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Effects of Ground Granulated Blast Furnace Slag & Lime on the Engineering Properties of Clayey Soil: A Review

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Abstract*—*Clayey soils are problematic due to the reactions of their minerals, which gives them an exhibition of shrink-swell properties. The shrink-swell property obtains clayey soils as inappropriate material for direct utilisation in construction. In underdeveloped nations due to the remarkable development in road infrastructure, soil stabilisation has become the most efficient solution in construction industries. To make these soils more workable for construction, various methods (mechanical, chemical) and materials have been used. Cement, Lime, fly ash, and ground granulated blast furnace slag (GGBS) has usually used us stabiliser for developing the engineering properties of soil. The main focus of this review paper is on the utilisation of GGBS by-product and lime to enhance the geotechnical properties of the clayey soil. Experimental results of different tests like strength, microstructure, and compaction of various stabilizers and their percentages are evaluated and discussed. Lime and GGBS as local natural and industrial sources implied for chemical stabilisation. However, the reduction of waste material and its usage in construction has become an area of potential and promise.

Keywords*—*Soil stabilization, clayey soil, GGBS, lime, strength characteristics,

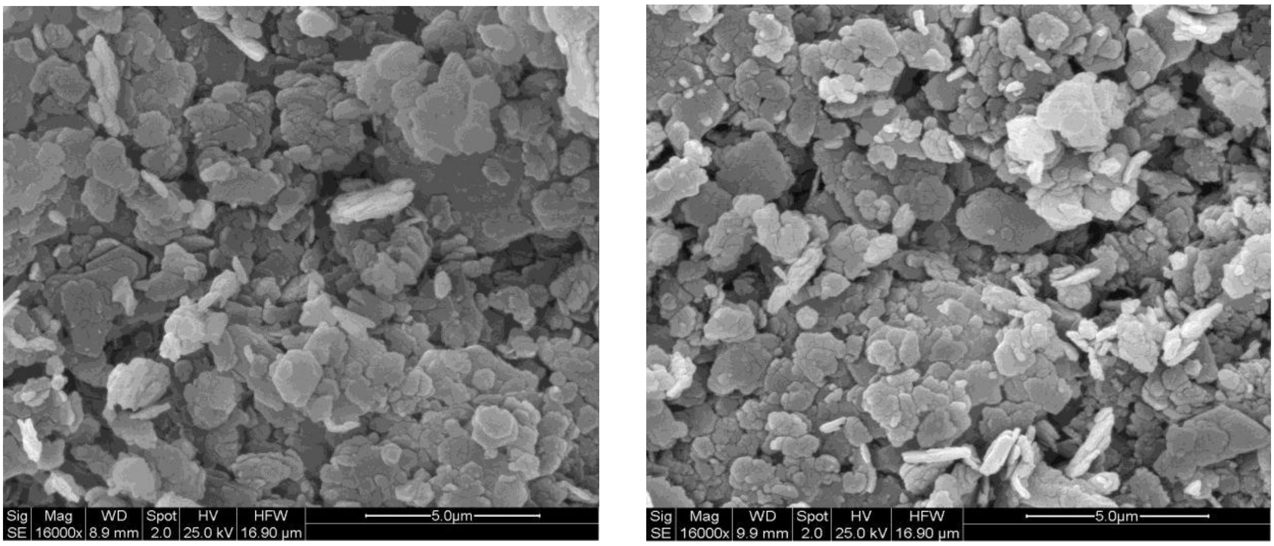
I. Introduction

Expansive soil is a global issue that lay numerous challenges to Engineers. Expansive nature soils are seen as global, mostly in the arid and semi-arid areas [1] Notably Australia, India, Canada, China, South Africa, and the United States. Due to the change in the moisture content, variations in the volume of soil occurs. This variation causes many problems in the structures constructed on it. Moreover, the level of crystallinity is significant in clay minerals, poor-ordered crystallinity and well-ordered crystallinity have different properties of the various groups of clay minerals which can be illustrated by the different levels of activity on the surface of the clay particle[1]. Clayey soils have a broad range of mineralogical composition, notably kaolinite, illite, montmorillonite which enable the soil to absorb more water. Shrink-swell soils expertise a loss of soil strength [2]and ensuing instability may end up in numerous kinds of issues like falling of structure, cracks in the foundation, etc. Clayey soil swells and becomes plastic when it exposed to water, shrinks when it is dried and expands in the presence of frosts [3], [4]. Expansive soil foundations Lead to lifting and failure due to the high level of ground moisture. Innovative methods of soil stabilisation like mechanical and chemical stabilisation are in high demand all over the world. Although mechanical stabilization, by increasing the amount of compaction, dry density of the soil mix, durability and strength increases [5], in other hand admixtures like lime, GGBS, fly ash, cement, and other additive materials using for soil stabilization is more advantageous. Replacing of poor-quality soil with good quality soil is another way to have a strong foundation, but there are economic and environmental concerns. Transporting a large amount of soil and disposal of industrial waste hurts projects economy and environment. Common strategies want to improve properties of soil including compressions (compaction, preloading), poor water reduction techniques (dewatering and electro-osmosis), bonding of soil particles by the freezing method, geotextile, and stone column [6]. Lime is among the earliest additives used for improving the engineering properties of the soil. Usually, lime has more or fewer influence on the plasticity of the soil. For example, calcium ions of lime cause to a decline in the plasticity of the soil which ends to a significant improvement in workability of the soil [7]. Generally, lime is used for the following reasons; first, drop in the liquid limit and an evaluation of plastic limit (PL) that leads to a substantial decrease in the plasticity index (PI) and excellent workability. Secondly, the chemical reaction that occurs between soil and lime leads to a decrease in the water content [8]. Four common lime additive generally used in geotechnical construction which is based on lime area, hydrated high calcium lime $Ca(OH)_2$, calcite quicklime Cao, monohydrated dolomitic lime $Ca(OH)_2$ MgO and dolomitic quicklime Cao Mgo [9]. By adding lime to clayey soil shrinkage characteristics improved significantly while the mixture of lime to such soils reduces their potential for swelling. In general, lime significantly improve the strength properties and performance of the soil [10]. Strength properties