fewer surfaces in contact and reduces viscosity. Final setting time of geopolymer paste decreases with increase in GGBS content.

5. FUTURE SCOPE

As discussed in previous chapter there are many results which can be related with each other. But some of study which is not researched in this study can be carried further.

Following are some of the views which can be further researched according to this project.

- In this study, alkaline solution used is of sodium hydroxide and sodium silicate while other alkaline solution can also be used e.g. Potassium activators.
- Further, some research is also carried on single alkaline activator (NaOH). This study can also be carried out with single alkaline solution.
- Sodium silicate to sodium hydroxide ratio is kept 2.5 in this ratio which can be changed and results of which can be manipulated with this experimental results.
- Limited molarities of sodium hydroxide are taken for this study which can be further increased till 16M at 2M interval. As some research, shows that compressive strength increases till 16M and further decreases.
- Durability plays an important role which is not studied in this experiment. Further, study can be carried out to determine the durability of geopolymer mortar with brick waste replacement.
- Ambient temperature curing condition is used to cure the mortar cubes and test was done on them after 28 days. Oven curing can be done for these cubes and mechanical properties of the cubes can be studied.
- After seeing the % finer passing graph of brick waste, it can be said that brick waste particles are coarser than sand and gap graded nature of brick waste particles are also seen.
- By taking well graded particles of brick waste and confirming to zone II, study can be carried further to determine mechanical properties.

These factors can be correlated with the compressive strength of mortar.

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REFERENCES

[1] A.Z. Warid Wazien; Mohd Mustafa Al Bakri Abdullah; Rafiza Abd. Razak; M.A.Z. Mohd Remy Rozainy; Muhammad Faheem Mohd Tahir : Strength and Density of Geopolymer Mortar Cured at Ambient Temperature for Use as Repair Material International Conference on Innovative Research 2016 - ICIR Euroinvent (2016)

[2] G. Mallikarjuna Rao; T. D. Gunneswara Rao: Final Setting Time and Compressive Strength of Fly Ash and GGBS-Based Geopolymer Paste and Mortar. Arab J Sci Eng 40:3067–3074 DOI 10.1007/s13369-015-1757-z. (2015)

[3] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

[4] G. Mallikarjuna Rao; T. D. Gunneswara Rao: Final Setting Time and Compressive Strength of Fly Ash and GGBS-Based Geopolymer Paste and Mortar. Arab J Sci Eng 40:3067–3074 DOI 10.1007/s13369-015-1757-z. (2015)

[5] Yip; C.K.; Van Deventer: Effect of granulated blast furnace slag on geopolymerisation. In: Proceedings of 6th World Congress of Chemical Engineering Melbourne, Australia, pp. 23–27 (2001)

[6] Hardjito, D.; Wallah, S.E.; Sumajouw, D.M.J.; Rangan, B.V.: On the development of fly ash-based geopolymer concrete. ACI Mater. J. 101(M52), 467–472 (2004)

[7] Zarina Yahya; Mohd Mustafa Al Bakri Abdullah; Kamarudin Hussin; Khairul Nizar Ismail; Rafiza Abd Razak; Andrei Victor Sandu: Effect of Solids-To-Liquids, Na2SiO3-To-NaOH and Curing Temperature on the Palm Oil Boiler Ash (Si + Ca) Geopolymerisation System. Materials 2015, 8, 2227-2242; doi: 10.3390. (2015)

[8] Neville, A.M.: Properties of Concrete. Trans-Atlantic Publications, Indian International Education, 5th edition, 856 p. (2012)

[9] Singh, B.; Ishwarya, G.; Gupta, M.; Bhattacharyya S. K. (2015): Geopolymer concrete: A review of some recent developments. Construction and Building Materials, Elsevier Ltd, 85, 78–90.

[10] S.M. Laskar; S. Talukdar: Preparation and tests for workability, compressive and bond strength of ultra-fine slag based geopolymer as concrete repairing agent. Construction Building Material 154 176–190. (2017)

[11] J. M. Ortega; V. Letelier; C. Solas; G. Moriconi; M. A. Climent; I. Sanchez: Long-term effects of waste brick powder addition in the microstructure and service properties of mortars. Construction and Building Materials, vol. 182, pp. 691–702. (2018)