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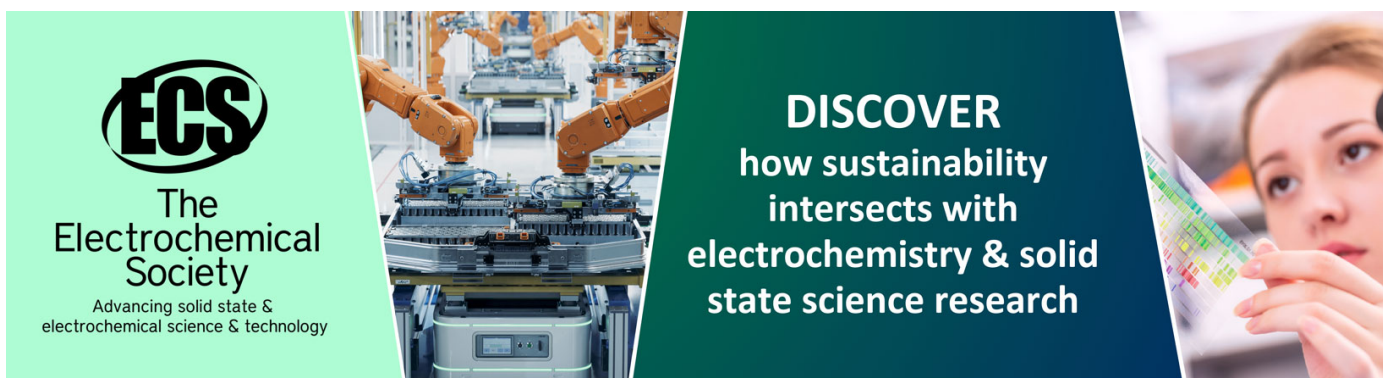
Energy efficient production of geopolymer bricks using industrial waste

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Energy efficient production of geopolymer bricks using industrial waste

Chithambar Ganesh A, Muthukannan M, Aakash S, Prasad, Subramanaian B

Kalasalingam Academy of Research and Education, Krishnankoil, Tamil Nadu, India

E-mail:chithambarmailid@gmail.com

Abstract: Bricks are the most predominant masonry units that are consumed globally. Brick manufacturing is energy consuming process and generates large amount of air pollution. The main objective of this paper is to synthesis geopolymer bricks made of Ground Granulated Blast furnace Slag (GGBS), M- Sand and Alkaline solution. The significance of this research work is the designing of geopolymer brick under economic condition with properties equivalent to the Class A first class bricks. The various factors that affect the geopolymerization such as proportions of raw materials, ratio of alkaline solution and molarity of the sodium hydroxide solution are optimized in this research work. Compressive strength and water absorption test were conducted over the brick specimens as per IS 3495 (Part 2): 1992. The results report that GGBS based geopolymer bricks could be designed with better engineering properties. This extends the scope of geopolymerization in the arena of bricks.

1. INTRODUCTION

Bricks are the ancient building materials from 14,000 BC, and are the common masonry items that are used in construction till now. Typically bricks are made from clay soil and their unique strength, durability, bonding with mortar makes the clay bricks predominant masonry units in the construction. Manufacturing clay bricks involves firing of bricks to high temperatures of about 1400 degree Celsius inside kiln. This requires large amount of fuel in the form of wood, coal, biomass etc. need to be burnt in the kiln causing serious issues of air pollution [1, 2, 3] Brick kilns pose serious health issues to nearby livelihood due to the emission of toxic substances in to the atmosphere. An energy efficient way of manufacturing bricks has to be made for a sustainable development.

River sand can be used as a filler component in the manufacture of bricks at lower temperatures of about 600 degree Celsius [4]. River sand is the non-renewable resource and its depletion has to be controlled for sustained development [5]. Excessive depletion of this non-renewable resource will result in soil erosion, affects water quality, affects water ecosystem, degradation of local livelihood [6,7]. Demand for the river sand and the gravel is also increasing due to developments in construction industry and it continues to propagate in an uncontrolled manner [8]. At present mining have become the most significant economic activities in most of the developing countries [9]. Hence an alternative material has to be identified to replace the application of river sand in various aspects.