of such soil can be influenced by the character of the soil, percentage of lime, curing time, conditions (i.e., temperature and humidity), moisture content, and the time passed between mixing and compaction. Thermal power plants and manufacturing industries produce million tons of unwanted by-product materials all over the world [11]. And most of these wastes left without any usage and are environmental hazard by polluting the air, water, and soil. Some of these like GGBS and fly ash which has pozzolanic properties are being used in different parts of the construction industry besides lime and cement as activators [12]. GGBS, in fact, it is a by-product of the steel industry, and it consists of glassy phase with a large content of Ca, Si, Al and magnesia (95%) [1]. These industrial by-products have mainly utilised as partial replacement of cement in concrete. This waste material also has excellent potential to be used as stabilising agents. GGBS has potential cementitious reactivity in powder form. However, less or no crystal production in case of turning molten slag into a glassy state. This process ends in the configuration of sand size fragments and Gradation. The physical structure of slag depends on the chemical fabrication of slag, the way of production, temperature and water quenching time. When smashed or break to very fine cement-sized particles, it shows cementations properties [13], which could be replaced or added to Portland cement. The reaction of GGBS with water leads to production of silicate hydrates (CSH) from its available calcium and silica. Mainly GGBS is very productive at combatting the swell and also increase the strength of the soil. There are some differences in the chemical properties of lime and GGBS. The mixture of these two substances can be more effective when applied as a stabilising agent than using them separately. Each of them can produce sufficient silica to raise pozzolanic reaction, thereby demanding lower amounts of chemical activators. This paper shows the result of experiments and discusses the method of stabilisation such as chemical and mechanical with different percentage of stabilisers such as lime and GGBS, furthermore the kind of tests which has been conducted by researchers.

II. Literature review

A. Engineering properties of stabilized soil using lime

[14] An investigation on lime stabilized clayey soil was conducted to see the effects of lime on the strength and microstructure of soil. 5% hydrated lime was mixed with kaolin clay soil, and different laboratory tests like SEM, UCS, Atterberg limits and compaction tests were conducted. An Improve in compaction properties and reduction in the plasticity of kaolin soil indicated after the addition of lime. kaolin soil showed a 23.6% increase in the PL and 26.6% in the liquid limit. An increase from 29.9% to 33.3% in optimum moisture content (OMC) and also showed a 3 % decrease in (PI) and 40kg/m3 in maximum dry density (MDD). Two variables, curing time and water content influenced the amount of developed strength. UCS decrease with an increase in water content and increase in the curing time. Twice increase of strength has been seen in lime-treated kaolin as compare to untreated kaolin soil. SEM micrographs showed a generation of cementitious material in the treated soil. Fig 1 portrays the SEM-micrograph of virgin soil. As the figure shows hexagonal particle generations, the clay exhibited flaky texture which almost vanished after 5% extension of hydrated lime. Fig 8 depicts the clay particles conversion of a flaky form into a flocculating composition. Lastly, the research claimed that mixture of lime in the kaolin soil improves the strength, compaction properties, and plasticity of kaolin soil.



(a) (b)

Fig 1 SEM image of kaolin clay: (a) virgin soil (29.9% OMC), and (b) treated soil (5% lime, 33.3% OMC, 28-day curing)

[15] In this research, the impact of lime studied on the compressibility and swilling traits of soil. Different percentages of lime (3,5,7and 9%) added by the Wight of soil. A series of tests like, Atterberg limits, specific gravity, compaction, and consolidation conducted on the soil. Due to the addition of lime, the (LL) and (PL) decreased. Liquid limit reduction observed by 9% addition of lime. The decline in LL is an outcome of transfers among the adsorbed cations of the clay mineral and the free calcium of the lime (Fig 2). Water content rises from 20 to 23% by the addition of 5% lime. Maximum dry density decreased from 1.63Kg/cm3 to 1.585Kg/cm3 with stabilizer content (Fig 3). Specific gravity increased from 2.64 to 2.72 with 5% stabilizer content(lime) and then decreased with more than 5% lime. According to lime soil reaction, the results showed that the optimal percentage of the stabilizer is 3 to 5% and showed that lime could improve the compressibility of kaolin clay soil.

