Subgrade Stabilisation using Alkali Activated Materials: A Review

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ABSTRACT

The performance of pavement construction is determined by the behaviour of the subgrade soil and its bearing capacity. Expansive subgrade soil is problematic to pavement and other types of construction activities because of its high swelling and shrinkage, necessitating stability with various materials. Soil stabilization using different chemicals has been used to enhance soil qualities to make them suitable for the desired engineering purpose. Expansive subgrade can be stabilized using alkali-activated slag, fly ash and other industry by-products and this also helps in solving disposal difficulties. A review of the literatures on this issue demonstrates the significance of studies on alkali activated materials to stabilize soil. It also demonstrates changes in the characteristics of soil following stabilization with alkali activated materials and this method is cost effective. It also contains several chemicals that, in various combinations, reduce the expansive tendency of soil. Based on the available literature, this paper examines the behaviour of soil following stabilization with alkali activated materials.

Keywords: Soil stabilization, Alkali activation, Expansive soil

1 Introduction

Because of the undesirable properties of clayey soils, like poor strength in shear and high compressibility, civil engineers need to use a good stabilization technique to get the needed soil strength. Chemical stabilization is the most popular and traditional way for improving soft soils, with lime and cement being used as common soil binders. Yearly rate of production of cement is expanding at an unprecedented rate. This amount of production has a number of negative environmental consequences. Producing 1 tonne of cement and 1 tonne of lime emits nearly 1 tonne of carbon dioxide. Tonnes of natural resources like clay and limestones are being used for the production of cement. Aside from environmental concerns, Portland cement has several disadvantages, including decrease in strength caused by loss of water and excessive shrinkage that is plastic. The aforementioned disadvantages have prompted researchers to study the use of geopolymers in stabilization works. Geopolymers are created by the chemical interaction of a precursor that is rich in alumina and silicate with an activator based on sodium or potassium. Sodium hydroxide, sodium silicate, or a combination of the two are the most often used activators. Sodium silicate can be obtained from soap or textile industries at a very cheaper price and sodium hydroxide when purchased in the form of pellets, also has lesser price.

Duxson *et al.* [1] studied the alkaline activation reaction mechanism in geopolymers. The geopolymerization process consists of two major steps: the first is the dissociation of the precursor in whichever activator that is being used, and the second step is the poly-condensation achieved by diffusion of silica and alumina oxide, followed by its interaction with the activator used, resulting in a gel formation, and this gel binds the soil together. The amount of alkali needed is way lesser than the amount of cement needed. As a result, carbon dioxide emissions are reduced.

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2 Aluminosilicate Precursors

Precursors that are rich in alumina and silica can be added to react with alkali in different combinations with other precursors or as a single precursor. Studies have shown better strength increase for soil treated with different combination of precursors when compared to single precursor addition. Glass fibers or polypropylene fibers can also be added to further increase the soil strength. Different alkali like sodium hydroxide, sodium silicate, potassium hydroxide etc. can also be used. In this review article, such studies are reviewed and are presented below.

2.1 Combination of precursors

2.1.1 Volcanic ash and slag

Miraki *et al.* [2] did scanning electron microscopy analysis and noticed the development of N-A-S-H gel in the correct proportion of volcanic ash and slag, accounting for increase in strength with the addition of slag. Replacing the ash by slag resulted in lesser values for carbon index, indicating that samples containing more proportion of slag and lesser proportion of ash are more sustainable.

2.1.2 Fly ash and slag

Praveen *et al.* [3] conducted a study to stabilize lithomargic clay using different proportions of fly ash and slag. According to experimental results, there is 30-40% rise in unconfined compressive strength for stabilized soil. Alkali activated samples passed all drying-wetting cycles within the limit of 14% weight loss, indicating that the soil has high durability and can be used in the base course of pavements. Above the base course, a stress absorbing membrane can be given to prevent the crack propagation.

