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A review on effect of soil stabilization using alkali activated geopolymer.

Una revisión sobre el efecto de la estabilización del suelo utilizando geopolímero activado por álcali.

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ABSTRACT

In order to confront the issues related to clay for construction, some adequate ground improvement technique is important. To enhance the properties of clay, alkaline solutions such as sodium hydroxide and sodium silicate are used along with Class F fly ash, Ground Granulated Blast Furnace Slag (GGBS) and metakaolin as additives. Flyash greatly modifies the strength properties of soft soils and it contain silica and aluminium materials (pozzolans) also as a particular 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 an outsized 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 economic and, compared to many chemical alternatives, are more effective and significantly less damaging to the environment. The combined impact of fly ash, GGBS and metakaolin will boost the soil's engineering efficiency.The alkali activation of waste materials has become an important area of research in many laboratories because it is possible to use these materials to synthesize

inexpensive and ecologically sound cement like construction materials.The activator solution is also very influential in the polymerization process and it's also one of the factors that determine the compressive strength.
Keywords—Alkali activation, Geopolymer, fly ash, GGBS, clay, stabilization.

RESUMEN

Para afrontar los problemas relacionados con la arcilla para la construcción, es importante contar con una técnica adecuada de mejora del suelo. Para mejorar las propiedades de la arcilla, se utilizan soluciones alcalinas como hidróxido de sodio y silicato de sodio junto con cenizas volantes de Clase F, escoria de alto horno granulada molida (GGBS) y metacaolín como aditivos. Flyash modifica en gran medida las propiedades de resistencia de los suelos blandos y contiene materiales de sílice y aluminio (puzolanas) también como una cantidad particular de cal, que se une químicamente al suelo blando y forma compuestos de cemento. El metacaolín es una puzolana altamente reactiva formada por las calcinaciones de caolinita (arcilla de China). En muchas construcciones de ingeniería civil, los suelos blandos y débiles a menudo se estabilizan con cemento Portland ordinario (OPC) y cal. Los procesos de producción de estabilizadores tradicionales consumen mucha energía y emiten una cantidad descomunal de CO2. Los geopolímeros ofrecen una mejor alternativa al OPC, con su alta resistencia, bajo costo, bajo consumo de energía y emisiones de CO2 durante la síntesis. Debido a los importantes impactos ambientales que conlleva la fabricación de OPC, se ha fomentado el uso de subproductos industriales. La razón del aumento en la resistencia a la compresión debido a GGBS puede ser causada por el alto contenido de calcio de GGBS. Estos polímeros son económicos y, en comparación con muchas alternativas químicas, son más efectivos y significativamente menos dañinos para el medio ambiente. El impacto combinado de cenizas volantes, GGBS y metacaolín aumentará la eficiencia de la ingeniería del suelo.La activación alcalina de materiales de desecho se ha convertido en un área importante de investigación en muchos laboratorios porque es posible utilizar estos materiales para sintetizar cemento económico y ecológicamente sólido como la construcción. La solución de activador también es muy influyente en el proceso de polimerización y también es uno de los factores que determinan la resistencia a la compresión.
Palabras clave: activación de álcalis, geopolímero, cenizas volantes, GGBS, arcilla, estabilización.

INTRODUCTION

Soft soil possesses low strength and undergoes excessive volume changes, making its use within the construction activities very difficult. The properties of the soft soils may also be altered by mechanical, thermal, chemical and other means in certain aspects.Expansive soil is one of the most devastation types of soil damagingroads, building, and pipe line each year. Various efforts are being done to stabilize the soil and mitigate the damage due to it. Utilization of industrial waste as low CO_2 cement is one of the sustainable method for industrial growth (P S Parhi, L Garanayak, Mahasakti, &Sarat Kumar Das, 2018). 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 specific amount of lime. It reacts chemically when mixed with soft soil and forms cement compounds.The presence of free lime and inert particles in fly ash suggests that it are often utilized in expansive soil stabilisation.Metakaolin is an amorphous alumino silicate, a highly reactive natural pozzolan formed at temperatures between 500 ° C and 900 ° C by the calcination and dehydroxylation of kaolinitic clay.Clay needs to be improved before it can be used in embankments, canal, roadway, dams, waste landfills etc.Clay soils feel very adhesive and when wet, they roll like plasticine.They can retain more total water than most other forms of soil, and crops seldom suffer from drought, but only about half of this is available to plants.Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained from a blast furnace in water or steam by quenching molten iron slag (a by-product of iron and steel making) to obtain a glassy, granularproduct which 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. In recent years, the novel green cementing agent Geopolymer, an industrial by-product, has been investigated as an alternative soil stabiliser to ordinary Portland cement, which during its processing emitsgreenhouse gases. 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 cost effective, better efficient and much less harmful to the environment. In recent years, stabilisation methods have been introduced using several stabilising agents based on polymers. Potassium Hydroxide Geopolymer (PHG) and Sodium Hydroxide Geopolymer (SHG) are added to increase the strength of the UCS 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.

