

Alkali Activation Technology for Production of Eco Bricks/Blocks- A Review.

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Abstract: The occurrence and distribution of soils in nature varies from location to location. The type of soil depends on the rock type, its mineral constituents and the climatic regime of the area. Soils are used as construction materials or the civil engineering structures are founded in or on the surface of the earth. Geotechnical properties of soils influence the stability of civil engineering structures. As soil is the ultimate load bearer so its stability is a necessity and hence many efforts have been done for its stabilization. The performance of any structure depends upon the behavior of underlying soil mass and on the bearing capacity of soil. Expansive soil or clay is considered to be one of the more problematic soils and it causes damage to various civil engineering structures because of its swelling and shrinking potential when it comes into contact with water. Expansive soils behave differently from other normal soils due to their tendency to swell and shrink. In a well-organized environment, disposal of waste poses a great threat as regards where and how to effectively dispose the waste material without any harmful effect to society. In the recent times, utilization of solid waste materials in soil stabilization has gained eminence as an effective means to manage wastes generated from various industries. In this paper, a review is given on utilization of different solid waste materials which have been used to stabilize soft soils. Though, there are lots of methods and techniques are available to stabilize these soil. This study provides how waste materials can be used to stabilize the soft soil using alkali activation technology.

Key Words: Alkali Activation Technology, Solid Waste Materials, Fly Ash, GGBFS, Soil Stabilization, Expansive Soil, Cementations Materials, etc.

I. Introduction

Expansive soils are these soils that have undergone significant volume change with the addition or removal of water. Expansive soils are composed mainly by kaolinite, montmorillonite, and illite group minerals. Their physical characteristics mostly include low bearing capacity, high settlement, low shear strength, and high water absorbability. The low bearing capacity of expansive soils creates problems in civil engineering structures, whereas their water content is high and responsible for consolidation settlements in cases of loaded grounds. In addition, their low shear and compressive strength usually result in shear failure. (1) This soil type is always a threat to the strength and stability of pavements and highways. (2) Soil stabilization refers to mixing and blending of certain additives/materials with soil so as to make properties of that soil better. The process might inculcate the soils to be blend with adequate admixtures to alter the plasticity or texture, gradation, or act as a binder for soil cementation. Soil modification refers to stabilization of soil with betterment of some properties without much vital improvement in soil durability and strength. Stabilizers can be divided into three categories (a) traditional stabilizers (cement, lime etc.), (b) by-product stabilizers (fly ash, phosphor-gypsum, slag quarry, dust etc.) and (c) non-traditional stabilizers (potassium compounds, sulfonated oils, polymer, ammonium chlorides, enzymes etc.). (3) One of the issues the civil engineering industry is facing now a days is the use of great amount of unsustainable materials in construction projects. Building Blocks is one of the most important masonry unit as a building material due to its properties. Many attempts have been made to incorporate wastes into the production of blocks. There is imbalance between the expensive conventional building materials coupled with depletion of traditional building materials. 60-70% of the families come under the low income group and housing becomes an acute problem to them. To address this situation, attention will be focused on low-cost alternative building materials. This results in reducing the cost of housing and to make affordable housing for India's increasing population. Conventional bricks are produced from clay with high temperature kiln firing or from ordinary Portland cement (OPC) concrete, and thus contain high embodied energy and have large carbon footprint. In many areas of the world, there is already a shortage of natural source material for production of the conventional blocks. For environmental protection and sustainable development, extensive research will be conducted on production of building blocks from waste materials. (4).

Soil stabilization is a reliable technique essentially practiced in improving the structural capacity of expansive soils via a variety of approaches; primarily under two broad categories. Physical methods are associated with altering the physical properties of soil to affect the gradation, solidity and other characteristics, while the chemical methods modify the soil properties by the addition of chemically active materials. The stabilization mechanism is governed by the cation exchange process and the geopolymer /hydration products formation. Alkaline activation treatment is expensive compared to the conventional Portland cement based stabilization methods, and yet the cost can be significantly reduced by employing cost effective silicates for alkaline activation. Overall,

alkali activated binders (AAB) can be sustainable stabilizers to treat expansive soils for satisfactory geotechnical performance (compaction, strength and durability). (5)



Figure 1: Expansive soil damage to civil engineering infrastructure across Oman, KSA, Pakistan, and USA (with some changes for comparison purpose) (43)

Alkali Activators

They are typically a mixture of alkali hydroxides and silicates and are the most common alkaline reagents. Alkali hydroxide raises the pH of the solution to encourage the dissolution of aluminosilicates and aid in preserving the structure's electrical neutrality by replacing silica ions with aluminium ions. The alkali silicate, meanwhile, is typically provided as a supplemental supply of silicates, which adjusts the AAMs' setting time. A system with too much silicate slows down reactions and extends the setting time. The majority of research shows that sodium-based alkaline reagents are the preferred activators because they have a better capacity for silica and alumina monomer liberation, are more abundant in natural resources, and are less expensive.(24)

Table 1 : Geological Properties of Expansive Soil(31)

Sl.No.	PROPERTIES	CONFIRMING TO IS CODE	VALUE
1	Coefficient of uniformity (Cu)	IS 2720:Part 4 :1985	2.43
2	Coefficient of curvature (Cc)	IS 2720:Part 4 :1985	0.51
3	Specific Gravity (G)	IS 2720:Part 3: Sec 1:1980	2.64
4	Maximum Dry Density(MDD)	IS 2720:Part VII :1980	1.55gm/cc
5	Optimum Moisture Content (OMC)	IS 2720:Part VII:1980	23.31%
6	Natural moisture content	IS 2720:Part 2 :1973	7.11%
7	Free swell index	IS 2720:Part XL :1977	100%
8	Liquid Limit	IS 2720:Part 5 :1985	72%
9	Plastic Limit	IS 2720:Part 4 :1985	21%
10	Swelling Pressure	IS 2720:Part XLI :1977	6kg/cm ²
11	Classification	IS 1498	CH

II. Review of Literature

Glass Powder

Glass is totally inert and therefore non-biodegradable. It degrades in a manner similar to natural rock. As an inert construction material, it can increase the strength of various road building elements. Glass has been experimented on as a substitute aggregate in asphalt concrete. Crushed glass has also been used as an aggregate for sub-base. Glass is an amorphous non crystalline material, which is typically brittle and optically transparent.

