Soil Stabilization by Alkali Activated Fly Ash: A Review

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***Abstract*: The construction industry has attained new heights because of research work and its applications. Not only development in concrete technology but also importance of soil has been realised and has greater impacts in construction industry. As soil is the ultimate load bearer so it's 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 is catastrophic to construction as it swells and shrinks frequently and thereby it needs stabilization with different materials. Soil stabilization with various combinations of chemical, physical and biological methods has been employed to improve soil properties to make it adequate for intended engineering purpose. There is a huge generation of fly ash by thermal power plants which contribute to about 57% of power generation in India. There have been efforts to stabilize expansive soil using fly ash which is activated by alkali as it serves the dual purpose of sustainable development and fly ash disposal issues as fly ash poses hazardous threat to environment. Literature survey on this subject shows the importance of investigations on fly ash and alkali activated fly ash to stabilize expansive soil. It also shows variation in properties of expansive soil after its stabilization by fly ash and alkali activated fly ash. It also contains various additives to curb expansive behavior of soil by different combinations. This overall leads to sustainability in construction industry. This paper reviews behavior of Expansive Soil after stabilization with alkali activated fly ash on the basis of available literature.**

***Keywords:* Expansive soil, fly ash, alkali activated fly ash**

I. INTRODUCTION

Soil is the accumulation of earth material resulted from weathering of rocks. Expansive soils are formed by chemical decomposition of rocks (basalt and trap) and also by igneous rocks weathering and subsequent lava cooling. These are often termed as shrink swell soils as it exhibits the property of shrinking and swelling with the alteration in moisture content. This property thereby arises distress in soil leading to damaging of overlaying structure whether foundations of building or road pavements. These soils functions as in monsoon they ingest water and swells thereby becoming soft and their water bearing capacity reduces, and also they become harder on drying up by shrinking thereby showing swelling shrinking behaviour. It is catastrophic to construction industry as it poses serious threats to both structures on it and human life. It proves to be boon to farmers but has been problematic to construction industry as many cases of cracking and breaking of pavements, foundations, irrigation systems, roadways, water lines and sewer lines have been reported. Stabilization treatment of expansive soils can be done to make it good for construction. Improvement of properties of these soils can be done by stabilization method and thereby making it durable for further construction.

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 [1]. Soil modification refers to stabilization of soil with betterment of some properties without much vital improvement in soil durability and strength [1]. 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.) [2].

Properties of expansive soil are improved by different materials that might have been just a waste with disposal issues. Blast furnace slag, foundry sand and slag, cement kiln dust and rice husk ash are industrial wastes that have been utilized to stabilize expansive soil which results in improved durability and strength properties of soil [3,4]. Shear strength improvement is achieved when coir fibres in combination with fly ash is used on expansive soil [5, 6, and 7]. CBR value increases 15 to 22 times when polypropylene fibres were used to stabilize peat soils [8]. CBR value of expansive soil increases when fly ash was used as a stabilizer due to fly ash – soil interlocking process [9, 10, and 11].

There has been increase in number of thermal power plants recently to meet the ever increasing demand of power supply due to brisk industrialization and urbanization. Fly ash or flue ash is a by-product of combustion of coal and is extracted from gases arising of thermal power plant. Presently fly ash production is in excess of its consumption or utilization. Management and dumping in a safer way of fly ash are two core concerns with fly ash production. Normally the waste developed is very perilous having multiple characteristics thereby making it vital for safer disposal of these wastes, ensuring safe ecological system and no crash to human life and nature. To protect from environmental pollution, pre-treatment provision of these wastes before dumping and storage should be inculcated. As per central electricity authority report 2019-2020 fly ash utilization has increased to 78.19% which is highest till now.

1.1 Different stabilization

*Lime stabilization***:** Swelling and compressibility characteristics of soil treated with lime shows effective improvement and 3% lime addition gives optimum results [12]. Expansive soil is provided with cemented material by lime –clay combination compound [13]. Expansive soil treatment with lime might lead to increment of optimum moisture content and reduction of maximum dry density. Expansive soil attains maximum strength when lime was 4% [14]. Here Examination of expansive soils stabilization by Class C fly ash and lime was done. The linear shrinkage reduction got better with stabilization by lime comparing to same % fly ash of Class C type [15].

