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Experiment Investigation and Physical Performance of Geopolymer Fly Ash Bricks

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Abstract. In India an approximate 400-500 million metric tons of fly ash are generated annually from thermal power plant. Maximum use of fly ash is necessary for the sustainable development. In this research, an attempt has been made to develop a method for manufacture of bricks using fly ash geopolymer technology. The influence of cement content in geopolymer fly ash based bricks has been studied. The fly ash, cement, silica fumes mixed with 2 molar of alkaline solution with varying cement content from 0% to 15% and heat curing at 100°C for 24 hours. Bricks were tested for compressive strength, flexure strength, water absorption, efflorescence. The compressive strength, flexure strength of the bricks increases with increase in with cement content up to certain limit then decreases. Efflorescence of bricks are slight as per IS1077:1992. Water absorption of geopolymer fly ash bricks are within limit as per IS1077:1992.

1. Introduction

An approximate 400-500 million metric tons of fly ash is generated annually from thermal power plant in the world. The main challenge today is the disposal of the large amount of fly ash produced and reduces the greenhouse gas emissions generated by thermal power plant. Presently 50% of fly ash is being used in cement and brick industry while the rest is dumped into ash bund wasting so much of agriculture land. The use of waste materials such as fly ash, GGBS, rice husk ash etc. for bricks can be reduced the consumption of clay material and can be reduce the environmental burden due to accumulation of waste materials[1]. For sustainable approach consumption of cement, clay should be reduced and use of maximum amount of fly ash is necessary. Fly ash when used cement based binders act as filler material and participate in the chemical reactions that originate binder[2].

Ibrahim et.al stated that NaOH concentration improves the compressive strength which is further studied the effect of the concentration of alkaline activator in the geopolymer mix. He had used the fly ash and sand with alkaline activator and achieved 20.3 MPa compressive strength with curing temperature of 70°C for 24 hours [2], Okoye et.al studied with 14 molar NaOH concentration and 100°C heat curing temperature with addition of silica fumes. Geopolymer concrete had compressive

strength 58 MPa.[3]. Jeyasehar et.al conducted research on geopolymer bricks from 5 molar to 12 molar NaOH concentrations got 16.11 MPa compressive strength for 5 molar concentration.. He had used steam curing at 60°C for 24 hour. high flexure strength, bond strength, acid resistance in comparison with country bricks and fly ash bricks[4]. Similar type of research done by Banupriya et.al on various combinations of fly ash and GGBS with 5 molar NaOH solutions and found compressive strength 14 MPa to 19 MPa with using 20% to 35% GGBS. As the heat curing is generally adopted for geopolymer concretes, it substantially improves the polymerisation processes and induces the development of their maximum strength in shorter periods of time [5]. Sukmak et.al worked with fly ash and clay and 10 molar alkaline solution to form geopolymer bricks cured at 65°C for 48 hours. Research showed that compressive strength increases with heat energy up to certain limit beyond which there was formation of microcracks[6]. Cicek et.al studied on the fly ash-lime brick with steam autoclaved curing gives compressive strength of 7.65 K MPa. This bricks are light in weight and low thermal conductivity of 0.225 W/m/k[7]. Peyne at.al studied on geopolymer calcined clay brick heated at 750°C. this bricks has good thermal resistant and higher mechanical property[8]. From the literature review, previous research works on large dose of geopolymer an heat curing 8 hours to 72 hours.

This research includes the maximum use of fly ash with silica fumes as an additive for manufacturing of geopolymer bricks and the decrease in the concentration of alkaline solution to 2 molar to reduce carbon footprint. As decrease in the concentration of alkaline solution and increase use of fly ash content decrease the cost of geopolymer bricks. In this research efforts have made to reduce cement, clay and the molarity of alkaline solution in geopolymer brick and increase in strength with additives like silica fumes.

2. Materials

Geopolymer fly ash bricks are manufactured with class F fly ash, cement, silica fumes and alkaline solution[9]. The fly ash was procured from National Thermal Power Corporation, Sipat, India (NTPC Sipat) and sodium silicate and sodium hydroxide of industry grade procured from Kerala, India. Sodium hydroxide has 90% purity. The cement has taken from locally available market supplier. The chemical and physical properties of fly ash, cement and are tabulated in Table 1 respectively.