Table 2: Source and primary composition of GP used in AAMs (30)

Source	SiO ₂	Na ₂ O	CaO
Fluorescent Lamps	58.4	15.3	11.7
Glass Containers	68.8	15.2	7.43
Solar Panel	72.3	12.9	8.8
Highway Safety Glass	72.5	13.7	9.70
Glass Bottles	72.6	12.5	10.5

The familiar type of waste glass materials are drinking vessels and windows, however, most of the readily available waste glass material is soda-lime glass composed of about 75% silica (SiO₂), Na₂O, CaO and several additives. A combination of Sodium silicate (Na₂SiO₃) and sodium hydroxide (NaOH) in the ratio 1:2.5 was used as an alkali activator. Recycled Glass powder in the proportion of 3%, 9%, 12%, 15% and 18% was added by weight to the soil and mixed thoroughly to obtain a homogenous mixture, the alkaline solution of Sodium hydroxide and Sodium silicate was added to this mixture to initiate the geopolymerization reaction. The prepared stabilized samples were air cured at room temperature for the period of 3 and 7 days. Unconfined Compression strength test was conducted on the cured samples. The Unconfined compressive strength of the treated soil samples is found to be increasing with increase in geopolymer dosage; Increase in Recycled glass powder up to an optimum value of 9% increased the UCS of the specimens. Increase in curing time of stabilized specimens increases the UCS value of soil. Stabilized samples that were cured for 7 days exhibited a higher UCS values than samples that were cured for 3 days. 3. The Recycled Glass powder based geopolymer is effective in increasing the strength of the soil and hence can be used as a soil stabilizer. (6)



Figure 2: Recycled Glass Powder (6)

Industrial Waste (Ground Granulated Blast Furnace Slag and Flyash)

GGBS (Ground Granulated Blast-furnace Slag) is a cementitious material whose main use is in concrete and is a by-product from the blast-furnaces used to make iron. Chemically GGBFS is composed of 40% Calcium Oxide, 35% Silica, 13% Alumina and 8% Magnesia. The Ground Granulated Blast Furnace Slag (GGBS) used for this experimental work had a specific gravity of 2.89, and fineness in the range of 400-600 m² /Kg. The ASTM Class F type fly-ash was procured from local thermal power plant. The material was greyish white in colour had a specific surface area in the range 290-350 m² /Kg, the specific gravity of 2.16. A finely ground glass was also used in the present investigation as a binding ingredient. The alkaline solution consists of solid sodium hydroxide crystals (NaOH) with 98% purity and liquid Sodium silicate solution. A M-40 mix design was made using the conventional Indian method. The amount of alkaline activator used was kept steady to preserve an activator modulus of 1.25 throughout the investigation. The water-binder ratio was kept maintained at 0.40. Two types of specimens were cast, one with 0% glass powder (denoted by Mix M-0) and one more with 25% glass powder (denoted by Mix M-25). In 0% glass powder mix, the 25% fly-ash was used; whereas in 25% glass powder mix, 0% fly-ash is used. The major binder material was GGBS which was kept at a dosage of 75% in the binder, which was kept constant in both the mixes. The experimental investigation showed that a quality concrete can be easily produced using alkali activation of industrial wastes satisfying its strength requirements. The statistical models developed shown that there are a significant relationship between various cube and cylinder strengths. Thus alkali-

activated concrete(AAC) can effectively reduce the environmental hazards associated with OPC concrete, which also provides an effective way of utilizing major industrial byproducts.(7)

Soils stabilised with alkali activated blast furnace slag resulted in the greatest strength and durability improvements; with other materials tested showing smaller improvements. The addition of alkali activators has been observed to allow pozzolanic reactions to occur, which has led to improved mechanical properties; primarily strength, which increased with time. The durability of the soil was improved by the additions of by-products, though alkali activation did not cause significant additional increase in durability (15).

Boiler Ash

The boiler ash, derived from three different Indian pulp and paper mills, has many undesirable characteristics for alkali activation. Alkali-activated bricks were made out of boiler ash, clay, hydrated lime, sodium hydroxide pellets, and municipal water. Increases in compressive strength relative to the fired clay alternative were achieved through robust mix design given the relative particle size and compositional variation in three ash types from the region. Early strength development was observed as more than 55% of the 28 day strength is achieved after one day curing. To achieve these strengths, supplementary materials in the form of clay and lime were used, but through cost and environmental analysis this was shown to perform well relative to the comparator, fired clay bricks. There is opportunity to lower the environmental impact by reducing the lime and NaOH quantities and by using additional wastes in the mix design. An economic and environmental analysis indicates that these bricks can be produced for similar costs as the clay fired brick with reduced environmental impact, making them a viable alternative in the market.(8)

Fly Ash

Fly ash production in India is currently expected to be 112 MT, which is a huge quantity. Fly ash disposal is still a major problem, according to a new study by the Centre for Science and Environment (CSE), as only 50 to 60 percent of the entire fly ash produced by the power sector is employed in cement, concrete, bricks, backfill or road embankments, adhesives, and wall bollards. The remainder is dumped into improperly constructed and maintained ash ponds.(21)

Table 3: Data of FA utilisation and production (45)

Sl.No	Country	Ash Utilization	Annual ash production (millions of tons/year)
1	Netherland	100	2
2	Italy	100	2
3	Denmark	100	2
4	France	85	3
5	Australia	85	10
6	Germany	85	40
7	Canada	75	6
8	USA	65	75
9	UK	50	15
10	Chaina	45	100
11	Italy	38	112

Table 4 : Physical Properties of Fly Ash(29)

S.No.	Properties	Values
1	Specific Gravity	2.08
2	Color	Light Grey
3	Plasticity Index	Nonplastic

Table 5: Chemical Properties of Fly Ash (29)