It was found out that optimum proportion of soil: lime: fly ash was to be 70:4:30 after examining combination of lime and fly ash on expansive soil for construction of embankments and roads [16]. CBR of expansive soil improves to 2.745, 3.9 and 6.5% from 1% after stabilization with 2.5, 5.0 and 7.50% of lime content and reduction in dry density is noted after treatment with lime [17]. CBR of marine soil rises by 129.76% when 15% sawdust was added and by 283.12% on addition of 4% lime and hence marine soil is stabilized by combination of lime and saw dust [18].

Fiber stabilization: Engineering attributes of soil gets better with fiber reinforcement of soil and use of fibers for stabilization of soil [19]. Study of effect of combination of lime and polypropylene fiber on characteristics of soil has been made and concluded that maximum dry density decreases and Optimum moisture content increases [20]. Reinforcement of soil aims at increasing its bearing capacity, strength and stability and also at lowering the settlement [21]. Here examination of the impact when nylon fiber with random distribution and stone dust were added to expansive soil by 3% and 20% respectively then swelling pressure reduction was achieved by approximately 48%. The increased and decreased by inclusion of fiber to stone dust stabilized expansive soil. Also increment in ultimate bearing capacity and reduction in settlement was observed when fiber and stone dust were inculcated in expansive soil [22].

Fly ash stabilization: Strengthening of expansive soils has been done by fly ash in various projects as fly ash increases the shearing strength and compressive strength of expansive soils by stabilization techniques. Addition of fly ash of class F type to about 20% to black cotton soil was done and CBR was improved to about 200% and by this expansive soil stabilization could be done [23]. It has been observed that optimum moisture content decreases and maximum dry density increases on application of fly ash to expansive soil thereby modifying its properties [24]. It has been concluded that soil and fly ash in combination of 30 % fly ash and 70 % soil was appropriate giving maximum CBR value and maximum dry density [25].

It has been observed that 25% of fly ash of Class-C type (CaO =18.98 %) and specimens were then cured for 7 and 28 days. It resulted in decreasing of swelling pressure by 75% after 7 days of curing and 79% after 28 days of curing at fly ash addition of 20% [26]. It has been observed that CBR increases to 20.53% from 5.64% when fly ash was 20% of expansive soil to be stabilized [27]. Here examination of fly ash effect on swelling and compressibility of highly plastic clay expansive in nature and of high plasticity clay of non-expansive nature respectively was done. The swelling pressure and swell potential, when found out at same dry unit weight of sample, it decreases about 50% and secondary consolidation coefficient and compression index of both the clays decreases by 40% at 20% content of fly ash [28].

Alkali activated fly ash stabilization: Here fly ash activated by 4M NaOH concentration achieves maximum compressive strength at curing under 90°C temperature as Compressive strength is directly related to curing temperature and NaOH concentration. Therefore fly ash activation in blended cement depends on activating material pH and fly ash to activator ratio [29].

Here researcher examined and observed that fly ash/slag cement activated by 10M NaOH achieves higher strength at curing under 25˚C temperature but it becomes lower for longer curing periods [30]. Better mechanical strength was achieved by Activated fly ash because of formation of sodium aluminosilicate gel having amorphous nature and formation of zeolite is related directly to curing period under the 85°C temperature [31].

Amorphous gel formation is observed from primary reaction of alkali activated fly ash whose Si/Al ratio depends on curing time and nature of alkaline activator [32]. Fly ash slurry was activated by different amounts of alkali and change in viscosity, compressive strength and permeability was noted down. It was found out that alkali addition enhances basic properties of fly ash and thereby maybe suitable for further applications in weak soil [33]. Investigation on stabilization of expansive soil by alkali activated fly ash was done with varying percentages of fly ash to total solids, varying ash/soil ratio and varying activator/total solids ratio. Compressive strength was also found out and compared at different percentages of fly ash and alkali activated fly ash and increase in compressive strength was noted [34].

II ALKALI ACTIVATED FLY ASH

Soil is utmost appropriate material for construction for its accessibility and economical effectiveness. Soil is used extensively and majorly in construction and in any branch of civil engineering. Its usage varies from foundation construction to pavements as it provides soundness to structure overlaying by giving appropriate strength. So bearing capacity and other properties of soil needs to be sound as well. Therefore specifically in case of expansive soil it's necessary to improve basic properties of soil. It's better to use waste products for enhancement of properties of soil and thereby utilization of harmful and waste products is achieved simultaneously with properties improvement. These by-products or waste products vary from plastics, stone quarry, and recycled combination of materials, lime, and fibre to fly ash etc. in India. This review paper inculcates alkali activated fly ash as a stabilizer for expansive soil.

