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Compressive Strength of Fly Ash –Cement Brick with Geopolymer Brick

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ABSTRACT
Bricks are important building material and in India about 140 billion bricks are annually produced. Majority of the people prefer burnt brick for the construction purpose which emits nearly about one ton of CO_2. Brick making, causes serious environmental pollution and health problems. Brick burning largely influence the concentrations of greenhouse gases in the atmosphere. To avoid all this environmental threats an attempt was made to study the behavior of bricks manufactured using, different materials like Fly Ash, Sand, Cement, Glass, Geo-Polymer. Now in the present days the increase in the popularity of using environmental friendly, low cost and lightweight construction materials in building industry. The aim of present research was to compare the compressive strength and water absorption of the bricks with adding the glass and geopolymer. Different percentage of materials were added in 5%, 10%, 15%, 20% & 25% by weight and then the compressive strength and water absorption of the bricks was estimated. It has been found that brick made of fly ash and cement, for 20% cement have 28 Day's compressive strength of 7.6 N/mm^2, which does not fulfill the requirement of first class brick. When the brick made of fly ash, cement and glass, in which fly ash is replaced by 5% glass (broken glass passing from 2mm IS sieve), for 20% cement have 28 Day's compressive strength of 6.4 N/mm^2. The brick made of fly ash and geopolymer, for 20% geopolymer have 7 Day's compressive strength of 26.8 N/mm^2, but have high water absorption of 18%. To reduce the water absorption of geopolymer brick, some proportion of fly ash have been replaced by sand and it has given the satisfactory result. The 7 Day's compressive strength of geopolymer brick having 60% fly ash, 20% geopolymer and 20% sand is 17 N/mm^2 and water absorption is 8.4%.

Keywords - About five key words in alphabetical order, separated by comma

1. INTRODUCTION

In 2018, CO_2 emissions related to human activities reached a world historical level of 37.1 billion metric tons [1]. An increasing awareness towards ecological issues has focused industries to develop materials & products that will be additional environment approachable and results in structure development. The products from a country's natural and waste by-products are important as so much because the industrialization of a nation is concerned. Brick has space with wide family of construction materials since it is primarily utilized for the advancement of external and inward dividers in structures [2]. For creating eco-friendly building it is essential, the structure exploitation in such construction method should be environment friendly. For ample manufacturing and use of bricks from waste materials, additional analysis and development is required, not only on the technical, economic and environmental aspects [3]. The Indian brick industry, which is the second biggest manufacturer on the globe, beside China, devours more than 150 million tons of coal yearly without including the power utilized in brick generation, the diesel for transporting the bricks alone create exactly 180 million tons of CO_2. On the other hand, the generation of fly ash from power plants and cement manufacturing industries are also the big problem for environment. Most suitable utilization of fly ash can be done in making bricks. But fly ash bricks have low compressive strength as compared to the conventional red bricks when blended with gypsum, hence to enhance the strength of fly ash brick different additives should be used, such as geopolymer, which is a upcoming science and technology to enhance mechanical properties.

The geopolymer technology was first introduced by Davidovits in 1978 [4]. His work noticeably shows that the acceptance of the geopolymer technology could diminish the CO_2 emission caused due to on fire of red bricks. Davidovits proposed that an alkaline solution could be used to react with aluminosilicate in a source material of geological origin or in by-product materials such as fly ash to make a binder [4]. Normally, good quality high-strength geopolymers can be made from class F fly ash [4]. Alkaline activate solution is important for dissolving of Si and Al atoms to form geopolymer precursors and finally alumino-silicate material. The most commonly used alkaline activators are NaOH and KOH [4]. Attempts were made in the present work to utilize the fly ash to produce high compressive strength bricks. Brick burning largely influence the concentration of greenhouse gases in atmosphere. This causes serious air pollution and also employees in brick industries are prone to respiratory diseases such as silicosis, pneumonocosis and musculo-skeletal disorders [5]. Brick making consumes larger amount of clay which leads to top soil removal and land degradation [6]. Large areas of lands are destroyed every year especially in developing countries due to collection of soil from depth of about 1 to 2 m from agricultural land. India generated 145,000 MW of power in 2008. The 63% power was generated from coal-based thermal power plants. During the power generation, approximately 150 million tonnes of pulverized ash was generated. This is the major source of generation of vast amounts of pulverized coal ash. As the power requirement goes up in coming years and more power plants are built, the amount of PCA (Pulverized Coal Ash) generated will increase and create more problems for safe disposal. It is estimated that by 2012, India will generate around 175 million tonnes of PCA every year.