Compounds	Composition (%)
SiO ₂	41.65
Al ₂ O ₃	22.38
Fe ₂ O ₃	15.04
MgO	4.76
CaO	4.75
K ₂ O	5.82
Na ₂ O	4.72

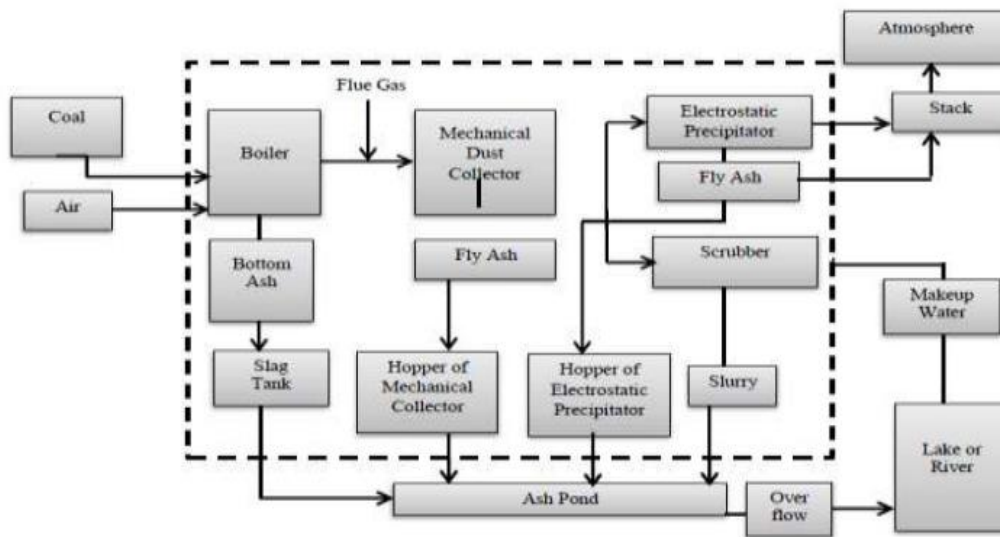


Figure 3: Schematic view of a typical coal based thermal power plant (28)

Fly Ash

Fly ash combines with alkalis such as Sodium Hydroxide (NaOH) and Sodium Silicate (Na₂SiO₃) creating an alumino-silicate gel, that shows properties similar to that of cement and it can be used as the environment-friendly binding material. Flyash is a waste from thermal power plant units. It is rich in siliceous and aluminous material and a lot of progressively different constituents. Fundamental constituents of flyash are Silicon dioxide (25-60%), Aluminum oxide (10-30%), Ferric oxide (5-25%) and Calcium oxide. Class F flyash is kind of flyash in which the absolute level of these three constituents are greater than or equal to 70% and calcium oxide is under 10%. Fly ash is finely divided material and hence has more surface area to react with chemicals which thereby improves its pozzolonic activity and thereby increases its cementitious properties (21).

Expanding soils' flexibility is lessened when Alkali Activated Fly Ash (AAFA) is added. As the fly ash content rises, the liquid limit falls and the plastic limit rises. Adding AAFA can successfully lower the free swell index of expansive soils. By adding 15% AAFA, the Free Swell Index for expansive soils was decreased by around one-third. The maximum dry density decreases and the optimal moisture content rises with an increase in AAFA content.(32)

Expansive soil stabilisation is very important these days, and many different methods and materials have been suggested for these weak expansive soils. The weak expansive soil that can be stabilised locally by fly ash activated with an alkaline chemical is presented in this experiment. Once the fundamental features of the expansive soil sample were established, a homogenous mixture of fly ash in the following percentages: 10%, 20%, 30%, 40%, and 50% was added to the expansive soil in terms of total solids. To activate fly ash and conduct the test, alkaline chemicals were utilised in different amounts (0, 0.5, 1, 1.5, and 2 molarities). On expansive clay soil, the specific gravity, atterberg limits, standard Proctor, and unconfined compressive strength tests were carried out. The results of the investigation showed that untreated expansive soil performed the worst, whereas alkali-activated fly ash treated soil produced better outcomes than fly ash mix. Following treatment with fly ash and alkali-activated fly ash, the expansive soil's geotechnical characteristics also improved(33).

Conventional binders, such as regular Portland cement, can also be used to stabilise expansive soil, although doing so comes with significant environmental risks. As a result, finding a substitute stabiliser that doesn't damage the environment was essential. They looked at employing fly ash and a sodium-based alkaline activator to stabilise clayey soil that was readily available in the area. The alumina-silicate crystalline chain is produced by the chemical interaction of fly ash containing silica and alumina with alkali. One molar of sodium silicate and twelve molal (M) concentrations of NaOH are combined to create an alkaline activator, and the mixture is diluted 2:1. By weight of total solid (clay + fly ash), fly ash is maintained at 10%, 15%, and 20%. The ideal moisture content (OMC) is determined for each mixture. The unconfined compressive strength test was used to observe samples at optimal moisture content and the 3% dry part of optimum moisture content. The utility of the binder was also compared with binder based on fly-ash during curing times of 7 days, 14 days, and 28 days. As a result, the data show a direct relationship between alkaline activator, fly ash, and mechanical strength: for a given amount of time, increasing the activator concentration and fly ash content increases the strength. The most efficient blend was found via FTIR analysis. The outcome reveals a steady improvement in the soil.(34).

Since silty soil is fragile and unsuitable for use as a subgrade for pavement, this work focuses on stabilising silty soil using alkali-activated fly ash. The application of stabilisers can help silty soil make up for its lack of geotechnical qualities, increasing its strength, volume stability, and durability. This instance involved stabilising silty soil and enhancing its characteristics by combining fly ash with alkali activated polymer. As per IS standards, basic engineering properties such as grain size distribution, specific gravity, and Atterberg's Limit of Lithomargic soil (shedi soil) were studied. Fly ash was put to expanding soil in different amounts: 10%, 20%, 30%, 40%, and 50%. The geotechnical properties of expanding soil that was stabilised and that wasn't were contrasted. By using a heavy compaction test, the maximum dry density and optimal moisture content were determined in accordance with IS 2720 Part 7. Alkali activated fly ash was made using 14M NaOH. Comparisons were made since the unconfined compressive strength test was conducted in conjunction with the California bearing ratio test at 0, 7, 14, and 28 days. The application of alkali activated fly ash to expansive soil resulted in an increase in compressive strength, according to UCS measurements. According to CBR results, the proportion of alkali-activated fly ash in expanding soil was 5.1% without it. The percentage of fly ash that was added to the soil varied, increasing from 10% to 20% and decreasing from 20% to 30%(35).