Soil stabilization refers to mixing and blending of certain additives/materials with soil so as to make properties of that soil better [1]. Fly ash or flue ash is a byproduct of combustion of coal and is extracted from gases arising of thermal power plant. They are taken from high chimney and usually comprises of particles of silt size. Fly ash comprises of particulate matter of non-combustible nature including little amount of unburned carbon. Fly ash substantially consists of silica, alumina and iron and particles are of micro size. These particles easily blend and flow owing to its spherical shape for making a suitable mixture. Minerals having both crystalline and amorphous nature makes up in fly ash. Fly ash results out to be glassy and amorphous if there is brisk fall in temperature otherwise for gradual fall in temperature they become crystalline. Fly ash size varies from 0.5 to 300 microns in size.

Alkaline activation may be termed as chemical process by which alumina-silicate in powder form like fly ash get mixed with alkaline activator so as to produce paste which has a capacity of setting and then hardening within a comparatively shorter time period. It may be termed as poly-condensation process, having alumina (AlO_4) and silica (SiO_2) tetraedrics interconnect with sharing of the ions of oxygen (O). Nowadays waste materials are subjected to alkali activation and this has become vital as it allows these materials to give cheap and ecological construction material like cement. The activated fly ash by alkali is lately generating good amount of interest in reference of environmentally friendly and innovative binders with similarity or improvement in properties like that of conventional materials. Alkali activated fly ash is found very useful in stabilizing expansive soil by improving its engineering properties.

Alkali activated fly ash is a construction worthy material. Engineering properties of fly ash has improved after application of alkali to it in varying amount. Alkali activation of fly ash decreases permeability and increases compressive strength of fly ash and also gives optimum viscosity when fly ash is treated with alkali in optimum amount [33]. Investigation on stabilization of expansive soil by alkali activated fly ash was done with varying percentages of fly ash, varying ash/soil ratio, varying activator/total solids ratio. Compressive strength was also found out and compared at different percentages of fly ash and alkali activated fly ash. It has been found that compressive strength of expansive soil improves generally with addition of fly ash and more with alkali activated fly ash [34]**.** Therefore alkali activation of fly ash and then its application to expansive soil for stabilization turns out to be the good utilization practice for fly ash generated from coal thermal power plants and thereby meeting twofold purposes of stabilization and adequate utilization.

Fig 1: Fly ash

2.1 Alkali activated fly ash advantages

The latest research investigations have affirmed the accompanying:

1. It is effective in stabilizing waste, toxic and hazardous materials.
2. It is resistant to aggressive acids, fire and aggregate-alkali reaction.
3. It has improved mechanical properties and is specifically durable.
4. It stabilizes expansive soil and thereby improving its geotechnical properties.
5. It is used in concrete construction exhibiting same properties as in traditional concrete with improved properties in terms of less shrinkage and stronger bonding between steel and matrix.
6. Less curing is required to achieve same compressive strength in concrete.

2.2 Physical Properties of fly ash [35]

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

2.3 Chemical Properties of fly ash [38]

Compounds	Composition (%)
SiO_2	41.65
Al_2O_3	22.38
Fe_2O_3	15.04
MgO	4.76
CaO	4.75
K2O	5.82
Na2O	4.72

III. REVIEW OF LITERATURE

Palomo *et al.* (1999) [36]examined that fly ash activated by alkali is smooth, shiny and glassy with good conditions of workability at liquid/solid ratio being low, but achieves smaller strength at curing of 24hr period. When activated by 10M NaOH higher strength is achieved for fly ash/slag cement at curing under 25˚C temperature but it then becomes lower for longer curing periods.

Ma *et al.* (2013) [37]Lower Pore structure of fly ash activated by alkali is there with increasing curing period and it is due to increasing alkali content and silica amount, but it can be developed by extending the curing period and temperature. Also author found that water permeability of alkali activated fly ash is higher at later ages but it become lower with increasing temperature, curing time, and higher silica content at later ages.

Sarat Kumar Das and Partha Sarathi Parhi (2013)[38] This investigation was carried out on black cotton soil for its stabilization by using class F fly ash and alkali activated fly ash as stabilizers. Unconfined compressive strength tests were done on expansive soil with fly ash and with alkali activated fly ash and hence results are discussed and compared at curing intervals of 3, 7 and 28 days.

