Characterization of Alkali Activated Bentonite - Fly Ash as Brick Material

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Abstract. Brick, one of the most common binding materials which need excess energy during manufacture. Gathering of excess industrial waste creates the environmental pollution as well as a health issue. To developing green environment, industrial waste can be used as an alternation of binder material as a brick. In this present study combination of sodium bentonite and fly ash get activated by sodium hydroxide (NaOH) and calcium oxide (CaO) whose Na₂O/CaO proportion varied as 1 with mole content. Mixing proportion of both solid particles were varied as 40/60 and 60/40 as weight percentages. Casted samples were conducted for the curing period of 0 days, 3 days, 7 days, and 28 days. Mineralogy, morphology, and compressive strength tests are conducted and found that 1.5 moles are the best for developing compressive strength that obtained as 135.8 kPa at 60°C oven curing temperature.

1. Introduction
Bricks are considered as versatile, durable and reliable building material in all over the world. Bricks are manufactured by clay and shale in kiln in large quantities, which needs a huge amount of coal and fuels for developing high temperature i.e., 900 to 1000°C. According to research, Indian brick industry is considered as the second largest producer in all over the world that consume more than 150 million tons of coal annually. Beyond that, diesel for transporting the bricks produce one third of the global industry, which emits around 550 million tons of CO₂. For developing eco-friendly building material, less consumption of natural resource (clay and shale) and energy, different type of waste materials is used as an alternation of binding material [1]. New binder material named as geopolymeric brick that more advantageous for its low energy consumption, good mechanical properties, lower pollution impact, good durability, significantly reduce the energy consumption, better resistance to chemical attack, and reduction of greenhouse effect [2, 3]. Although fire bricks are more strength than sun dried brick, but reduction of energy consumption and CO₂ emission motivate to prepared brick using industrial waste products. However, utilization of industrial wastes as brick can be categorized as three production methods i.e., firing, cementing, and geopolymerization [3]. But geopolymer bricks are turns to be most popular which can replace the industrial waste as an alternation of binding material without emission of CO₂ content. Silica and alumina rich material are carried out for a synthesis of geopolymer brick which are found to be most common elements in industrial waste.
Geopolymer also named as “inorganic polymer”, “alkali-activated cements”, “geocements”, “alkali-bonded ceramics”, “hydro-cermics” etc. It was discovered by Prof Joseph Davidovits in 1972 and considered as aluminosilicate binder chiefly obtained in alkaline environment condition.
Geopolymerization is the technology which is based on the chemical reaction of amorphous silica and alumina rich solids with high alkaline solution at ambient and elevated temperature [3]. It has numerous applications in transportation, industrial, agricultural, residential, mining, oil well cements, high-volume application etc. [4]. Si rich material like fly ash, slag, rice husk and Al rich material like clay which belongs to kaolin, bentonite are the major part of developing geopolymerization [5-10]. Alkali concentration is the most significant factor of geopolymerization. Solubility of alumino-silicate gets increased with increase of hydroxide ion concentration.

Research is still continuing on developing low-cost, light weight and environmentally friendly construction material from industrial waste products as equivalent to traditional brick affirmed in the standard. Geopolymer brick is most popular among firing, cementing brick for less consumption, energy and reduction of global warming effect. Si and Al are the major part of developing the geopolymer product. So, alumina and silica based industrial wastes are considered as – fly ash, blast furnace slag, mine tailing, red mud etc. But very few studies are related to bentonite. Here research is based preparing geopolymer brick using fly ash and bentonite that activated with low concentration of a combining solution of sodium hydroxide (NaOH) and calcium oxide (CaO).