On the other hand there has been series problems associated with the disposal of flyash and Ground Granulated Blast Furnace Slag (GGBS) which are by products of thermal power plant and steel plants. These products cannot be disposed in water or over land as they affect the ecosystem. Hence their disposal has to be addressed by utilizing in the development of building blocks.



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Manufacturing of geopolymer bricks is seeking attention recent days owing to its ecofriendly nature. Geopolymer technology is said to be environment friendly due to its support in reducing the emission of carbon dioxide from the cement manufacturing and addressing the problem of fly ash and GGBS disposal [10]. Geopolymer concrete are synthesized through the alkaline activation of aluminosilicate source material and its engineering and mechanical properties are determined to be higher than the cement concrete. Geopolymer is also found to exhibit fair properties even under elevated temperatures thereby replacing the cement concrete in all facets in construction industry [11-16]

The properties of Geopolymer bricks vary considerably depending upon the proportions of raw materials, ratio of alkaline solutions to be used and the molarity of sodium hydroxide solution. This research work puts forth series of tests to optimize these various factors that decide the strength, hardening and durability properties of geopolymer bricks. This work paves way for designing the energy efficient ecofriendly bricks.

2. METHODOLOGY AND MATERIALS

The Experimental work is divided in to three parts as it involves optimization of various factors that affects the properties of geopolymer bricks. At first, the raw materials required for the synthesis of geopolymer bricks such as GGBS and M-sand are to be optimized. The optimized proportion is selected and then the ratio of sodium hydroxide and sodium silicate solution to be used as the alkaline solution is then varied and optimized. Finally the molarity of the sodium hydroxide solution is varied and optimized.

Geopolymer bricks in this work are synthesized using GGBS, M-sand and alkaline solution. Combination of sodium hydroxide and sodium silicate solution is used as the alkaline activator solution. The bricks are cured under ambient conditions for 7 days. Materials used in this work were tested as per standards. Specific gravity of GGBS and M-sand was determined to be 2.9 and 2.72. M-sand falls under zone 3. Initially GGBS and M-sand are mixed in a Pan mixer for about 2 minutes followed by the addition of alkaline solution. The mixer is then operated for about 4 to 5 minutes. The mortar is then poured in to the special rubber moulds of size 200 x 100 x 100 mm. the mix proportions are tabulated in Table 1, Table 2 and Table 3.

3. RESULTS AND DISCUSSIONS

3.1 Optimization of raw materials

The base raw material such as GGBS and M-Sand are optimized in this phase. The two materials GGBS/M-sand are proportioned in various proportions such as 70/30, 60/40, 50/50, 40/60, 30/70 and 20/80. The compressive strength and water absorption test are conducted as per IS 3495 (Part 2): 1992 [17]. The results are tabulated in Table 1. Figure 1 and Figure 2 depicts the variation of compressive strength and water absorption results with the variation of ratio of GGBS and M- Sand.

Table 1. Mix proportions and Test results

Specimen ID	M-Sand (%)	GGBS (%)	NaOH: Na ₂ SiO ₃	Molarity of NaOH	Compressive Strength (MPa)	Water absorption (%)
GB1	30	70	1:2.5	10	23.8	5.5
GB2	40	60	1:2.5	10	20.5	6.4
GB3	50	50	1:2.5	10	16.2	8.5
GB4	60	40	1:2.5	10	14.6	10.0
GB5	70	30	1:2.5	10	9.4	14.5
GB6	80	20	1:2.5	10	5.1	21.8