GEOPOLYMER

Nearly scientists have currently been drawn and focused on the development of 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 a high alkaline solution of silica-rich and alumina-rich solids to form amorphous to semi-crystalline alumina-silicate polymers exhibiting 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.

GGBS BASED GEOPOLYMER

Alkali activation of fly ash and ground-granulated blast-furnace slag (GGBS) is a sustainable technology that promotes recycling of industrial by-products in the form of geopolymer composites.The effect of partial lime substitution with GGBFS on the strength and mechanical properties of lime stabilised clay was investigatedby conducting unconfined compressive strength (UCS).The different percentage of GGBFS to a certain percentage of lime (2%) significantly improved the compressive strength. The application of GGBFS led to a decrease in the cracks created by shrinkage by increasing the soil's tensile strength.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. For soil stabilization, the most commonly used GGBS activator is, however, lime [CaO or $Ca(OH)_2$] (Keramatikerman, M., Chegenizadeh, A., & Nikraz, H, 2016).

To reduce the use of PC in soft-clay stabilization this study investigated the stabilization efficacy of alkali-activated GGBS for a marine soft clay compared with that of PC (control).Quicklime and hydrated lime are used in order to enable ground granulated blast furnace slag (GGBS), a by-product of the steel industry for stabilising marine soft clay. It could be expected that replacing PC with lime-GGBS for soft clay stabilisation would provide 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 hydrated lime activated GGBS stabilised clay, 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's optimum hydrated lime-activated GGBS stabilised clay.Hydrated lime-activated GGBS achieved slightly higher 90-day UCS in stabilized clay than quicklime-activated GGBS (Yaolin Yi, Cheng Li,& Songyu Liu,2015).

The chemical stabilisation of soft clay based on industrial waste such as Granulated Blast Furnace Slag (GBFS) and Basic Oxygen Furnace Slag (BOFS) was carried outwith calcium oxide (CaO) activated 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 addition of stabilizers, up to 20% provides a minor effect on UCS of clay sample.The UCS value of these samples at the content of 20% after 90 days of curing attains 4 and 4.7 Mpa.The degree of geopolymerization of the slag-clay-based geopolymer system is generally poor. One of the major issue associated with geo-materials is the loss of strength and weathering due to adverse environment exposure (Salimi, M, & Ghorbani, A, 2020).

The strength and durability features 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 were examined.The impact of GGBS activation of 0.25, 0.5 and 1.0 M(M) sodium silicate alkaline on UCS is being studied.The addition of 5, 15 and 25% GGBS in NRM increases the UCS by 26.52, 66.42 and82.99% after 3 days curing period, while the UCS value increasesby 87.60, 172.76 and 290.63% after the curing period of 28 days. However, the increase in UCS value afteraddition of 5, 15 and 25% GGBS in HRM was observed as 1.20,64.90, and 91.59% after 3 days curing period, while after 28 days curingperiod, an increase of 143.72, 179.67, and 241.45% of UCSvalue is observed.The activated NALCO red mud (NRM)-25% GGBS mix shows the maximum strength of 11.21 MPa, which is 35.12% higher than that of activated HINDALCO (HRM)-25% GGBS mix (8.30 MPa). As the NRM / HRM stabilised with any percentage of GGBS, the maximum UCS was obtained when activated with 1.0 M Na_2SiO_3 is given (Alam, S., Kumar Das, S., & Hanumantha Rao, 2019).

The basic slag of the ladle furnace is a by-product of the method of processing steel. Here, LS (ladle slag) is used in order to enable ground granulated blast furnace slag (GGBS) for stabilisation of soft clay. 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 LS:GGBS ratio of 2:8-5:5 could achieve higher UCS compared to corresponding OPC stabilized clay. 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 (Xu, B, & Yi, Y,2019).