2. Materials & Methods

2.1. Source materials
Fly ash, an industrial waste was collected from NALCO industry situated in Angul of Odisha, India. It is pozzolanic type due to the presence of Al and Si content which helps to provide the geopolymer product. Sodium bentonit (known as a clay colloid material) was collected from Jagatpur of Odisha, India. Both fly ash and bentonite were carried out for oven dried maintaining temperature as 105-110°C for 24 h. Since fine particles help to improve high compressive strength, hence both fly ash and bentonite were sieved under 150µ sieve to obtain uniform fine particles.

2.2. Chemical activator
Two chemicals, i.e., sodium hydroxide and calcium oxide were used as chemical activator. Sodium hydroxide pellet of Merck Life Science Private Limited were used whose specification varies as: > 97%. Calcium oxide powder pure of Sisco Research Laboratories Pvt. Ltd., were used whose specification varies as: min 95%.

2.3. Mixing method
Both solid particles, i.e., fly ash and bentonites were mixed homogeneously with two different proportions i.e., 40/60 and 60/40 as weight percentages. Both were categorized as FB40 and FB60 respectively. Here F refers to fly ash, B refers to bentonite. Subscription 40 and 60 refer to weight percentages of fly ash.

Chemical solutions were prepared with distilled water one day prior to the casting of the sample variance with mole proportion of Na₂O and CaO as 1:1. Solutions were prepared as two type moles i.e., 1 and 1.5 moles separately. They were notified as NC1 and NC1.5 respectively. Here N refers to Na₂O, C refers to CaO. Subscription 1, 1.5 refers to the mole. After a homogeneous mix of solid part as said proportion, prepared solution was added whose solution/solid ratio varied as 0.4.

2.4. Curing method
Casted samples were exposed to curing method that categorized as two type i.e., atmosphere, oven drying. Atmosphere samples are provided to no cure in the oven, but only on the ambient condition up to testing ages. Oven drying samples is provided to cure in the oven at 40 and 60°C temperature for 24 h that each sample wrapped with cling film to avoid moisture loss. Then, each oven drying cling free sample was exposed to room temperature.
2.5. Curing ages
Each sample was considered to be cured as 0, 3, 7 and 28 days respectively. Atmosphere curing samples were denoted as A. Oven curing samples are denoted as T. Here T refers to 40°C or 60°C.

3. Result and Discussion

3.1. Physical properties
Oven dried both fly ash and bentonite were tested for specific gravity by following the IS: 2720 (Part III/Sec 1)-1980 [11] and obtained as 2.09 and 2.9 respectively. Here bentonite was found as high specific gravity in comparison to fly ash.

Maximum dry density (MDD) and Optimum moisture content (OMC) of both fly ash and bentonite were calculated by following IS: 2720 (Part VII)-1980 [12, 13] that shown in Figure 1. For fly ash it is observed as 1.378g/cm$^3$ 11.28%; and for bentonite it is observed as 1.358g/cm$^3$ and 28%, respectively.

![Figure 1. MDD and OMC curve of fly ash and bentonite](image1.png)

3.2. Mineralogy
Figure 2 (a) and (b) shows the XRD image of fly ash and sodium bentonite. From Figure 2 (a), it is observed that, NALCO fly ash is amorphous type whose hump angles (2θ) varies between 10 to 20°. In its quartz and mullite are found as common material that indicate to Al and Si as the major element. From Figure 2 (b), quartz and montomorillonite are found as the major element. Sodium bentonite is found as the amorphous type whose humps angle varies 10 to 30°.

![Figure 2. XRD image of (a) fly ash, and (b) bentonite](image2.png)

3.3. Morphology
Figure 3 (a) shows the SEM image of NALCO fly ash, which is a spherical type with smooth surface whose shape varies from 1 to 100µm. Figure 3 (b) shows the microstructure of sodium bentonite that varies as non-uniform structure and considered as prismatic type.
3.4. Effect of mole vs solid proportion

Compressive strength was represented as a bar chart that shown in Figure 4 (a) and (b). Two proportions i.e., FB\textsubscript{40} and FB\textsubscript{60} get activated with NC\textsubscript{1} and NC\textsubscript{1.5}. The compressive strength of each sample was calculated after curing up to 0, 3, 7, and 28 days.