NaOH having 10M, 12.5M and 15M plus sodium silicate of 1 molarity was used as activator with fly ash as 20%, 30% and 40 %, to that of total solids. Compressive strength of expansive soil was increased after treatment with alkali activated fly ash as compared to fly ash and also least compressive strength was that of untreated expansive soil. XRD analysis for mineralogy was also done for most adequate mix. This study also discusses the suitability of alkali activated fly ash as a grouting material by examining and comparing attributes such as density, setting time and viscosity with cement grout. Also fluidity correlates well with unconfined compressive strength.

Sara Rios and António Viana da Fonseca (2014) [39] this experimentation inculcates fly ash, silty sand and an alkali solution mix. Unconfined compression test at curing period of 90 days was conducted on this mix and stiffness and strength were evaluated by strain instrumentation. Also geo-mechanical characteristic and its evolution with time were evaluated by calculations of seismic wave velocities along the curing period. This indicates material behaviour as time passes by. Comparisons of these results without application of alkali activated fly ash were made. A vital rise in stiffness and strength because of activator was determined highlighting the capacity of this methodology as a replacement of cement and bonding agent. The use of waste products like fly ash instead of cement makes this technique especially respectable for the environment, prospectively competitive economically and friendly for the sustainability of our resources. This methodology of utilizing fly ash in place of cement makes it vital as waste product utilization has been done and proving to be environment friendly, sustainable and economical method.

Prashant Hiremath *et.al (2016)* [40]This investigation was carried out on expansive soil for its stabilization by using fly ash and alkali activated fly ash as stabilizers. Varying amount of fly ash as 5%, 10%, 15%, 20%, 25% and 30% was used with respect to total solids. Sodium hydroxide having 2M concentration was used as an activator. The specific gravity, atterberg limits, standard Proctor and unconfined compressive strength tests were performed on expansive clay soil. Basic characteristics like liquid limit, plastic limit (Atterberg's limits), compressive strength and compaction were determined. The results indicated that liquid limit and plasticity decreases and plastic limit of expansive clay soil increases after addition of fly ash and alkali activated fly ash to expansive clay soil. After fly ash addition to expansive soil, a graph was plotted between optimum moisture content and maximum dry density and it shows increase in optimum moisture content and reduction in maximum dry density. Compressive strength of expansive soil was increased after treatment with alkali activated fly ash as compared to fly ash and also least compressive strength was that of untreated expansive soil with increase in curing period in general.

Sara Rios *et al*. (2016) [41]Geo-polymeric cement can replace ordinary Portland cement with advantages of lesser carbon dioxide emissions is formed when fly ash is activated by alkali. Also it improves soil and reduces landfill issues of fly ash since fly ash proves to be hazardous to human and environment. This investigation analyzes the characteristics of silty sand treated with alkali activated fly ash. Uniaxial compression test and triaxial compression test were performed from small to large strains and analysis was done, also measurements of velocities of seismic wave was done throughout the curing time period. The cyclic, static and dynamic tests show a vital rise in stiffness with curing, even after 28 days of curing time period. Non- destructive wave propagation method was used to evaluate elastic shear modulus and Poisson ratio values as rise of compression wave velocities and shear wave velocities were plotted. The secant Young modulus via mechanical tests was compared to corresponding dynamic Young modulus. Also, evolution of characteristics of stabilized soil with curing was confronted and compared to soil- cement on the basis of elastic stiffness, showing that the most important difference depends on the rate of curing.

Praveen Kumar P and kavya T M (2017) [42] The Expansive soil stabilization is of much significance nowadays and various techniques and materials have been advised for stabilization of these weak expansive soils. This experimentation presents the weak expansive soil locally available to be stabilized by fly ash activated with an alkaline compound. After determining the basic characteristics of expansive soil sample varying amount of fly ash as 10%, 20%, 30%, 40% and 50% was mixed homogeneously to expansive soil with respect to total solids. Alkaline compounds with varying concentrations as 0, 0.5, 1, 1.5 and 2 molarities were used to activate fly ash and hence to conduct tests. The specific gravity, atterberg limits, standard Proctor and unconfined compressive strength tests were performed on expansive clay soil. Investigation found out that alkali activated fly ash treated soil gives better results as compared to fly ash mix and least performance was that of untreated expansive soil. Also geotechnical attributes of expansive soil were improved after treatment with fly ash and alkali activated fly ash.