The amount of chemical in the activated fly ash and the length of the curing period are discovered to affect the soil's unconfined compressive strength. The 10 molal samples are more cost-effective than the 12.5 and 15 molal samples because they provide stronger results after three and seven days. Long-term strength is higher for samples containing 12.5 molal. The maximum strength of an activated sample after three days is 3.25 times more than that of samples treated with fly ash. The maximum strength of an activated sample after 7 days is twice that of fly ash treated samples. The maximum strength of the activated sample after 28 days is 2.7 times more than the maximum strength of the fly ash treated samples. The mechanical strength that a mixture acquires is directly correlated with the activator/ash ratio. The results of this experimental study also demonstrate that mixtures with lower activator/ash ratios exhibit greater strength than mixtures with larger activator/ash ratios. This also turns out to be affordable and efficient. It is not recommended to reduce the viscosity of alkaline grouts to the level of cement grouts, as this will eventually have a detrimental influence on the final strength, as the final strength of the combination is determined by the viscosity and fluidity of the mixture created. Effective application of alkali-activated fly ash presents a hurdle to its potential use as a chemical stabiliser for expanding soils.(36).

The amount of chemical in the activated fly ash and the length of the curing time affect the soil's unconfined compressive strength. In comparison to 12.5 and 15 molal samples, the findings of 10 molal samples yield better strengths of 3 and 7 days, making it a more cost-effective combination. The overall 3-day strength of the 10-molal sample is 22.23 kPa, 2.5 times stronger than that of the samples treated with fly ash. For 12.5-molal samples, a 28-day curing period is more dependable and the best option. The targeted sample's average strength after seven days is 573.98 kPa, which is three times more than what the samples were able to achieve. Compared to the samples treated with fly ash, the desired sample's average 28-day strength is 4.4 times higher, at 743.6 kPa. Additionally, the intensity of the mixture and the ratio of activator to ash are interdependent. According to the preceding results, increasing the activator/ash ratio is advantageous since it increases intensity or strength outcomes, which in turn increases ultimate cost(37).

The amount of chemical in the activated fly ash and the length of the curing period are discovered to affect the soil's unconfined compressive strength. The 10 molal samples are more cost-effective than the 12.5 and 15 molal samples because they provide stronger results after three and seven days. Long-term strength is higher for samples containing 12.5 molal. The maximum strength of an activated sample after three days is 3.25 times more than that of samples treated with fly ash. The maximum strength of an activated sample after 7 days is twice that of fly ash treated samples. The maximum strength of the activated sample after 28 days is 2.7 times more than the maximum strength of the fly ash treated samples. The mechanical strength that a mixture acquires is directly correlated with the activator/ash ratio. The results of this experimental study also demonstrate that mixtures with lower activator/ash ratios exhibit greater strength than mixtures with larger activator/ash ratios. This also turns out to be affordable and efficient. It is not recommended to reduce the viscosity of alkaline grouts to the level of cement grouts, as this will eventually have a detrimental influence on the final strength, as the final strength of the combination is determined by the viscosity and fluidity of the mixture created. Effective application of alkali-activated fly ash presents a hurdle to its potential use as a chemical stabiliser for expanding soils (38).

Fly Ash with Quarry Dust

The main components of geopolymer brick using quarry dust are the mixture of flyash and alkaline solution as the binder, quarry dust as fine aggregate(9). 54% of fly ash, 44% of foundry sand, 4% of bentonite and a 10M solution is used for the final experimental work. The ratio of alkaline solution to fly ash is 0.5 and the ratio of Na_2SiO_3 to NaOH is 1.5(9) According to the reference normally a good building brick should have a compressive strength equal to or greater than 3.5MPa. The geopolymer bricks developed has a compressive strength value of 5.93MPa. Geopolymer bricks are lighter in weight compared to normal clay brick and it also has relatively less water absorption capacity than normal brick due to less number of pores in it and also due to its compact structure(9).

Fly Ash with Ground granulated blast furnace slag

The development of geopolymer masonry units is a relatively new concept, whereas, the research on geopolymer concrete is extensively reported. Low calcium Class-F fly ash and ground granulated blast furnace slag (GGBFS) can be used as binders in the manufacturing of masonry units. The fly ash, GGBFS and M-sand were mixed thoroughly in dry condition and then alkali solution was added to prepare fresh mortar. The geopolymer blocks were prepared by compressing the required amount of mortar and cured in open air without any special treatment. The compressive strength of geopolymer block at the age of 3 day was more than 3.5MPa, which makes the user to handle without any serious issues. The water absorption, initial rate of water and modulus of elastic of the units were well within the limits prescribed the relevant codes of practice. The use of geopolymer blocks and mortar are greatly influences to make use of the masonry units. The unreacted flyash particles were of size $2\mu\text{m}$ which is quite finer than cement particles. The flexural strength bond strength is higher than that of regular cement blocks(13).

In order to lessen the amount of PC (Portland Cement) used in soft-clay stabilisation, this study examined the stabilisation performance of PC (control) and alkali-activated GGBS for a marine soft clay. Ground granulated blast furnace slag (GGBS), a by-product of the steel industry, can be used to stabilise marine soft clay with the help of quicklime and hydrated lime. It would make sense that switching from PC to lime-GGBS for soft clay stabilisation would have positive effects on the economy and ecology. While the similar hydrated lime activated GGBS stabilised clay had a little lower UCS of 90 days, the fast lime activated GGBS stabilised clay had a slightly greater UCS of 7 and 28 days. The ideal hydrated lime-activated GGBS stabilised clay, as determined by the PC stabilised clay, had a UCS of 1.7 times greater after 90 days. In stabilised clay, hydrated lime-activated GGBS produced a somewhat higher 90-day UCS than quicklime-activated GGBS(39).