Alkaline solution is formed by mixing NaOH and Na_2SiO_3. There has been much research with NaOH and Na_2SiO_3 vs strength of geopolymer. The ratio of Na_2SiO_3/NaOH fixed to 1.5 to prepare alkaline solution[10]. For every Kg of 2 molar alkaline solution 80 gram of NaOH and 120 gram of Na_2SiO_3 was added in 800 gram of water. To make 1 litre of alkaline solution. U.S. Agrawal et.al has conducted research for deciding molar ratio.

Table 1. Chemical and Physical Properties of Fly Ash and Cement.

Chemical Parameters	**Fly Ash**	**cement**
Silica content (SiO_2) % by mass	52.32	19.6
Ferric oxide +Aluminium Oxide () % by mass)	32.29	14.8
Calcium Oxide (CaO) (% by mass)	5.83	58.7
Sulphate (SO_3) (% by mass)	0.15	1.3
Magnesia (MgO) (% by mass)	1.57	0.76
Na_2O + K2O(% by mass)	0.04	0.79
Loss on ignition(% by mass)	4.48	3.1
Physicals Parameters	**Fly Ash**	**cement**
Fineness (M^2/Kg)	329	416
Soundness (%)	0.08	0.095
Specific gravity	2.23	3.14

3. Manufacturing of Geopolymer Bricks

3.1 Manufacturing Process of Geopolymer Bricks

The preheated fly ash at 100°C, cement and silica fume mixed with heated alkaline solution at 75-80 °C. The fly ash preheated to remove moisture content in it and alkaline solution heated to enhance the polymerization reaction of geopolymer mix. The workability geopolymer mix was dry when mixed. This geopolymer mix placed in 200mm×100mm×90mm brick mould and gave pressure by vibro-compaction in brick making machine. These geopolymer fly ash bricks were allowed to air cure for a period of 24 hours before heat curing to them. The bricks were heated in oven at 100°C temperature for 24 hour in electric oven. The manufacturing of geopolymer bricks is given in figure 1.

Figure 1. Manufacturing of geopolymer bricks.

3.2 Trial mixes

The following mixes were cast to decide the optimum combination of geopolymer fly ash brick in laboratory of VNIT Nagpur. In these trials, molarity of alkaline solution was kept 2 molar and temperature of heat curing for every brick was 100 °C. The material required for the making 100 numbers of geopolymer bricks are given in table 2.

Table 2. Mix Proportion for 100 Numbers Geopolymer Bricks.

Serial Number	Identification Mark	Fly Ash (Kg)	Cement (Kg)	Silica Fumes (Kg)	Alkaline Solution (Kg)
1	GB0	228	0	12	60
2	GB5	216	12	12	60
3	GB10	204	24	12	60
4	GB15	192	36	12	60

Figure 2. Typical Geopolymer Fly Ash Brick.

4. Results and Discussion

Geopolymer bricks were caste with different proportions and tested for strength parameters. The following tests conducted and results obtained are discussed in the subsequent section.

4.1 Compressive Strength

Compressive strength of geopolymer fly ash bricks was conducted according to IS 3495:1992. The geopolymer bricks were casted with 2 molar alkaline solution varying cement content and heat cured or 24 hours in laboratory oven. 5 heat cured bricks of each mixes were tested for compressive strength.The compressive strength of geopolymer fly ash bricks increases with increase in cement content up to certain limit then starts decreasing. The strength of all trial mix bricks were greater than 3.5 MPa and for GB10 it was found that 12.13 MP which is the maximum compressive strength among all the trial mix, satisfies as per IS1077:1992. However strength of bricks increases with increase in further molar but for cost effectiveness and to reduce carbon footprint of alkaline solution. The compressive testing of geopolymer fly ash brick is given in figure 3. The compressive strength is given in table 3 and their graphical representation shown in figure 4.

Figure 3. Compressive Strength Testing on Geopolymer Brick.