2. ITERATURE REVIEW

Silverstrim et. al.(1997), The ratio of total activation chemical to fly ash has a significant effect on both ultimate strength and strength development. The basic trend is that the higher the ratio, higher the resulting strength of the paste. For economical reasons, the ratio should be kept below 20%. The molar ratio SiO2/Na2O of water-glass has critical effect on both ultimate strength and strength development [7].

Xie Zhaohui and Xi Yunging (2001), found that when the water-glass has a modulus of 1.64, the gelatinous compound Na2O–Al2O3–SiO2 together with another hydrolysis product, i.e. silica gel, serve as the binder that hardens the fly ash mixture and results in the high strength [8].

Weng et. al. (2003), developed bricks from dried sludge collected from an industrial wastewater treatment plant. The bricks incorporated with sludge conformed to the Chinese National Standards for building bricks [9].

Yoshizawa et. al. (2004), Globally the estimated quantity of waste generation was 12 billion tonnes in the year 2002, of which 11 billion tonnes were industrial wastes and 1.6 billion tonnes were municipal solid wastes (MSW). About 19 billion tonnes of solid wastes are expected to be generated annually by the year 2025 [10].

Hanifi et al. (2005), presented an earthquake-resistant material with high compressive strength. He elaborated the compressive strength of fibre reinforced mud bricks made out of clay, cement, basaltic pumice, lime and gypsum using plastic fibre, straw, polystyrene fabric as fibrous ingredients, each at a time. It was demonstrated that the fibre reinforced mud brick fulfil the compressive strength requirement of Turkish codes, whereby reducing the weight and material handling cost for housing. Furthermore, it can store more elastic energy compare to the other types of mud brick which renders it more resistant to earthquake [11].

Vorrada et al. (2009), recycled wasted glasses from structural glass walls into clay mixtures. The compressive strength of bricks was as high as (26–41) MPa and water absorption as low as (2–3) % were achieved for bricks containing (15–30) % by weight of glass content and fired at 1100°C. When the glass waste content was 45 % by weight, apparent porosity and water absorption was rapidly increased [12].

Martínez et al. (2012), replaced clay in a ceramic body with different proportions of sludge. Results for mechanical properties as water absorption, compressive strength and water suction showed that the bricks incorporated 5% of sludge showed good mechanical properties [13].

Badr et al. (2012), investigated the complete substitution of clay brick by sludge mixed with rice husk ash (RHA) and silica fumes. Bricks were fired at 1000°C. Bricks contained 25% SF and 50% sludge showed superior mechanical properties as compared with conventional bricks and with those available in the Egyptian code [14].

Vilamova and Piecha (2016) have carried out based on analysis of the possibilities to reduce the total price of material costs for the production of 1m^3 of concrete, with possible using in the industry. The main method for economic evaluation of using geopolymer is the classical cost calculation. The results of the analysis show possible reducing of cost, which is possible through replacement of cement by fly ash more than 18 % of the material [15].

Youssef et. al. (2019), have studied, the potential for reuse of waste brick (WB) by alkaline activation in a new geopolymer brick was examined. The efect of the incorporation of ground granulate blast furnace slag (GGBFS), the molarity of sodium hydroxide (NaOH) and the silicate to sodium hydroxide ratio (Na_2SiO_3/NaOH) on the mechanical properties of the fnal product was investigated. The manufacturing of geopolymer bricks was carried out by mixing WBs, GGBFS, sand with a solution of hydroxide and sodium silicate. The samples were prepared according to diferent formulations. The optimal compressive strength obtained is 89.91 MPa, for a GGBFS/WB ratio of 80/20, an 8 M molarity of NaOH and a silicate/hydroxide ratio of 2/1. This study shows an efective feasibility for the recovery and recycling of industrial waste into a valuable product for the construction sector [16].