Calcium oxide (CaO) activated and medium reactive magnesia (MgO) were used in the chemical stabilisation of soft clay based on industrial waste, such as Granulated Blast Furnace Slag (GBFS) and Basic Oxygen Furnace Slag (BOFS). By using this eco-friendly method, the risks connected with inappropriate waste disposal will be eliminated, and the emissions of greenhouse gases from cement manufacture will be decreased. In this area, alkaline solutions function as activators, and geopolymers based on clay-slag are promoted by CaO and MgO. Stabiliser additions up to 20% had a negligible impact on the clay sample's UCS. After 90 days of curing, these samples' UCS values at 20% content reach 4 and 4.7 Mpa. The geopolymer system based on slag and clay typically exhibits a low degree of geopolymerization. The weathering and loss of strength brought on by exposure to harsh environments is one of the main problems with geo-materials(40).

The microstructural characteristics and strength and durability of stabilised red mud made from alkali (Na_2SiO_3) activated granulated blast furnace slag (GGBS) for possible application as a geo-material were investigated. Research is being done on the effects of GGBS activation of 0.25, 0.5, and 1.0 M(M) sodium silicate alkaline on UCS. After a 3-day curing time, the addition of 5, 15, and 25% GGBS in NRM enhances the UCS by 26.52, 66.42, and 82.99%, whereas a 28-day curing period results in increases in the UCS value of 87.60, 172.76, and 290.63%. However, after adding 5, 15, and 25% GGBS to HRM (HINDALCO Red Mud), the UCS value increased as much as 1.20, 64.90, and 91.59% after three days of curing; however, after twenty-eight days, the UCS value increased as much as 143.72, 179.67, and 241.45%. The highest strength of the activated NALCO red mud (NRM)-25% GGBS mix is 11.21 MPa, which is 35.12% greater than the activated HINDALCO (HRM)-25% GGBS mix (8.30 MPa). When 1.0 M Na_2SiO_3 was used to activate the NRM / HRM, which stabilised with any percentage of GGBS, the maximum UCS was achieved (41).

Fly Ash with Pulverized coal

Fly ash is a by-product from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal fuse in suspension and float out of the combustion chamber with the exhaust gases. Two types fly ash are commonly used in concrete. Class C and Class F. Class C are often high-calcium fly ashes with carbon content less than 2 %; whereas Class F are generally low calcium fly ashes with carbon content less than 5% but some times as high as 10%. In general, class C ashes produced from burning sub-bituminous are anthracite coals.

Fly Ash with Red Gypsum

The use of Fly Ash and Red gypsum binders to enhance the properties of alluvial soil with Sodium hydroxide and sodium silicate as a Activator shown that the Alkali-activated fly ash and red gypsum exhibited higher strengths and much higher brittleness in comparison with untreated soil (16).

Low calcium fly ash and High calcium fly ash

Low calcium fly ash and High calcium fly ash are the binders used as a stabilizers for soft soil, where in Sodium hydroxide and sodium silicate are the activators. The results show that the alkali-activated binder is a successful method of deep soil stabilisation. Also, alkaline activation method is a simple process and it does not involve any sophisticated or costly procedures. In the case of fly ash (source binder) with various calcium contents, a lower percentage of calcium in the silica and alumina source has a positive effect on mechanical performance of treated soil through long curing time. (17)

Fly Ash based Agro Waste (Palm Oil Ash)

One of the well-known agro-wastes, palm oil fuel ash (POFA), was used as a source binder. Sodium hydroxide (NaOH) and potassium hydroxide (KOH) were used as alkaline activators in one of the study. The influence of four factors including the kind of alkaline activator, the use of source binder, the curing condition and the water content of the soil on the strengthening performance of soil was evaluated according to the improvement of the unconfined compression strength (UCS). At the same alkaline concentration, both sodium hydroxide and potassium hydroxide were able to enhance the strength development rate of specimens. However, potassium hydroxide-POFA-stabilised soil yielded the highest UCS value following a long curing time (90 and 180 d of curing). The size and charge density of the alkaline activator play significant roles in controlling the rate and extent of the activation process for the strength performance. With regard to soil strength improvement, when the POFA content in the activation process increased from 0% to 15%, the UCS value increased substantially, irrespective of the alkaline activator type. This achievement implies a tremendous effect of this agro-waste on the strength behavior of treated soil(18).

Fly Ash, Sand and Cement

The alkaline activator solution is prepared by mixing of sodium hydroxide in one litre of distilled water in a volumetric flask to obtain 2M concentration. We are using proportion of Fly Ash, Sand and 53 grade of OPC cement as 60%, 30% and 10%. A slurry paste is formed from the geopolymer mixture, which is poured into the steel mould and kept for curing for 7days, 14 days and 28 days. Through this brick manufacturing process Environmental effects of wastes and disposal problems of waste can be reduced. This study gives the provision of converting harmful fly ash into efficient and economical construction materials. Density with Higher load bearing, high compressive strength with less dampness and 13% saving in cost of production is obtained from eco black brick. (19)

Pulverised fly ash (PFA) and High calcium content wood ash (HCWA)

In this work, the mechanism of strength growth in pulverised fuel ash and high calcium wood ash bricks was investigated. The objective of the work was to report on the mechanical strength of a block made from pulverised fly ash (PFA) and high calcium content wood ash (HCWA) with low geopolymer content. Due to the angular particle form and porous nature of HCWA in comparison to PFA, the amount of mixing water required to attain standard consistency rose proportionally as the HCWA concentration increased in the HCWA-PFA hybrid geopolymerpaste system.(20)

