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Stabilization of Soil using Geopolymer: A Review

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Abstract - *In order to confront the problems associated with clay for construction, some adequate ground improvement technique is essential. The alkaline solutions such as sodium hydroxide and sodium silicate along with class F fly ash, Ground Granulated Blast Furnace Slag (GGBS)and metakaolin as additives are used to improve the properties of clay. Flyash greatly modifies the strength properties of soft soils and it contain silica and aluminium materials (pozzolans) as well as a certain amount of lime, which chemically binds to soft soil and forms cement compounds. Metakaolin is a highly reactive pozzolana formed by the calcinations of kaolinite (China clay). In many civil engineering constructions, soft and weak soils are often stabilized with Ordinary Portland cement (OPC) and lime. The production processes of traditional stabilizers are energy intensive and emit a large quantity of CO_2. Geopolymer offer a better alternative to OPC, with its high strength, low cost, low energy consumption and CO_2 emissions during synthesis. Due to the major environmental impacts involved in the manufacturing of OPC, the use of industrial by-products has been encouraged. The reason for the increase in compressive strength due to GGBS can be caused by the high GGBS calcium content. These polymers are cheaper and, compared to many chemical alternatives, are more effective and significantly less damaging to the environment. The combined effect of fly ash and GGBS can enhance the engineering performance of the soil.*

Key Words*: *Alkali activation, Geopolymer, fly ash, GGBS, clay, stabilization.

1. INTRODUCTION

Soft soil possesses low strength and undergoes excessive volume changes, making its use in the construction activities very difficult. The properties of the soft soils may be altered in many ways viz, mechanical, thermal, chemical and other means. Modification of soft soil by chemical admixtures is a common stabilization method for such soils. Fly ash contains siliceous and aluminous materials (pozzolans) and also certain amount of lime. When mixed with soft soil, it reacts chemically and forms cementitious compounds. The presence of free lime and inert particles in fly ash suggests that it can be used in expansive soil stabilisation. Metakaolin is an amorphous aluminosilicate that is a highly reactive natural pozzolan produced by the calcination and dehydroxilation of kaolinitic clay at temperatures between 500°C and 900°C. Clay needs to be improved before it can be used in embankments, canal, roadway, dams, waste landfills etc. Clay soils feel very sticky and rolls like plasticine when wet. They can hold more total water than most other soil types and, although only about half of this is available to plants, crops seldom suffer from drought. Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag, (a by-product of iron and steel-making) from a blast furnace in water or steam, to obtain a glassy, granular product that is then dried and ground into a fine powder. Ground-granulated blast furnace slag is strongly cemented and high in CSH (calcium silicate hydrate), which is a compound that improves strength. Geopolymer, an industrial by-product is a novel green cementing agent, has been investigated in recent years as an alternative soil stabilizer to ordinary Portland cement that emits greenhouse gases in its production. There are a lot of significant advantages to the Polymer method of stabilisation over physical and chemical methods. Compared to many chemical alternatives, these polymers are cheaper, better efficient and much less harmful to the environment. In recent years, stabilisation methods have been introduced using several stabilising agents based on polymers. The addition of Potassium Hydroxide Geopolymer (PHG) and Sodium Hydroxide Geopolymer (SHG) increases the UCS strength and young's modulus. There is very little to no problem as long as this soil is confined and dry, but when exposed to cutting or when it comes into contact with water, it significantly loses its strength.

2. GEOPOLYMER

Currently, almost scientists have been drawn and focused on developing eco - friendly products such as geopolymer. Geopolymers, first named and developed by Davidovits in the late 1970s, are amorphous three-dimensional alumina silicate binder materials. They are a chain structure formed of aluminium (Al) and silicon (Si) ions on the back bone and are a component of the inorganic polymer family. Basically, all materials are specific sources of geopolymer production if they contain more amorphous silica (SiO_2) and alumina (Al_2O_3). Alumina-silicate based materials rich in silicon (Si) and aluminium (Al) were needed for the production of the geopolymer, where alkaline solutions were enabled.

Geopolymer is an inorganic substance of alumina-silicate formed by polycondensation of tetrahedral silica (SiO) and alumina (AlO), which are alternately connected by sharing all the oxygen atoms. Geopolymerization is a reaction between silica-rich and alumina-rich solids with a high alkaline solution to form amorphous to semi-crystalline alumina-silicate polymers, which exhibit excellent physical and chemical properties. Geopolymerization can be simplified as two main steps that interact with each other along the reaction. For the first step, amorphous alumina-silicate materials are first dissolved to form reactive silica and alumina by alkali hydroxide solution and/or alkaline silicate solution, and the second step is the dissolved species then polycondensed into amorphous or semi-crystalline oligomers.