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 alkali-activator. 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 (Shengnian Wang, Xue Q, Zhu Y, Li G., Wu Z.& Zhao, K ,2020).

Lean clay with metakaolin-based geopolymer at different concentrations was stabilised to investigate the feasibility of geopolymer in stabilising soils (ranging from 3 to 15 wt. percent of unstabilized soil at its optimum water content).Further research on the long-term performanceof geopolymer-stabilized soils, the use of geopolymerssynthesized from industrial waste, and the economic and environmental costs of the use of geopolymers in soil stabilisation should be carried out.The UCS values of metakaolin based geopolymer[MKG]stabilized soils are higher than the soil, and higher than 5% PC stabilized soil when MKG concentration is higher than 11%. In developing high early strength, geopolymerstabilised soils require less time than OPC. Geopolymer provides apromising alternative to OPC, with its high strength, low cost, low energy consumption and CO_2 emissions during synthesis(Zhang M., Guo H., El-Korchi, T., Zhang G., & Tao M,2013).

EFFECT OFMOLARITY OF ALKALI ACTIVATOR

Geopolymerisation is a process that can transform alumina and silica rich waste materials into valuable binding materials, having excellent mechanical properties. The use of industrial by-product such as FA, silica fume (SF), ground granulated blast furnace slag (GGBS), metakaolin, bottom ash, and quarry fines, in the development of sustainable materials has substantially reduced pollution.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 can be studied. By replacing the soil with 20 percent, 30 percent, and 40 percent of GGBS and fly ash, the various mixes are prepared. There is 30–40%increase in UCS and CBR of more than 100% for stabilized soil. The maximum strength of 13873 kPa is obtained when the soil is replaced with 40% GGBS and adding 2% alkali solution.The alkali solution treated soil with either fly ash or GGBS is passing all 12 cycles of wetting and drying within the limit of 14% weight loss, hence the stabilized soil can be laid as a base course in case of both low and high-volume roads(Amulya, S, A. U. Ravi Shankar, & Praveen, M,2018).

The normal consistency, final setting time and compressive strength of geopolymer, which are routine tests normally performed for cement, are investigated 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. The complete replacement of fly ash by GGBSS showed a compressive strength of 79MPa.The reason for increase in compressive strength due to GGBS can be attributed to higher calcium content present in GGBS (RaoMallikarjuna G& Rao TD, 2015).

In terms of the ratio of Na_2/SiO_2, various combinations of sodium hydroxide and sodium silicate were used. With various percentages of Class F fly ash, the activator to ash ratios (liquid to solid mass ratio) were also varied. Fly ash is activated with sodium hydroxide concentrations of 10, 12.5 and 15 molal, along with 1 molar sodium silicate solution. The different percentages of fly ash (20, 30 and 40 percent) are used relative to the total solids of the expansive soil. The maximum strength obtained in this case was corresponding to activator/ash ratio of 0.3 to 0.6, and the maximum strength was gained by the samples corresponding to higher amount of fly ash content.In the activated fly ash and curing phase, the unconfined compressive strength of the soil varies with chemical concentration (P S Parhi, L Garanayak, Mahasakti, & Sarat Kumar Das, 2018).

The Na_2SiO_3 / NaOH ratio is one of the factors that affects the geopolymers compressive strength. The Na_2SiO_3/NaOH ratio of 2.5 contributed to the high compressive strength of 57.00 Mpa. The FA based geopolymer with 12 M NaOH showed excellent result, including a high compressive strength of up to 94.59.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 MPa (Mustafa Al Bakri, A. M., Kamarudin, H., Bnhussain, M., Rafiza, A., & Zarina, Y, 2012).