Fly Ash, GGBFS and Cement Kiln Dust(CKD) (Cement Fuel Dust) and Aggregates

CKD, often referred to as cement flue dust or by-pass dust, is a byproduct of the manufacturing of Portland cement. It is gathered in the air-control devices that are located after the kiln. A micron-sized, greyish-tan powder with a high specific surface makes up the look. Lagan Cement provided CKD to the factory at Kinnegad, Republic of Ireland. Commercially available materials, including solid sodium hydroxide of commercial grade (99% purity) and sodium silicate solution with a SiO₂: Na₂O ratio of 2:1 (Na₂O 12.8%, SiO₂ 25.5%, water 61.7%), supplied by Fisher Scientific, were employed as activators. 30% weight-to-weight NaOH solution was created. The mechanical strength of blocks made from FA/GGBS mixtures activated with chemicals that are readily accessible on the market exceeded expectations, demonstrating that alkali activation is a well-established technology with high potential. The use of CKD proved to be more difficult, and factory trial results that were less than ideal highlighted the significance of tightly controlling every stage of production, from mixing to curing, as bad weather and uncertainties about the aggregate's moisture content had a negative impact on the performance of building blocks. The idea of obtaining activators from waste streams is unquestionably the most promising advancement in the industry. This would cut their cost, lower CO₂ emissions from concrete, and promote beneficial circular economy loops. (22)

Fly Ash and Unground rice husk ash (URHA)

In the study, the potential for creating alkali-activated green construction bricks using geopolymerization technology and a variety of solid waste sources is assessed. Fly ash (FA), an industrial waste, was used as the principal binder ingredient to create solid bricks in compliance with official Vietnamese product specifications. FA was activated by a potent sodium hydroxide (NaOH) solution. To find a new application for this waste material, unground rice husk ash (URHA) was employed as a partial fine aggregate replacement (0%-45%). The brick samples were kept at room temperature after casting until the required ages for testing. Dimensions and obvious flaws in these samples were verified. Including compressive and flexural strengths, water absorption, bulk density, average weight, and void volume, the impacts of URHA content on the engineering characteristics of the bricks were also examined. The results of the experiments demonstrated that the brick samples exhibited good engineering characteristics that closely matched the recognised Vietnamese standard. Between 9.2 and 20.8 MPa and 3.2 and 5.3 MPa, respectively, were the ranges for

compressive strength and flexural strength. The potential for employing FA and URHA in the manufacture of green construction bricks is clearly shown by these results. (23)

Fly ash, GGBS, Iron ore tailing (IOT)

In the study, iron ore tailing (IOT) from mining operations was used to make alkali-activated bricks. Fly ash, GGBS, IOT, and Na_2SiO_3 sol were used to create six distinct brick compositions. To assess the strength and durability of the developed bricks, a number of conventional tests were performed on them. Maximum compressive strength of 18.45 MPa and lowest water absorption of 12.6% were demonstrated by the created bricks. Alkali-activated bricks have also demonstrated exceptional resistance to brick ageing, which was explained by an increase in the microstructure of bricks as a result of the filling of voids with byproducts of the polymeric reaction. Finally, it was interesting to note that more than 50% IOT can be used to manufacture high-quality bricks at ambient curing conditions when 8% Na_2SiO_3 is used as an alkaline activator and when fly ash and GGBS are combined.(24)

Ceramic Waste

Ceramic is non-metallic solid which is inorganic, produced by the action of heat and subsequent cooling. The structure of ceramic materials may be crystalline or partly crystalline, or amorphous (e.g., a glass). Since most common ceramics are available in crystalline form, the term ceramic is often referred to inorganic crystalline materials. Ceramic materials contribute the highest percentage of wastes within the C&D wastes (54%) . This waste of ceramic industries dumped at nearby places resulting in environmental pollution causing effect to habitant and agricultural lands (10).

Alkaline activation of aluminosilicate wastes in the presence of ceramic wastes and clay brick wastes (grog) results in the formation of sustainable building materials with efficient features up to 20 % grog (clay brick waste) replacement. Increasing the grog replacement results in an increase in the crystalline content with low potential for increasing the structure homogeneity. Compressive strength of 20 % grog achieved 445 and 490 at 28 and 90 days which can be used in the formation of heavy duty bricks(12) and in severe aggressive medium as reported by ASTM C-62 [11]. Ceramic waste particles are expected to influence the mechanical properties of the matrix more positively, as they are stronger and better bonded to the matrix than clay brick waste (grog) particles. Possibility of waste ceramic and clay brick waste as recycled material used in geopolymer mortar production increases and may beneficial to decreases further CO_2 burden to the environment and helpful for conserve natural resources. Water absorption of mostly all the produced geopolymer bricks are in the range 13 to 16% (12) which is lower than required for the severe weathering clay bricks according to ASTM-C62(11)

Metakaolin based Geopolymer in clay

The “properties of metakaolin-based geopolymer are directly impacted not only by the specific surface and composition of initial metakaolin and the type, composition and relative amount of alkali activator used but they also depend on the conditions during the initial period of geopolymerization reaction. The unconfined compression strength of geopolymer improved soil increases first and then decreases with the contents of metakaolin and alkaliactivator. The soil sample M10A5 with 10% of metakaolin and 5% of alkali-activator reached the maximum 7-day unconfined compression strength. Its average peak value was 418.63 kPa”.(14)

Surgical Mask

Due of the COVID19 epidemic, the use of surgical masks has dramatically increased over the past few years. Due to plastic contamination, the environment will be seriously threatened by the careless disposal of surgical masks. However, due to its heavy reliance on natural resources, the construction sector has a growing carbon impact. Investigating novel construction materials from a sustainability standpoint is therefore necessary. In this work, rice husk ash (RHA), ground granulated blast furnace slag (GGBFS), sand, and sodium silicate (SS) were used to create alkali-activated bricks. Processed surgical masks (PSM) were added to the mixture in varied amounts of 0%, 1%, 2%, 3%, and 4% by volume. The outcomes showed that the bricks' strength qualities were greatly improved by the addition of PSM, reaching a maximum compressive strength of 6.85 MPa with an inclusion of 4% PSM. In addition, it has decreased brick density to a minimum of 1.54 g/cm³ with inclusion of 4% PSM. With a maximum increase of 4.76% and 7.75% for bricks with 4% PSM, respectively, as compared to bricks with 0% PSM, the incorporation of PSM has somewhat increased the water absorption and porosity of the bricks. The results of the accelerated ageing test revealed that the bricks lost between 55.2% and 58.6% of their compressive strength after three cycles of soaking and drying.(25)