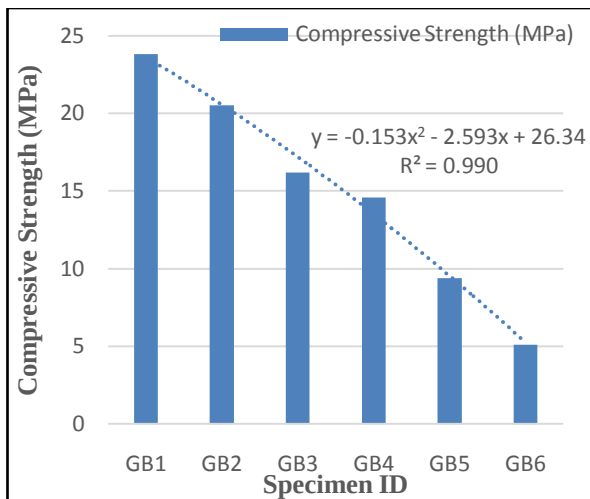


Figure 1. Compressive Strength

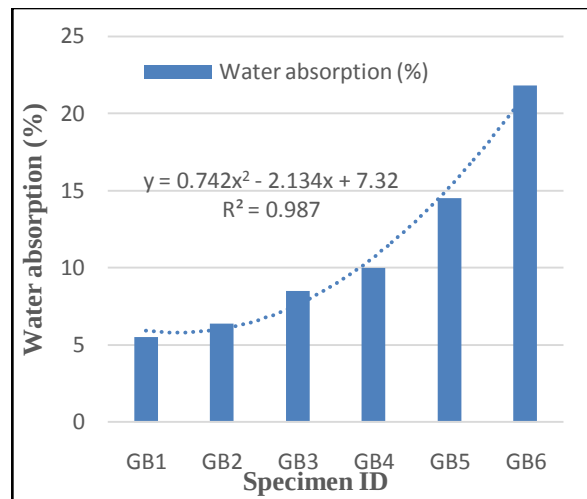


Figure 2. Water absorption results

From Table 1, it is inferred that the strength of the brick reduces with the increase in the M-sand content. The increased strength witnessed with the increase in GGBS content is due to the presence of CaO content in it. Specimen GB1, GB2 and GB3 exhibits strength more than 13.8 MPa and fall in to first class bricks category whereas the GB5 specimen fall in to second class bricks category depending upon the crushing strength. Hence under economic conditions GB3 specimen has been selected as the optimized specimen with strength more than 13.8 MPa with minimum GGBS content. It has also been observed that all the specimens except GB6 exhibited less than 20 percent which is the permissible limit.

3.2 Optimization of ratio between NaOH and Na₂SiO₃

The ratio between sodium hydroxide and sodium silicate solution is varied in this phase. The ratio NaOH and Na₂SiO₃ is varied as 1:0.5, 1:1, 1:1.5, 1:2 and 1:2.5. The compressive strength and water absorption test are conducted as per IS 3495 (Part 2): 1992. The results are listed in Table 2. Figure 3 and Figure 4 depicts the variation of compressive strength and water absorption results with the variation of ratio of NaOH and Na₂SiO₃ solution.

Table 2. Mix proportions and Test results

Specimen ID	M-Sand (%)	GGBS (%)	NaOH: Na ₂ SiO ₃	Molarity of NaOH	Compressive Strength (MPa)	Water absorption (%)
GB4	60	40	1:2.5	10	14.6	10.0
GB5	60	40	1:20	10	15.5	9.5
GB6	60	40	1:1.5	10	16.2	9.4
GB7	60	40	1:10	10	16.9	9.3
GB8	60	40	1:0.5	10	17.3	9.3
GB9	60	40	1:0	10	17.8	9.3