3. EFFECT OF ALKALI ACTIVATED GGBS

Chegenizadeh et.al (2016) investigated the effect of the partial substitution of lime with GGBFS on the strength and mechanical properties of lime stabilised clay by conducting unconfined compressive strength (UCS). The application of GGBFS led to a decrease in the cracks created by shrinkage by increasing the soil's tensile strength. Compared to lime combined with clay mixtures, the addition of GGBFS to a certain volume of lime significantly enhances the unconfined compressive strength of the soil. The role of GGBFS in accelerating the production of cemented crystalline products in lime stabilised clay samples such as Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH) could be attributed to this trend. The calcium ions formed by GGBFS and lime are distributed among the clay flaky particles, encouraging the formation of CSH and CAH.

Yi Y et.al (2015) used quicklime and hydrated lime, to activate ground granulated blast furnace slag (GGBS), a byproduct of the steel industry for the stabilisation of marine soft clay. This study reported that replacing PC with lime-GGBS for soft clay stabilisation could be expected to provide both environmental and economic benefits. The quick lime activated GGBS stabilised clay had a slightly greater UCS of 7 days and 28 days than the corresponding GGBS stabilised clay activated by hydrated lime, while the former had a slightly lower UCS of 90 days. The 90-day UCS was 1.7 times that of the PC stabilised clay of the optimum hydrated lime-activated GGBS stabilised clay.

Salimi M et.al (2020) conducted the chemical stabilisation of soft clay which is based on industrial waste such as Granulated Blast Furnace Slag (GBFS) and Basic Oxygen Furnace Slag (BOFS) activated with calcium oxide (CaO) and medium reactive magnesia (MgO). This environmentally friendly approach will remove the hazards associated with improper disposal of waste and reduce the emissions of greenhouse gases produced by the production of cement. Alkaline solutions act as activators in this section, and CaO and MgO act as promoters of geopolymers based on clay-slag. The degree of geopolymerization of the slag-clay-based geopolymer system is generally poor. Therefore, the use of such promoters will increase the mortar 's compressive strength. The UCS strength of treated samples depends heavily on the kind of promoter and the Na_2SiO_3: NaOH ratio.

Xu B et.al (2019) attempts to use LS (ladle slag) in order to enable ground granulated blast furnace slag (GGBS) for stabilisation of soft clay. The basic slag of the ladle furnace is a by-product of the method of processing steel. For different time periods, LS-GGBS-stabilized clays with different binder contents and LS: GGBS ratios were cured and then subjected to the compressive strength (UCS) test. The findings showed that for soft clay stabilisation applications (e.g. deep mixing for soft ground improvement), the LS-GGBS blend could theoretically replace OPC, which could minimise the cost of both soft clay stabilisation and landfilling LS.

Alam S et.al (2019) discussed the strength and durability characteristics of stabilised red mud using alkali (Na_2SiO_3) activated granulated blast furnace slag (GGBS) and its microstructural properties for potential use as a geo-material. One of the major issue associated with geo-materials is the loss of strength and weathering due to adverse environment exposure. The effect of 0.25, 0.5 and 1.0 M(M) sodium silicate alkaline activation of GGBS on UCS is being studied. The UCS was found to be 564.08 kPa and 441.45 kPa respectively for the NALCO red mud (NRM) and HINDALCO red mud (HRM). The maximum UCS when activated with 1.0 M Na_2SiO_3 is given as the NRM / HRM stabilised with any percentage of GGBS.

4. METAKAOLIN BASED GEOPOLYMER

Zhang M et.al (2013) analyzed in order to investigate the feasibility of geopolymer in stabilising soils, a lean clay was stabilised with metakaolin-based geopolymer at different concentrations (ranging from 3 to 15 wt. percent of unstabilized soil at its optimum water content). This study showed that metakaolin-based geopolymer can be an efficient soil stabiliser for clay soils. It is worth performing further studies on the long-term performance of geopolymer stabilised soils, the use of geopolymers synthesised from industrial waste, and the financial and environmental costs of geopolymer use in soil stabilisation. In developing high early strength, geopolymer stabilised soils require less time than OPC. Geopolymer provides a promising alternative to OPC, with its high strength, low cost, low energy consumption and CO_2 emissions during synthesis.