2.1.3 Slag and paper sludge ash

Mavroulidou *et al.* [4] investigated the effect of potassium hydroxide and a range of alkali salts in stabilizing clay and silty soil. The studied alkali activated cement mixes improved unconfined compressive strength and stiffness while decreasing swelling tendency. Alkali activated cement with potassium hydroxide and calcium hydroxide had the highest strengths and stiffness. Paper sludge ash shows strength increase gains when added to silty soil and had better performance than potassium hydroxide. Paper sludge ash added solid demonstrated good performance in wetting and drying cycles.

2.1.4 Calcium carbide residue and fly ash

Phetchuay *et al.* [5] studied the development of strength in clayey soil with the addition of fly ash and calcium carbide residue. A higher fly ash content necessitates a higher amount of sodium hydroxide for the purpose of leaching. Thus, the ratio of sodium silicate/sodium hydroxide decreases with increase in fly ash. This rise in liquid/fly ash ratio initially enhances the unconfined compressive strength, but if liquid/fly ash exceeds the optimal value, the strength falls because of precipitation that occurs at an early stage even before the process of poly-condensation.

2.1.5 Slag, fly ash and ordinary Portland cement

Chen *et al.* [6] worked on soft clayey soil stabilization by adding fly ash, lime and cement with sodium based alkali. Unconfined compressive strength of stabilized samples were found to increase considerably with curing time and alkali activated binder content, but the unconfined compressive strength of untreated specimens does not increase. The presence of calcium silica hydrate paste was advantageous to form a closely packed soil matrix due to which there was an improvement in the soil’s unconfined compressive strength.

2.1.6 Slag and fly ash (added with construction and demolition waste)

Abhilash *et al.* [7] carried out the research in four types of prepared clayey soil samples. Cement, ground granulated blast furnace slag and construction and demolition waste were mixed with soil in the first type. In the second type, cement was replaced with lime. In the third and fourth mixes, slag and fly ash were replaced by cement and lime respectively. Sodium hydroxide was also used in the third and fourth mix for the alkali activation to take place. In terms of achieved strength, lime stabilized mix was found to be the least effective. Strength was lesser than cement stabilized mix. In alkali activated samples, fly ash stabilized samples were found to be more effective than ground granulated blast furnace slag stabilized samples.

2.2 Addition of fibers

2.2.1 Fly ash, slag and polypropylene fibers/glass fibers

Mazhar and GuhaRay [8] added slag and fly ash together in Black Cotton Soil (BCS). Alkali activators used are sodium hydroxide and sodium silicate. Polypropylene fibers and glass fibers were also added separately in the samples. As the fiber content increased, the unconfined compression strength and indirect tensile strength of alkali activated binder treated black cotton soil increased by approximately 65% and 48%, respectively. Furthermore, the shear strength of fiber and slag added soil is higher than that of fly ash-fiber in both fiber-alkali activated binder mixtures. The strength bearing of treated black cotton soil in terms of California bearing ratio improved significantly due to cementitious bonds and better friction around clay particles and added fiber.

Syed and A. GuhaRay [9] analyzed micrographs of fiber-alkali activated binder mixed black cotton soil and it shows distinct surface morphology that can operate as a spatial thread-bridge network, improving particle interlocking density around fiber surfaces. The suggested equations for both unconfined compression strength, indirect tensile strength, and California bearing ratio findings are well correlated with experimental data, with a margin of error of less than 10%.

2.2.2 Fly ash and coir fiber

Murmu *et al.* [10] studied the effectiveness of Class-C fly ash treated clayey soil that is reinforced with treated and untreated fibers of coir by using potassium hydroxide. The Class-C fly ash added with treated fiber combination has greatest CBR values. According to the atomic force microscopy data, higher UCS with treated fiber is mostly owing to its great packing efficiency in filling pores. It provides compelling evidence that Class-C fly ash added with fibers that are treated improves strength of soil. Peak strength of the treated fiber reinforced stabilized soil has increased significantly. The treated fiber added mixture has the greatest unconfined compressive strength value, which was 35% higher than a comparable mixture without fibers.