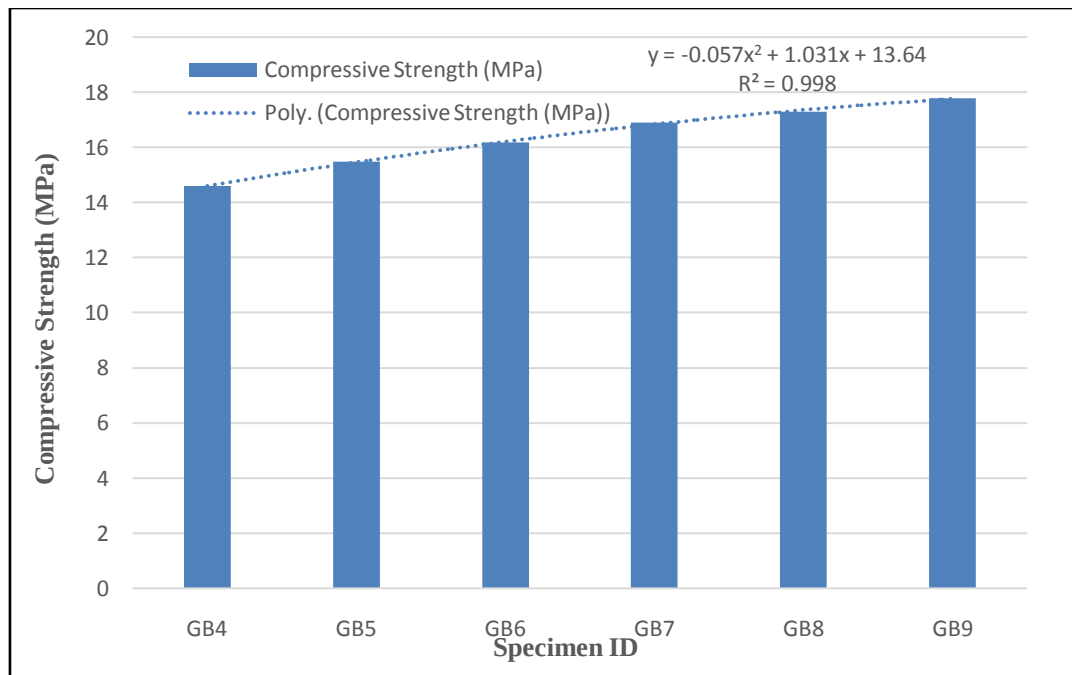


Figure 3. Compressive Strength

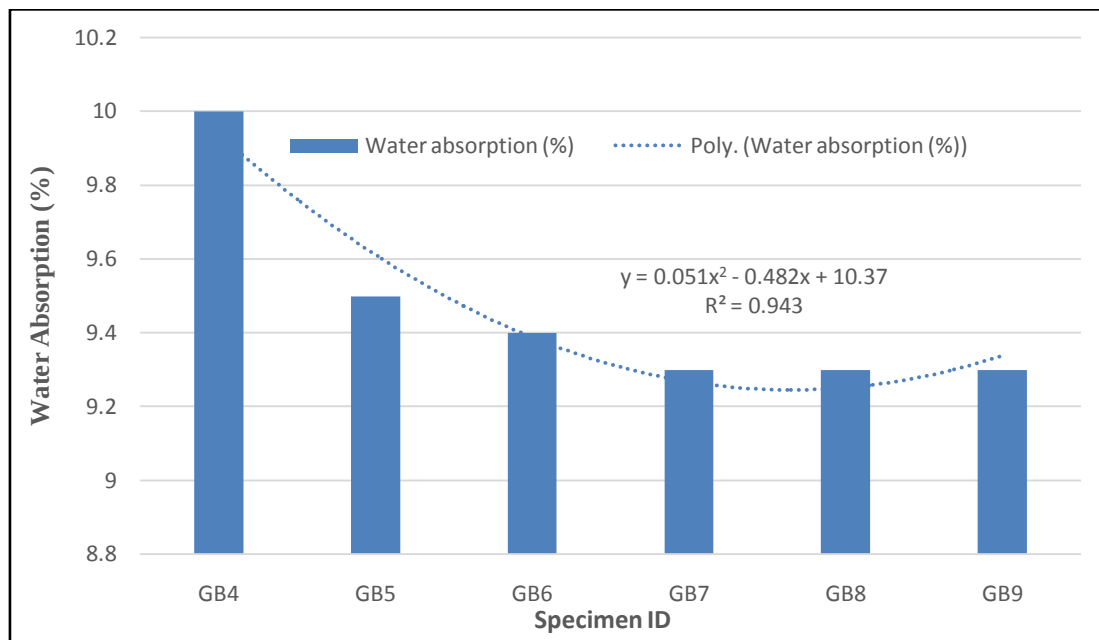


Figure 4. Water absorption results

From Figure 3, it is inferred that with the increase in the amount of sodium hydroxide solution to be used along with the sodium silicate solution as the alkaline solution there is an increase in the compressive strength of the bricks. This is because of the increased polymerization reaction due to the excess sodium hydroxide solution which leads to the formation of C-S-H bond. Under the economic conditions, it is possible to use completely replace sodium silicate solution with sodium hydroxide solution. Hence GB9 is selected as the optimized specimen with maximum compressive strength and minimum water absorption capacity.

3.3 Optimization of Molarity

The concentration of the sodium hydroxide solution to be used as the alkaline activator solution is varied in this phase. The molarity of the NaOH solution is varied as 8M, 10M, 12M, 13M, 14M, 16M, 18M. The compressive strength and water absorption test are conducted as per IS 3495 (Part 2): 1992. The results are listed in Table 3.

Table 3. Mix proportions and Test results

Specimen ID	M-Sand (%)	GGBS (%)	NaOH: Na_2SiO_3	Molarity of NaOH	Compressive Strength (MPa)	Water absorption (%)
GB9	60	40	1:0	8	17.8	9.3
GB10	60	40	1:0	10	18.2	9.2
GB11	60	40	1:0	12	18.7	9.2
GB12	60	40	1:0	13	19.8	9.0
GB13	60	40	1:0	14	19.3	9.3
GB14	60	40	1:0	16	17.0	9.7
GB15	60	40	1:0	16	15.2	10.4