Table 3. Mean Compressive Strength (MPa).

Serial Number	Combination	Mean Compressive Strength (MPa)	IS 1077:1992 limit
1	GB0	3.69±0.21	Min 3.5 MPa
2	GB5	7.45±0.23	
3	GB10	12.13±0.25	
4	GB15	8.26±0.24	

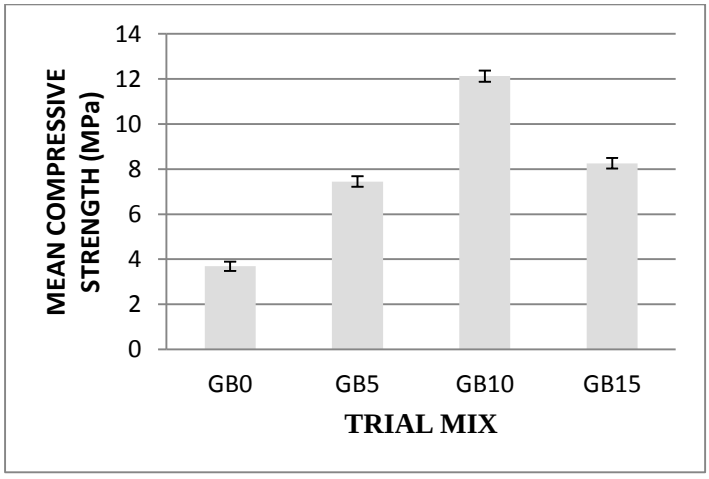

Figure 4. Trial Mix vs Compressive Strength of Bricks.

4.2 Flexure Strength

The flexure strength of geopolymer bricks were calculated by applying one point load on brick as shown in figure 5. The flexure strength of geopolymer bricks is given in table 4. For trial mix composition of GB10 mix bricks the flexure strength was 2.64 MPa.

Figure 5. Flexure Strength Testing of Brick.

Table 4. Mean Flexure Strength (MPa).

Serial Number	Combination	Mean Flexure Strength (MPa)
1	GB0	1.986±0.16
2	GB5	2.126±0.12
3	GB10	2.64±0.15
4	GB15	2.31±0.14

4.3 Water absorption

The bricks were tested to water absorption test as per IS 3495:1992[11]. Arrangment for water absorption is shown in figure 6. The water absorption for all trial mixes was found in range of 14-17% for all bricks which is less than 20% which is within limit as per IS 1077:1992[12]. Table 4 gives the water absorption of geopolymer bricks was conducted in laboratory.

Figure 6. Water Absorption of Geopolymer Bricks.

Table 5. Mean Water Absorption of Geopolymer Fly Ash Bricks.

Serial Number	Combination	Mean Water Absorption of Bricks (Percentage)	Water Absorption Limit as per IS 1077
1	GB0	14.8±0.36	< 20 %
2	GB5	16.2±0.41	
3	GB10	15.8±0.54	
4	GB15	14.8±0.36	

4.4 Efflorescence of brick

Efflorescence test was conducted as per IS 3495: 1992[11]. It was observed that there was very thin deposit of salts observed on all the combinations of sample bricks. This deposit of salts covered with exposed area less than 10% of the brick which can be expressed as SLIGHT efflorescence as per IS1077:1992. The figure 7 shows the testing of efflorescence of geopolymer bricks.

Figure 7. Efflorescence of Bricks.

5. Conclusion

- The cement content increases compressive strength of bricks increases upto certain limit then it decreases. The maximum compressive strength for geopolymer brick achieved for 10% cement replacement with fly ash.
- The compressive strength corresponding to 10 % replacement of fly ash in geopolymer brick (GB10) was 12.13 MPa, and flexure strength is 2.64 MPa.
- This Geopolymer brick are ready to dispatch in 1 day and does not require conventional water curing for 7 to 28 days.
- Water absorption and efflorescence of geopolymer fly ash bricks were within permissible limit as per IS1077:1992. The efflorescence of geopolymer bricks were slight and may be due to alkaline solution used to prepare the geopolymer fly ash bricks.

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