2.2.3 Fly ash, slag and coir fibers/hemp fibers

Syed and GuhaRay [9] studied the effectiveness of slag and fly ash in clayey soils like black cotton soil. Coir fibers and hemp fibers were added separately in the samples. This addition improved California bearing ratio and the value of resilient modulus was also increased. A regression model to predict California bearing ratio of treated hemp fiber as well as treated coir fiber reinforced alkali activated binder treated black cotton soil was created.

2.2.4 Slag as precursor

Thomas *et al.* [11] examined the maximum dry density and optimum moisture content findings on soil samples stabilized with alkali-activated slag, enzyme, and cement, respectively. The cohesiveness of the treated soil rose substantially. The optimal dosage is 20% slag with 1 Molar sodium hydroxide solution,

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12% ordinary Portland cement. The unconfined compressive strength and shear strength values of the alkali-activated slag stabilized soil outperformed those of the ordinary Portland cement-stabilized soil.

Lang *et al.* [12] studied the development of strength in clay soil with dredged sludge stabilized with ground granulated blast furnace slag that has been alkali-activated. When optimal unconfined compressive strength was compared under the same activator dose, composite activators were shown to be more efficient than single activators in activating ground granulated blast furnace slag to acquire greater stabilized dredged sludge strength. It is suggested that a 20% sodium hydroxide/sodium silicate-ground granulated blast furnace slag binder can be used. The experimentally derived linear empirical equations were used to estimate the 60 and 90-day unconfined compressive strength of alkali-activated slag stabilized dredged sludge by the known 28-day unconfined compressive strength.

Du *et al.* [13] added slag and it was activated with magnesium oxide, to stabilize kaolin clay. When subjected to the drying-wetting cycle, the slag stabilized kaolin clay showed greater dry density while exhibiting reduced loss in mass than the cement stabilized samples. The pH of the slag stabilized clay and cement stabilized samples fell as the drying-wetting cycle increased.

2.3 Fly ash as precursor

Rios *et al.* [14] investigated the rise in strength and stiffness over time, following a logarithmic law considerably beyond the normal 28 days found in materials treated with binders, the short-term strength (7 days) remains beyond 1 MPa. Early immersion may impact the curing process, actively lowering final strength, unless balanced by high temperatures that accelerate the curing process.

Phetchuay *et al.* [5] stabilized black cotton soil by separately adding fly ash of particle size 75 microns and 425 microns, with and without using alkali. The geopolymer stabilized black cotton soil has significantly increased unconfined compressive strength. Both the samples are equally effective in reducing swelling and shrinkage. The UCS value of the geopolymer stabilized BCS was found to be more than the minimum strength requirement stipulated in IRC 37 (2012) for stabilized sub-base.

Syed and GuhaRay [9] also examined the suitability of fly ash to stabilize clay soil. Fly ash was added to stabilize black cotton soil by using the conventional activators. Plasticity and the swelling index are significantly reduced in the treated BCS sample. Reduction in volumetric instability (swell/shrink) by encasing the particle in a thin cementitious gel surfaces. The California bearing ratio value was greatly improved with black cotton soil treatment using alkali activated binder.

3 Results and Discussions

The use of alkali activated materials raises the California bearing ratio value of weak expansive soil, allowing for significant reductions in pavement thickness. Alkali activated materials treated expansive soil has higher compressive strength than fly ash, cement and slag treated expansive soil and untreated expansive soil. Unconfined compressive strength typically increases with increasing curing duration. Alkali activated samples have lower mass loss and passes all the cycles in durability test. Therefore, durability of the alkali activated samples are high. Alkali activated samples have lower carbon footprints and low swelling. When precursors are added in combination, the strength was found to be greater than alkali activation using single precursor. Addition of fibers further improved the engineering properties.

4 Conclusions

The use of aluminosilicate materials in alkali activation in stabilizing weak expansive soil improves its geotechnical characteristics and performance. Furthermore, it gives the best available option for fly ash and slag management through proper application, otherwise, it proves to be disastrous to humans and the environment. After reviewing all of the studies conducted by various researchers, it was found that alkali activated binders in expansive soil stabilization serves two purposes. It improves the geotechnical characteristics of soil and is environmentally benign.

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