Unmodified banana fibres (UMBF)

Unmodified banana fibres (UMBF) and alkaline (1 molar aqueous sodium hydroxide) modified banana fibres (AMBF), fine sand, and regular Portland cement were combined with scrap paper pulp in an effort to create paper bricks as an alternative to traditional masonry units. By weight of the pulp, the fibers were added in varied ratios of 0, 0.5, 1.0, 1.5, 2.0, and 2.5 wt%, and curing took place for 28 and 56 days. Properties like thermal conductivity, specific heat capacity, compressive, flexural, and splitting tensile strengths, among others, were evaluated. The results of the tests showed that water absorption increased as fibre loading increased, and that AMBF reinforced samples absorbed less water volume than UMBF reinforced samples—a feat made possible by treating banana fibre with alkaline. With paper bricks doped with UMBF, moisture absorption increased, however with paper bricks doped with AMBF, it was shown that property value decreased with an increase in AMBF proportion. Compressive, flexural, and splitting tensile strengths improved as a result of fibre loading, while AMBF reinforced samples showed superior performance. According

to the thermal test results, adding UMBF caused thermal conductivity to decrease while adding AMBF to the bricks caused value to increase. For a particular heat capacity, opposite behaviour was seen: UMBF increased heat capacity, but AMBF resulted in depreciation. An examination of experimental trends shows that curing time and alkaline fiber modification effectively increased the characteristics of paperbricks for masonry building.(26)

Spent Coffee Grounds and Tea Wastes

Due to the high firing temperature and greenhouse gas emissions, the conventional brick-making firing process which is not sustainable. As a result, there is an increasing motivation to spend money on environmentally friendly technologies. This study determined if used coffee grounds and tea waste may be used as additions in the production of unfired clay bricks using an alkali process. This study aims to improve sustainable construction methods and redirect SCG and TW from landfills. In this study, mill clay residues (precursors) were activated with a liquid mixture of NaOH and Na₂SiO₃ solutions at a set Na₂SiO₃/NaOH ratio of 0.7 to create an alkali-activated binder. SCG and TW were added to the binder in small amounts (1, 2.5, 5, 10, and 15 wt%) and mechanically blended for 2.5 min. Slurry samples were compressed in a steel mould to create blocks. After being demolded, the block samples were dried for 24 hours at a temperature of 110 °C in an oven before being cured at room temperature. The unconfined compressive strength test, moisture absorption test, and optical and scanning electron microscopy (SEM) were all performed on the manufactured samples. SEM images revealed that active fungus were found in samples with high SCG contents (5 wt%) but not in those prepared with TW. The findings demonstrated that the samples up to 2.5 weight percent SCG and 10 weight percent TW satisfied the minimum compressive strength requirement of 8.6 MPa for structural applications with acceptable moisture absorption values.(27)

Egg Shell Powder

In order to determine how well alkali activated egg shell powder (ESP) can stabilise soil, researchers have examined the behaviour of unconfined compressive strength (UCS), compaction features, and Atterberg's limits in cohesive soil. Activator egg shell powder has been tested in the lab at several ratios (5%, 10%, 15%, 20%, 25%, & 30% of total solid mass). The alkaline activator solution is made up of sodium hydroxide and sodium silicate. There was a 0.45 activator to alkali ratio in use. NaOH was kept at a constant 10 Molar concentration, and the mass ratio of Na₂SiO₃ to NaOH was set at 2. The results were examined at various curing times of 1, 7, and 28 days. The improvement of soil geotechnical qualities is implied by the rise in maximum dry density and unconfined compressive strength. This demonstrated that alkaline activated egg shell powder might be used to stabilise soil(42) .

Sugarcane Bagasse Ash

Due to inadequate bearing capacity and excessive settlement, many civil engineering projects built on problematic soils—such as soft soil, expanding soil, etc.—run the danger of failing. Soft soils are usually treated with another cementing material for improved engineering features, or they are replaced with some strong materials like crushed rock, hard soils, etc. Due to the high cost and detrimental environmental effects of traditional stabilisers like cement and lime, as well as the issue with managing the disposal of agricultural industrial wastes, it is necessary to look into the possibility of using agricultural industrial waste to stabilise these problematic soils in place of traditional stabilisers, either entirely or partially. This study presents the one-dimensional compressive behaviour (UCS) of soft soil stabilised with sugarcane bagasse ash and by-products of sugar mill activated by alkali activator (NaOH & Na₂SiO₃). Laboratory tests were conducted at different proportions of bagasse ash content (15%, 25%, and 35% of total solid mass), concentration of alkali (8M, 10M, & 12M), and activator/alkali ratio (0.25, 0.45 & 0.665) at different curing times (7, 14, 28 & 56 days). The test findings demonstrated that the alkaliactivated binder's high reactivity encouraged the growth of strength. According to UCS testing, the AB-25-12-0.25 mixture reaches a maximum strength of 0.41 MPa after 7 days of curing, which is 1.78 times and 78.3% greater than raw soil. Similarly, at 14, 28, and 56 days of curing, the AB-25-12-0.25 mixture's 0.51 MPa, 1.89 times and 88.9%, the AB-25-12-0.45 mixture's 0.56 MPa, 1.93 times and 93.1%, and the AB-25-10-0.65 mixture's 0.59 MPa, 1.97 times and 96.7% greater than raw soil, are all higher than raw soil. It has been determined that 25% of total solids is the ideal amount of bagasse ash for stabilising soil (44).