3.5. Effect of NC\textsubscript{1}

NC\textsubscript{1} was the combine solution of NaOH and CaO where the mole content of both Na\textsubscript{2}O and CaO were taken as 1. Figure 4 (a) and (b) shows the compressive strength of FB\textsubscript{40} and FB\textsubscript{60}. Atmosphere curing and 24h oven curing samples were placed in ambient condition up to different curing aging as mentioned above. It is observed that maximum strength is observed with FB\textsubscript{40}-NC\textsubscript{1}-60°C that obtained as 90.8 KPa after 28 days of curing aging. Similarly, Figure 4 (b) shows 129KPa strength with FB\textsubscript{60}-NC\textsubscript{1}-60°C. This strength was found to be comparatively lower due to low concentration of sodium hydroxide (NaOH) i.e., 1 mole of NaOH was added to 1 mole of calcium oxide (CaO). For low concentration, there might be low reaction formation in between solid and solution which results to no better strength was formed.

3.6. Effect of NC\textsubscript{1.5}

NC\textsubscript{1.5} was the combine solution of NaOH and CaO where mole content is 1.5. Here, maximum strength is observed with FB\textsubscript{60}-NC\textsubscript{1.5}-60°C that obtained as 102.4 KPa as shown in Figure 5 (a). Similarly, Figure 5 (b) shows the maximum strength with FB\textsubscript{60}-NC\textsubscript{1.5}-60°C that obtained as 135.8 KPa after 28 days curing aging. In this case NaOH and CaO concentration were increased to 1.5 moles which results to growth of reaction and results to increase strength than previously.
Although strength in atmosphere curing condition is gradually increased, but better strength is achieved with oven curing conditions. It is conformed that; strength gets increased by increase the mole content of Na$_2$O and CaO. In alkali activated system, enriched mechanical strength is possible due to Al-O and Si-O bond which developed N-A-S-H gel under highly alkaline solution.

4. Conclusion
Development on greener environment by reducing energy sources, utilizing industrial waste are the major criteria in the construction industry. Now-a-days, alkali activated brick turns to be more popular than traditional brick for less consumption of electric energy, heat energy. Although, researches are still carried on alkali activated brick, but those are related to high concentration of alkali solution. This work is related to developing alkali activated fly ash bentonite brick using low concentrations of chemical activator. Here, sodium hydroxide (NaOH) and calcium oxide (CaO) are used whose preparation method is based on mole content i.e., 1 and 1.5. Combine solution of NaOH and CaO are added as the chemical solution to maintaining a solid solution ratio as 0.4. Atmosphere and oven dry curing (for 24 h) conditions are preferred to compare the unconfined compressive strength of alkali activated fly ash bentonite brick under two different mole proportion (1 and 1.5). It consists with following conclusion:

- Specific gravity of bentonite is maximum as compared to fly ash.
- MDD (maximum dry density) of fly ash and bentonite is 1.378g/cm$^3$ and 1.358g/cm$^3$. OMC (optimum moisture content) is 11.28% and 28% respectively.
- NALCO fly ash is major with mullite and quartz which indicates that it is pozzolanic type. Sodium bentonite is major with montomorillonite and quartz. Both solid materials are amorphous type that conforms from hump angles.
- NALCO fly ash is spherical with smooth surface whose shapes are varied as uniformly. Sodium bentonite is varied as a non-uniform shape with prismatic type.
- Oven curing condition is better compared to the atmosphere curing condition.
- 60°C oven curing condition is better for developing strength in alkali activated fly ash-bentonite.
- 1.5 moles of the Na$_2$O and CaO is better in compared to 1 mole for developing strength.
- Maximum strength is observed as 135.8 KPa from FB$_{60}$-NC$_{1.5}-60^\circ$C.

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