Shah and Pandya (2017) [43] Expansive soil can also be stabilized with conventional binders in the form of ordinary Portland cement but it poses serious threats to environment. Therefore it was necessary to determine alternative stabilizer which is not harmful to environment. They examined the stabilization of clayey soil locally available using sodium based alkaline activator and fly-ash. The chemical reaction between fly-ash having silica and alumina contents and alkali creates alumina-silicate crystalline chain.

Alkaline activator is made from 1 molar of sodium silicate along with 12 molal(M) concentration of NaOH and it is mixed at the a ratio of 2:1. Fly ash is kept as 10%, 15% and 20% by weight of total solid (clay + fly ash) and finding optimum moisture content (OMC) for each mixture. Samples at optimum moisture content and 3% dry part of optimum moisture content and usefulness of binder was observed using unconfined compressive strength test at curing time of 7days, 14days and 28 days and also compared with binder based on fly-ash. Hence the direct relation between alkaline activator, fly ash and the mechanical strength from the results is that if we increase the activator concentration and fly ash content for certain amount it increases the strength for the increasing curing periods. FTIR analysis was used to determine utmost effective mixture. Result shows successive improvement in soil.

Sayed saba (2018) [44] This investigation emphasis on soil stabilization of silty soil using alkali activated fly ash as silty soil is weak and not good for foundation construction and pavement subgrade. This lack in geotechnical attributes of silty soil can be improved by use of stabilizers and thereby improving its durability, volume stability and strength. Here combination of fly ash with alkali activated polymer was used to stabilize silty soil and improving its properties. Basic engineering attributes like grain size distribution, specific gravity and Atterberg's Limit of Lithomargic soil (shedi soil) were investigated according to IS recommendations. Varying amount of fly ash was added to expansive soil as 10%, 20%, 30%, 40%and 50%. Geotechnical characteristics of stabilized and unstabilized expansive soil were compared. Optimum Moisture Content and Maximum dry density were found by heavy compaction test according to IS 2720 Part 7. NaOH of 14M was used to prepare alkali activated fly ash. Unconfined compressive strength test at 0,7,14 and 28 days was performed along with California bearing ratio test and hence comparisons were done. UCS results indicated increment of compressive strength after treatment of expansive soil with alkali activated fly ash. CBR results indicated that expansive soil without alkali activated fly ash was 5.1% and CBR with varying amount of alkali activated fly ash on expansive soil increases when fly ash percentage was increased from 10% to 20% and decreases when fly ash percentage increased from 20% to 30%.

IV. CONCLUDING REMARKS

Utilisation of fly ash after alkali activation in stabilizing weak expansive soil enhances the geotechnical properties and performance of expansive soil. Also it provides with the best alternative for fly ash disposal and management by its adequate utilization otherwise fly ash proves to be catastrophic to human and environment. Studying all the investigation done by various researchers accompanying concluding remarks can be made:

i. Alkali activated fly ash utilization in stabilizing expansive soil serves twofold purposes of improving geotechnical properties of expansive soil and is environment friendly since fly ash would have been hazardous to human and environment.
ii. Alkali activated fly ash stabilizes weak expansive soil by addition to it in varying proportions to total solids at optimum moisture content.
iii. Maximum dry density and optimum moisture content increases with increasing content of alkali activated fly ash in general not always.
iv. As amount of fly ash is increased with other quantities being constant then it was found that liquid limit and plasticity index decreases but plastic limit increases.
v. As amount of fly ash and alkaline compound in expansive soil matrix increases, unconfined compressive strength increases usually (not always) with increasing curing period.
vi. Alkali activated fly ash treated expansive soil gives better compressive strength in comparison to fly ash treated expansive soil and also much better compressive strength then untreated expansive soil where untreated expansive soil has least compressive strength as tested by unconfined compressive strength test.
vii. The cyclic, static and dynamic tests show a vital rise in stiffness with curing, even after 28 days of curing time period when alkali activated fly ash was used to stabilize soil as a cementing material.
viii. Stiffness rise is gradual in alkali activated fly ash treated soil whereas it is rapid in cement treated soil and stiffness value doubles itself in alkali activated fly ash treated soil from 28 to 90 days.
ix. Application of alkali activated fly ash increases the California bearing ratio value of weak expansive soil and thereby it allows reduction of pavement thickness considerably.

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