3. MATERIAL AND ITS ENGINEERING PROPERTY

3.1 Fly Ash

The dry fly ash used for present research was supplied by NTPC Sipat located in Bilaspur (CG) by Ma Durga Brick Industry. The alkaline activators that have been used for activating fly ash include Portland cement, lime, NaOH, $NaCO_3$, and water-glass (sodium silicate solution). The effect of activation strongly depends on the physical–chemical nature of the fly ash and the type of activator. The laboratory grade sodium hydroxide in flake form (97% purity) and sodium silicate (50.72% solids) solutions were used as alkaline activators [17]. The ratio of total activation chemicals to fly ash, the molar ratio of silica dioxide to sodium oxide (SiO_2/Na_2O, also known as the modulus of water-glass) is the control parameter particularly important for paste and it has critical effect on both strength development and ultimate strength. On the basis of literature data when the water-glass has a modulus of 1.64, the gelatinous compound Na_2O–Al_2O_3–SiO_2 together with another hydrolysis product, i.e., silica gel, serve as the binder that hardens the fly ash mixture and results in the high strength, hence the modulus of water glass for this work is kept constant at 1.64.

Locally available river sand was used as filler material. The sand is sieved using IS sieves of sizes 2 mm, 1 mm, 500 micron, and 90 micron. These size fractions are combined in equal proportion to maintain grading complying with standard sand as per IS 650:1991[18].

3.2 Preparation of Sodium Hydroxide Solution

Sodium based solutions were chosen because they are cheaper than Potassium based solutions. Generally sodium hydroxide and sodium silicate are readily available in market in the form of pellets and gel [18]. Analytical grade sodium hydroxide was used in pallet form to get solution of concentration 14M. 14M sodium hydroxide solution consists of 14 × 40 = 560 grams of NaOH solids per litre of solution.

Figure 1 NaOH Pellets

Sodium hydroxide solution was prepared two days prior to the casting of bricks so as to cool down the solution up to room temperature. It is also found that too much alkali in the composition will adversely affect the strength. So there should be an optimum alkali content for providing maximum mechanical property.

3.3 Preparation of Geopolymer Brick Mixes

The primary objectives of the present study is: To find out the optimum mix design for making brick so as to achieve the maximum compressive strength. Investigating the compressive strength, water absorption, dimensional tolerance and chemical resistance of fly ash brick based on the following: Effect of different additives as a binder.

Figure 2 Fly Ash

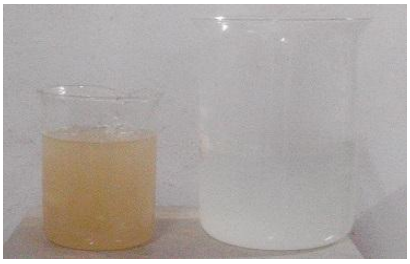

Figure 3 Alkali Activator

Figure 4 Mix of Fly Ash and Alkali Activator

Glass

Waste glass from demolished structure is used. It is crushed and broken into small pieces, and allowed to pass through 2mm IS sieve is used as a replacement of cement. On the basis of different hit and trial it has been found that addition of glass beyond 5% produces the harsh mix and renders poor bonding.

Figure 5 Fly Ash and Cement

Figure 6 Glass passing 2mm IS Sieve

3.4 Screw Jack Machine

Screw jack machine based on the principal of reciprocating compressor, comprising of vertical threaded shaft reciprocating into the rectangular mould thus rendering the compressive force to fill material (Figure 7 shows the setup of Screw Jack Machine). The mould used is of the dimension to cast a brick of standard dimension of 19cm×9cm×9cm. The machine is also fitted with a pressure measuring device “Electronic weighing scale, Model-EPS-8199” (as shown in Fig 3.8 &3.9) having high precision strain gauge sensors system and capacity of 180Kg/396lb. A constant force of 165Kg is used to achieve a uniform compaction of all the bricks. A compressive force is kept constant to avoid the effect of varying compaction, since the main objective of the project is to investigate the effect of amount of binding material on ultimate compressive strength and to determine the optimum amount of alkali activator to be used as a binding material.

Figure 7 Brick Making Machine [Screw Jack]

Figure 8 Electronic Weighing Scale

Figure 9 Uniform Pressure Applied on Brick

4. COMPRESSIVE STRENGTH AND OTHER TESTS

4.1 Compression Testing Machine (CTM)

The Screw Jack Machine was used to cast the brick and Compression Testing Machine was used to determine the compressive strength of brick. The prepared bricks of FA + Cement, FA + Glass have been curried for 3 Day's, 7 Day's and 28 Day's.