STRENGTH CHARACTERISTICS OF ACTIVATED FLYASH AND GGBS

Ground granulated blast furnace slag (GGBS)-based geopolymer is an excellent binder that attains high strength by curing at room temperature. Fly ash-based geopolymer binder, on the other hand, attains high strength when heated in particular temperature range. The efficacy of alkali-activated GGBS and enzymes on the soil collected from the Tilda area of Chhattisgarh, India, compared to ordinary Portland cement (OPC) is investigated.Optimum dosage can be selected as 20% for GGBS with 1M NaOH solution, 12% of OPC and 645 ml/m3 of enzyme. The effects on optimum moisture content (OMC), maximum dry density, plasticity index, unconfined compressive strength (UCS) and shear strength parameters have been assessed and evaluated at different dosages of the selected stabilisers.UCS of untreated soil, 37 kPa is increased to 803,135 and 697 kPa by addition of GGBS (20%), enzyme (645ml/m3 of soil) and OPC (12%), respectively, after 28 days. UCS of alkali-activated GGBS-stabilized soil is 1.15times that of OPC-stabilized soil whereas it is 5.5 times that of enzyme-stabilized soil. Alkali-activated GGBS is more effective in developingstrength compared to enzyme for the selected soil (Ansu Thomas, R. K. Tripathi, &L. K. Yadu, 2018).

The structural and chemical characteristics that are common to all geopolymeric materials and, as well as those that are determined by the specific interactions occurring in different systems, providing the ability for tailored design of geopolymers to specific applications in terms of both technical and commercial requirements. The fundamental chemical and structural characteristics of geopolymers derived from metakaolin, fly ash and slag are explored in terms of the effects of raw material selection on the properties of geopolymer composites. Conceptual model of geopolymerization is shown in Figure1. It is shown that the raw materials and processing conditions are critical in determining the setting behavior, workability and chemical and physical properties of geopolymeric products (Duxson P, A Provis,J.L , LukeyG.C , PalomoA. & Deventer, J. S, 2007).

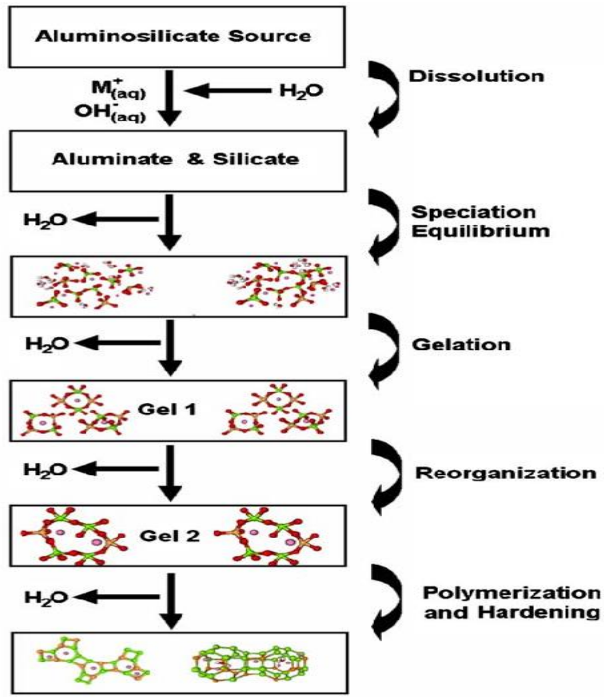

Figure1. Conceptual model of geopolymerization (Duxson P et al.,2007)

Sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) solutions were mixed in different ratios (0.5, 1, 1.5, and 2) and used for synthesizing the geopolymer. The stabilized BCS samples were characterized in the laboratory for various properties viz., Atterberg's limits, free swell ratio, and unconfined compressive strength. An increase in the unconfined compressive strength and reduction in free swell ratio as well as shrinkage limit was observed after stabilization with geopolymer.Results also indicate binding of soil particles and formation of dense microstructure resulting in higher strength and less swelling and shrinkage characteristics. The UCS of geopolymer stabilized BCS was found to depend on the particle sizes of FA, amount of FA in the mixture and SS/SH ratio of the alkaline solution. Allthe geopolymer stabilized specimens gains adequate strength to be used as the stabilized sub-base material after proper curing. It is to mention here that as per the codes of Indian road congress (IRC 37, 2012), a stabilized sub-base material must achieve aminimum strength of 750 kPa at the end of 28 days curing period. The development in strength after geopolymerization is attributed to the formation of cementitious materials and transformation of soil particles into a more densely packed form (Murmu A. L., Jain, A., & Patel, A, 2019).

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. Geopolymer has been researched during the past few decades as an alternative to sustainable construction materials, which can minimize CO_2 emission for its use of industry by-products. Compared to other chemical additives, these polymers are very effective and less hazardous to the environment. Potassium Hydroxide Geopolymer (PHG) and Sodium Hydroxide Geopolymer (SHG) are applied to increase 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 a 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.When further studies are done; the efficacy of geopolymer on soil stabilisation can be understood.

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