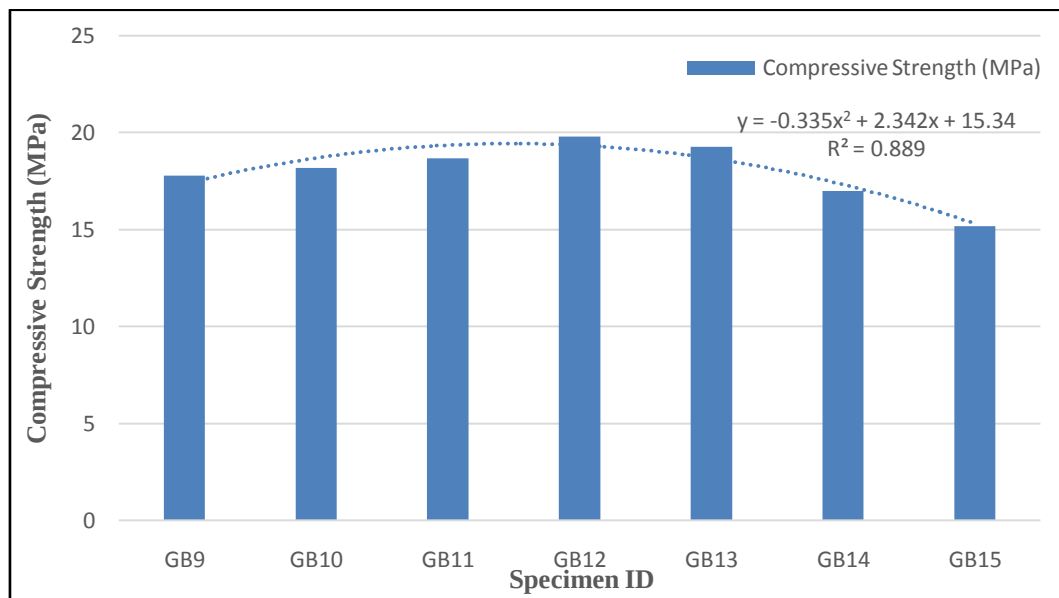


Figure 5. Compressive Strength

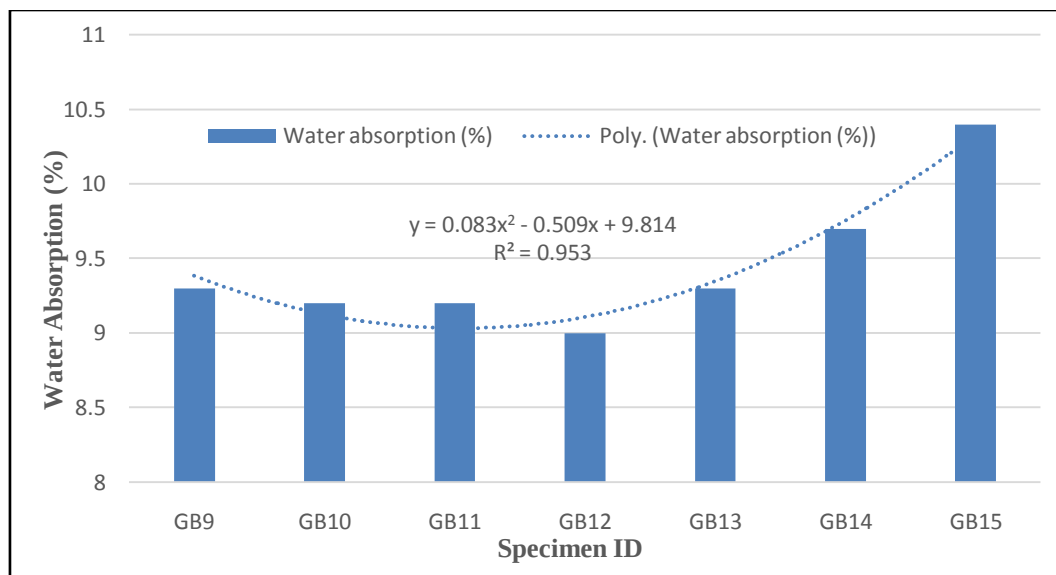


Figure 6. Water absorption results

From Figure 5, it is inferred that with the increase in molarity of NaOH solution till 13M there has been an increase in the compressive strength of the bricks. Figure 6, depicts the variation of water absorption capacity with the increase in molarity and it is observed that it is minimum at 12M and 13M. Beyond 13M, the compressive strength decreases. Specimen GB12 with 13 molarity of NaOH solution exhibited maximum compressive strength and minimum water absorption capacity. The increase in strength till 13M is due to the reason that at increased concentration of NaOH, the polymerization reaction increases. But when it is added in excess particularly in specimens G14 and G15, excess hydroxide ions remains inert and fails to participate in the reaction. This is observed during mixing as well. When the molarity increases more than 14, the sodium hydroxide got precipitated in the form of salts at the bottom of the beaker during the rest period. This reduced the efficiency of mixing and hindered in the hardening and strength gaining process of geopolymer bricks.

4. CONCLUSION

From the detailed discussion, the following conclusion could be made

- Geopolymer bricks with equivalent quality of first Class A bricks can be manufactured using GGBS and M-sand.
- GGBS/ M- Sand proportion of 40/60 yielded required compressive strength under economic conditions
- Complete replacement of sodium silicate solution with sodium hydroxide solution yielded maximum compressive strength and least water absorption capacity
- Sodium hydroxide solution of 13 molarity yielded maximum compressive strength and least water absorption capacity.

Eco friendly bricks can be synthesised using this geopolymer technology thereby reducing the problems associated with the energy consumption of clay bricks and scarcity problems of river sand.

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