Figure 9 Brick Sample

Compressive strength tests are performed on a CTM machine using 19cm×9cm×9cm samples (see Fig 10). Three samples for each proportion are tested, with the average strength values reported in this test. The loading rate on the brick is 0.1 mm/min. This section provides the illustration of the estimation of 3 Day's, 7 Day's and 28 Day's compressive strength of (a) Fly ash brick having cement as a binder, (b) Fly ash brick having cement as a binder and broken glass (passing from 2mm IS sieve) as a additive and (c) Geo-Polymer brick. The compressive strength was estimated following the procedure as stated in IS 3495 (Part 1 Determination of Compressive Strength). Results have been represented pictorially.

Table 1 Compressive Strength of Fly Ash -Cement Bricks

S. No.	FA (%)	Cement (%)	w/c (%)	3 Day's Strength N/mm^2	7 Day's Strength N/mm^2	28 Day's Strength N/mm^2
1	90	10	0.2	1.8	3	4.1
2	85	15	0.2	2.3	3.7	5.4
3	80	20	0.2	2.6	5.7	7.6
4	75	25	0.2	3.5	6.8	9.5

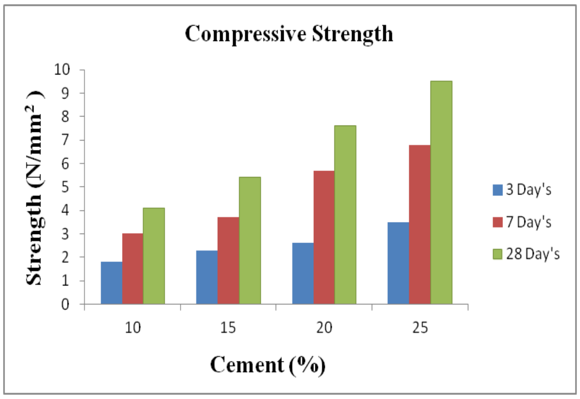

Figure 11 Compressive Strength Fly Ash -Cement Bricks

Table 2 Compressive Strength of Fly Ash –Cement –Glass Bricks

S. No	FA (%)	Cement (%)	Glass (%)	w/c (%)	3 Day's Strength N/mm^2	7 Day's Strength N/mm^2	28 Day's Strength N/mm^2
1	85	10	5	0.2	1.2	2.4	3.5
2	80	15	5	0.2	1.8	3.2	4.2
3	75	20	5	0.2	2	4.9	6.4
4	70	25	5	0.2	3	6.3	7.4

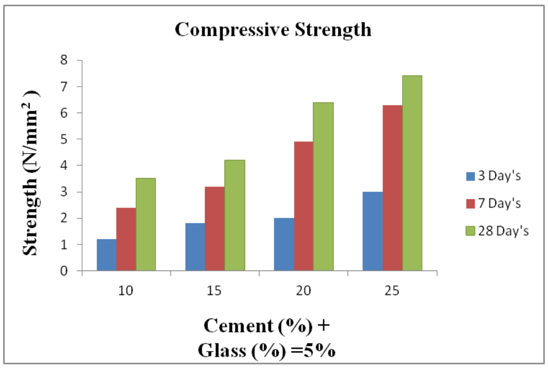

Figure 12 Compressive Strength of Fly Ash – Cement–Glass Bricks

Table 3 Compressive Strength of Fly Ash - Geopolymer Bricks

S. No	FA (%)	Geopolymer (%)	H2O /(Total Solids) w/w ratio	7 Day's Strength N/mm2
1	95	5	0.2	5.5
2	90	10	0.2	12.5
3	85	15	0.2	25.2
4	80	20	0.2	26.8
5	75	25	0.2	29.8