Concluding Remarks

Poor waste management - ranging from non-existing collection systems to ineffective disposal -causes air pollution, water and soil contamination. Open and unsanitary landfills contribute to contamination of drinking water and can cause infection and transmit diseases. Utilisation of Solid waste materials using alkali activation in stabilizing weak expansive soil enhances the geotechnical properties and performance of expansive soil. Also this technique provides with the best alternative for waste disposal and management by its adequate utilization otherwise this solid waste proves to be catastrophic to human and environment. Studying all the investigation done by various researchers accompanying concluding remarks can be made:

The Recycled Glass powder based geopolymer is effective in increasing the strength of the soil and hence can be used as a soil stabilizer.

Alkali-activated concrete(AAC) can effectively reduce the environmental hazards associated with OPC concrete, which also provides an effective way of utilizing major industrial byproducts.

Soils stabilised with alkali activated blast furnace slag resulted in the greatest strength and durability improvements; with other materials tested showing smaller improvements. The durability of the soil was improved by the additions of by-products, though alkali activation did not cause significant additional increase in durability.

Alkali-activated bricks were made out of boiler ash, clay, hydrated lime, sodium hydroxide pellets, and municipal water. An economic and environmental analysis indicates that these bricks can be produced for similar costs as the clay fired brick with reduced environmental impact, making them a viable alternative in the market.

Geopolymer brick is produced using quarry dust having a mixture of flyash and alkaline solution as the binder. The geopolymer bricks developed has a compressive strength value of 5.93MPa. Geopolymer bricks are lighter in weight compared to normal clay brick and it also has relatively less water absorption capacity than normal brick due to less number of pores in it and also due to its compact structure(9).

Low calcium Class-F fly ash and ground granulated blast furnace slag (GGBFS) can be used as binders in the manufacturing of masonry units. The results show that the alkali-activated binder is a successful method of deep soil stabilisation.

One of the well-known agro-wastes, palm oil fuel ash (POFA), was used as a source binder along with Sodium hydroxide (NaOH) and potassium hydroxide (KOH) as alkali activators. With regard to soil strength improvement, when the POFA content in the activation process increased from 0% to 15%, the UCS value increased substantially, irrespective of the alkaline activator type. This achievement implies a tremendous effect of this agro-waste on the strength behavior of treated soil.

Alkaline activation of aluminosilicate wastes in the presence of ceramic wastes and clay brick wastes (grog) results in the formation of sustainable building materials with efficient features up to 20 % grog (clay brick waste) replacement.

The unconfined compression strength of geopolymer improved soil increases first and then decreases with the contents of metakaolin and alkaliactivator.

An examination of experimental trends shows that curing time and alkaline fiber modification effectively increased the characteristics of paperbricks for masonry building using unconfined banana fibers.

The findings demonstrated that the samples up to 2.5 weight percent spent coffee ground and 10 weight percent tea waste satisfied the minimum compressive strength requirement of 8.6 MPa for structural applications with acceptable moisture absorption values.

Comparative Analysis of Alkali-Activated Materials

A comparative analysis of different alkali-activated materials (AAMs) is essential to identify the most effective and sustainable solutions for soil stabilization and eco-block production. The table below summarizes the unconfined compressive strength (UCS), cost implications, durability, environmental benefits, and key limitations of various AAMs.

Table 6: Comparative Analysis of Alkali-Activated Materials

Material / Mix	UCS (MPa)	Range	Cost	Durability	Environmental Impact	Limitations
Fly Ash (Class F)	0.57–0.74	(soil), up to 20 (bricks)	Low	Moderate	High	Longer curing needed
GGBFS	4–11		Moderate	High	High	Requires lime/activation
Glass Powder	↑ UCS up to 9%		Low	Moderate	High	Optimum % critical
Boiler Ash	Comparable to	clay bricks	Moderate	Moderate	Good	High variability
Fly Ash + Quarry Dust	5.93		Low	Moderate	High	Durability data limited
Fly Ash + GGBFS	>3.5 (3-day), >7 (28-day)		Moderate	High	Very High	Needs optimized mix
Fly Ash + CKD	High		Moderate	Moderate	High	Moisture sensitive
POFA	↑ UCS to 15%		Low	High (long term)	High	Slow strength gain
Ceramic Waste (Grog)	4.45–4.9		Low	High	Very High	↓ Homogeneity >20%

Red Gypsum + Fly Ash	↑ UCS	Low	Moderate	High	Brittle
Egg Shell Powder	Up to 0.59	Low	Low	Very High	Lower UCS
Bagasse Ash	Up to 0.59	Low	Moderate	Very High	Lower strength
Coffee/Tea Waste	8.6–20.8	Very Low	Moderate	Excellent	Biodegradability risk
Surgical Masks + RHA + GGBFS	Up to 6.85	Moderate	Moderate	High	↓ Strength after aging
Banana Fibers	Moderate	Low	Moderate	High	↑ Water absorption
Metakaolin + Soil	~418 kPa	Moderate	Moderate	Moderate	Narrow optimum content

Recommended Material Combinations

Based on the comparison, the following combinations are identified as the most promising for eco-block production and expansive soil stabilization based on strength, cost, durability, and environmental benefits.

Table 7: Recommended Material Combinations

Combination	Strength	Cost	Durability	Environmental Impact	Remarks
Fly Ash + GGBFS + NaOH/Na ₂ SiO ₃	High	Moderate	High	Very High	Optimal strength and sustainability
Fly Ash + Quarry Dust	Moderate	Low	Moderate	High	Low-cost masonry option
Fly Ash + POFA / Bagasse Ash	Moderate	Very Low	High (long term)	Excellent	Rural-friendly blend
Fly Ash + Ceramic Waste	Moderate	Low	High	Very High	Durable and sustainable
GGBFS + Red Mud + Na ₂ SiO ₃	High	Moderate	High	Very High	For heavy-duty applications
Surgical Mask + RHA + GGBFS	Moderate	Moderate	Moderate	High	For lightweight blocks

Getting into the reviews, Solid waste materials can be effectively used as an Stabilization of Expansive Soil. Different solid wastes from Industries and Agricultural waste can be studied to check the effectiveness of Soil Stabilization. Further, the study can be carried out by varying the different parameters such as, combination of Solid waste, by varying the curing temperature, curing time, curing method and mix proportions.

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