Shengnian Wang et.al (2020) analyzed the unconfined compression strength test of the clay soil improved by metakaolin-based geopolymer binder. The material ratio of the metakaolin-based geopolymer binder was analyzed, the optimal mixing ratio of the metakaolin based geopolymer binder in the clay soil was investigated, and the impacts of metakaolin and alkali activator on the mechanical properties of the geopolymer-improved soil were discussed. Experimental results indicate that the unconfined compression strength of the geopolymer-improved soil increases first and then decreases with the contents of metakaolin and alkali-activator (a mixture of unslaked lime (CaO) and sodium bicarbonate ($NaHCO_3$) with the mass ratio of 1:1). The failure of the geopolymer-improved soil with the increasing contents of metakaolin and alkali-activator shows that there is a tendency from plastic shear failure to brittle split failure. The results of this study can provide a parameter basis for the application and popularization of the soil improved by metakaolin-based geopolymer binder in engineering.

6. EFFECT OF MOLARITY IN GEOPOLYMER

Rao Mallikarjuna G et.al (2015) investigated the normal consistency, final setting time and compressive strength of geopolymer, which are routine tests normally performed for cement, to analyse the use of geopolymer as a substitute for cement. In these experiments, the cement is replaced by geopolymer materials and the water is replaced with alkaline activator solution. The geopolymer source material (fly ash and GGBS) and alkaline activator consisting of sodium meta silicate and sodium hydroxide of different molarities (8, 12, 16 M) are the parameters considered in this investigation. The ratio considered in this study for sodium meta silicate to sodium hydroxide is 2.5. The ratio of the alkaline liquid to the binder is set at 0.45. The test results showed that fly ash and GGBS combinations result in reduced final setting time and increased compressive strength. A compressive strength of 79MPa was exhibited by the complete replacement of fly ash by GGBS. This implies that if GGB Sand fly ash together is used as a source material, geopolymer can achieve strength even under outdoor curing. The explanation for the increase in compressive strength due to GGBS can be attributed to the higher GGBS calcium content.

Amulya S et.al (2018) analyzed the stabilization of lithomargic clay with alkali activated fly ash and GGBS. Together with class F fly ash and Ground Granulated Blast Furnace Slag (GGBS) as additives to boost the properties of lithomargic clay, the effectiveness of alkaline solutions such as sodium hydroxide and sodium silicate is studied. By replacing the soil with 20 percent, 30 percent, and 40 percent of GGBS and fly ash, the various mixes are prepared. The maximum dry density (MDD) obtained from the soil was replaced with 40% GGBS and replaced with 30% fly ash for the soil. For the varying sodium oxide dose at 2, 3 and 4 percent, an activator module of 1.25 is kept constant. The alkali-activated soil's Unconfined Compressive Strength (UCS) cured for 3, 7 and 28 days is calculated and compared with the soil's UCS replaced by fly ash and GGBS at both standard and modified proctor densities.

Bakri A M et.al (2012) analyzed the geopolymer production using FA and alkaline activators. As alkaline activators, sodium hydroxide and sodium silicate solution were used. The results show that the geopolymer paste produces the highest compressive strength with a combination of a Na_2SiO_3 / NaOH ratio of 2.5 and a 12 M NaOH concentration. The Na_2SiO_3 / NaOH ratio is one of the factors that affects the geopolymer 's compressive strength. The NaOH solution concentrations that can be used are in the 8 to 16 M range. In this research, six different Na_2SiO_3/ NaOH ratios (0.5,1.0,1.5,2.0,2.5, and 3.0) were used. At a Na_2SiO_3 / NaOH ratio of 2.5, the maximum compressive strength of 57.00 Mpa was observed. The highest molarity of NaOH does not necessarily produce the highest strength of compression. As the FA amount and concentration of the activator solution increases, compressive strength increases. This is due to a rise in sodium oxide content.

7. CONCLUSION

A novel green cementing agent, Geopolymer, an industrial by-product, has been investigated in recent years as an alternative soil stabiliser to ordinary Portland cement that emits greenhouse gases during its processing. There are a range of important benefits to the Polymer method of stabilisation over physical and chemical methods. Compared to many chemical alternatives, these polymers are cheaper, more effective and less environmentally harmful. The addition of Potassium Hydroxide Geopolymer (PHG) and Sodium Hydroxide Geopolymer (SHG) increases the UCS value and young's modulus. There is very little to no problem as long as this soil is confined and dry, but when exposed to cutting or when it comes into contact with water, it dramatically loses its strength. The mechanical and compressibility characteristics of soil stabilised with geopolymer based on fly ash and GGBS are stronger. Geopolymer paste with a combination of an Na_2SiO_3 / NaOH ratio of 2.5 and with an alkali binder ratio of 0.45 produces the highest compressive strength and properties of geopolymer changes as NaOH concentration varies. It is essential to investigate the compressive strength of geopolymer of different molarities. The effectiveness of geopolymer on soil stabilization can be understood if further studies are done.

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