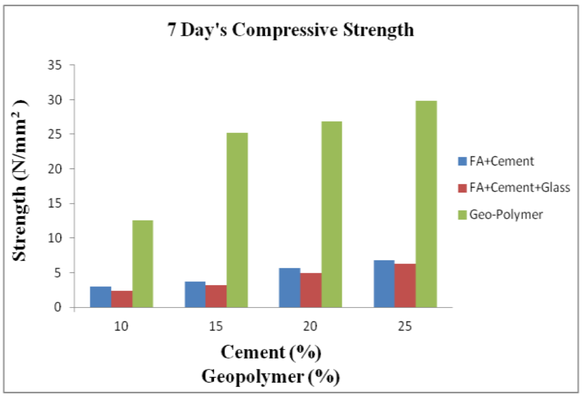

Figure 13 Compressive Strength of Fly Ash – Geopolymer Bricks

The strength of geo-polymeric brick increases rapidly from 5.5 N/mm^2 at an addition of 5% geopolymer to 12.5N/mm^2 at an addition of 10% geopolymer, it further increases to 25N/mm^2 at an addition of 15% geopolymer, but then there is very gradual increase in strength i.e., at 20% geopolymer only 26.8N/mm^2 of strength is obtained. Further at 25% addition of geopolymer compressive strength obtained is 29.8N/mm^2, hence it can be concluded that cement as a binder and glass as an additive. Fig 11 shows comparison of compressive strength of fly ash bricks having only cement as a binder, cement as a binder and glass as a additive and geo-polymer brick. From figure 13 it is clear that the 20% addition of an geopolymer is an optimum quantity from strength point of view [19].

4.2 Water Absorption

The Figure 14 shows the comparison of water absorption of bricks having Fly Ash-Cement, Fly Ash-Cement- Glass and Fly Ash –Geopolymer Bricks. The brick having only cement as a binder has minimum water absorption as compared to the other combinations but still it's water absorption is quite high as compared to the water absorption limits of first class brick (12-15%). However, the geo-polymer brick impart the high compressive strength but it also has high water absorption 10% & 15%, hence an attempt has been made to reduce the water absorption of geo-polymer brick by using sand.

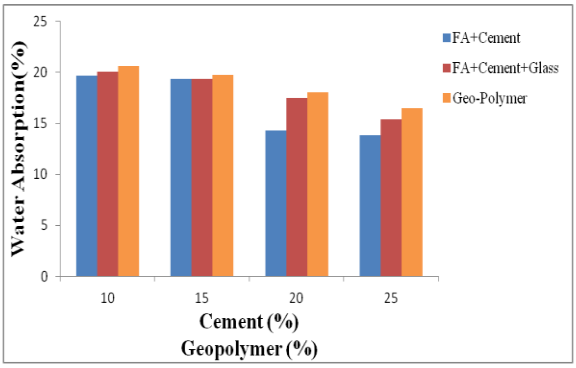

Figure 14 Water Absorption

4.3 Dimensional Tolerances

Measurement of the dimension of brick was done based on the procedures provided in IS 12894:2002. The mean measurement for individual length was 190 mm. The individual measurement of width and height was also in the limits of IS 12894: 2002, which showed the value of 90 mm × 90 mm.

4.4 Visual Inspection

In this test bricks are closely inspected for its shape. The bricks of good quality should be uniform in shape and should have truly rectangular shape with sharp edges.

Figure 15 Visual Inspection

4.5 Hardness

Nail Scratch Test

In this test, a scratch is made on brick surface with the help of a finger nail.

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Figure 16 Hardness Test

4.6 Drop Down Test

When dropped down from a height of one metre on firm surface such as plain cement concrete or another brick resting on ground it should not break.

Figure 17 One Meter Fall Test

Figure 18 Top View after Fall

Figure 19 Side View after Fall

4.7 Structural Test

A brick is broken and its structure is examined. It should be homogeneous, compact and free from any defects such as holes, lumps etc.

Figure 20Broken Structure of Brick

5. Conclusions

Replacement of fly ash with glass has not given satisfactory result, having low compressive strength of 7.4 N/mm^2 after 28 day's curing and high water absorption of 15.3%, with cement content of 25%. Geopolymer brick with 20% geopolymer has significant high compressive strength of 26.8 N/mm^2 but have high water absorption of 18%. Fly ash brick having 20% geopolymer and 20% of sand as a replacement of fly ash gives the best result, having compressive strength of 17N/mm^2 and water absorption of 8.4%. Geopolymer bricks have high compressive strength compared to normal bricks. Geopolymer bricks have uniform in shape – hence no plastering is required if used for compound wall or godowns. In geopolymer brick less mortar is required in construction, because all bricks are machine made and even in shape. Due to perfect size savings in cement mortar for making the walls and plastering, in geopolymer brick. Geopolymer bricks with 20% geopolymer and 20% sand are less porous, absorbs very little water, whereas fly ash bricks absorbs more water during construction. Temperature effect can be studied by oven heating the bricks at moderate temperature.

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