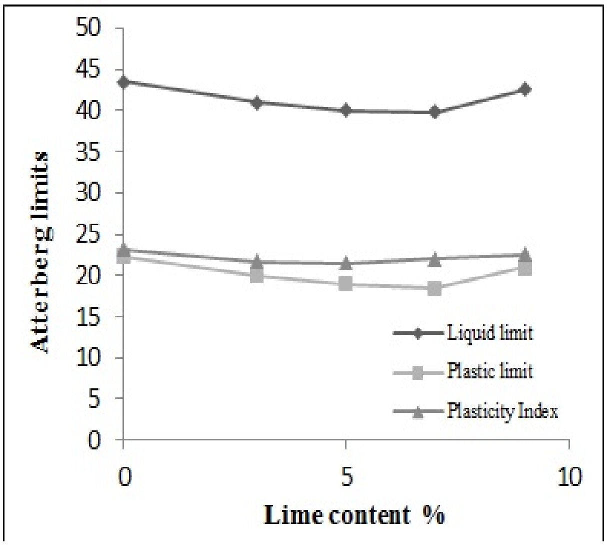


Figure 2 Atterberg limits of kaolin soil with different percentages of lime.

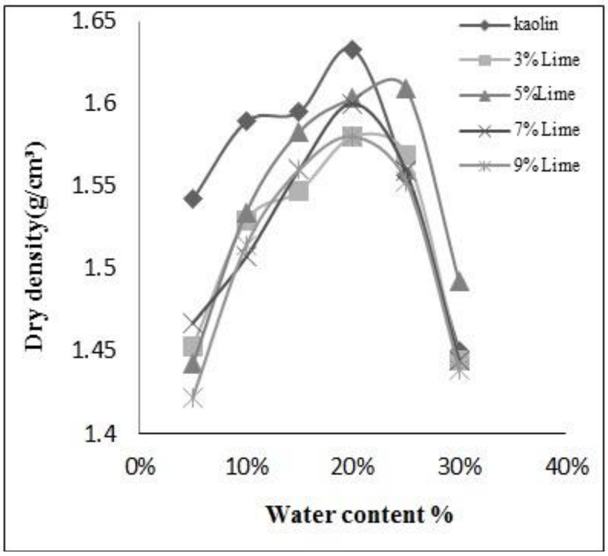
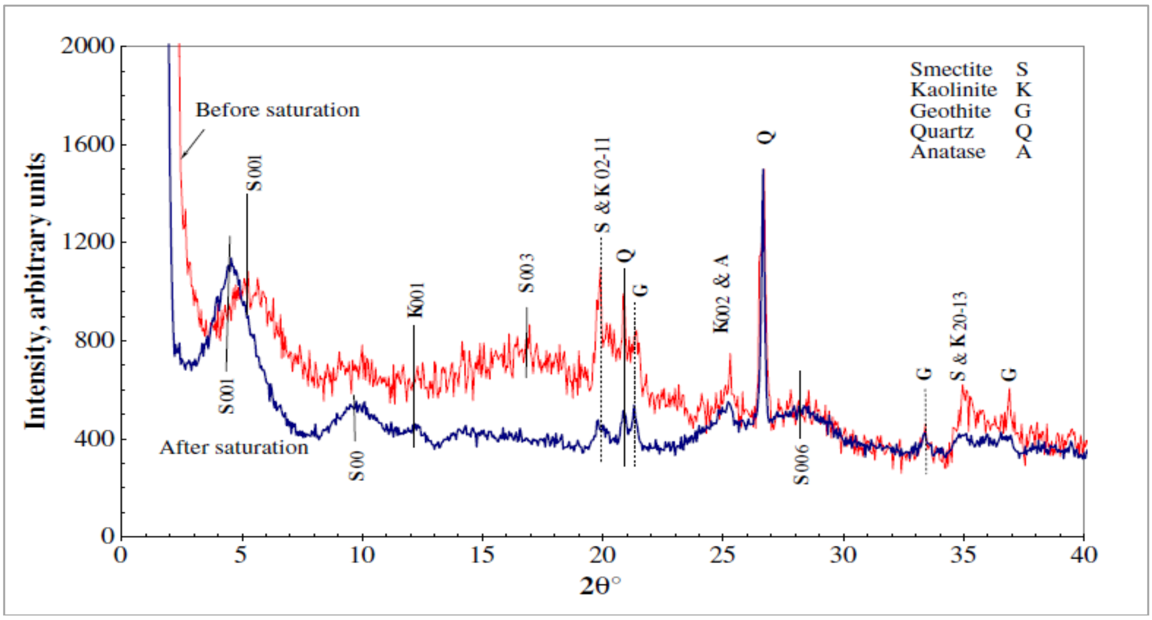
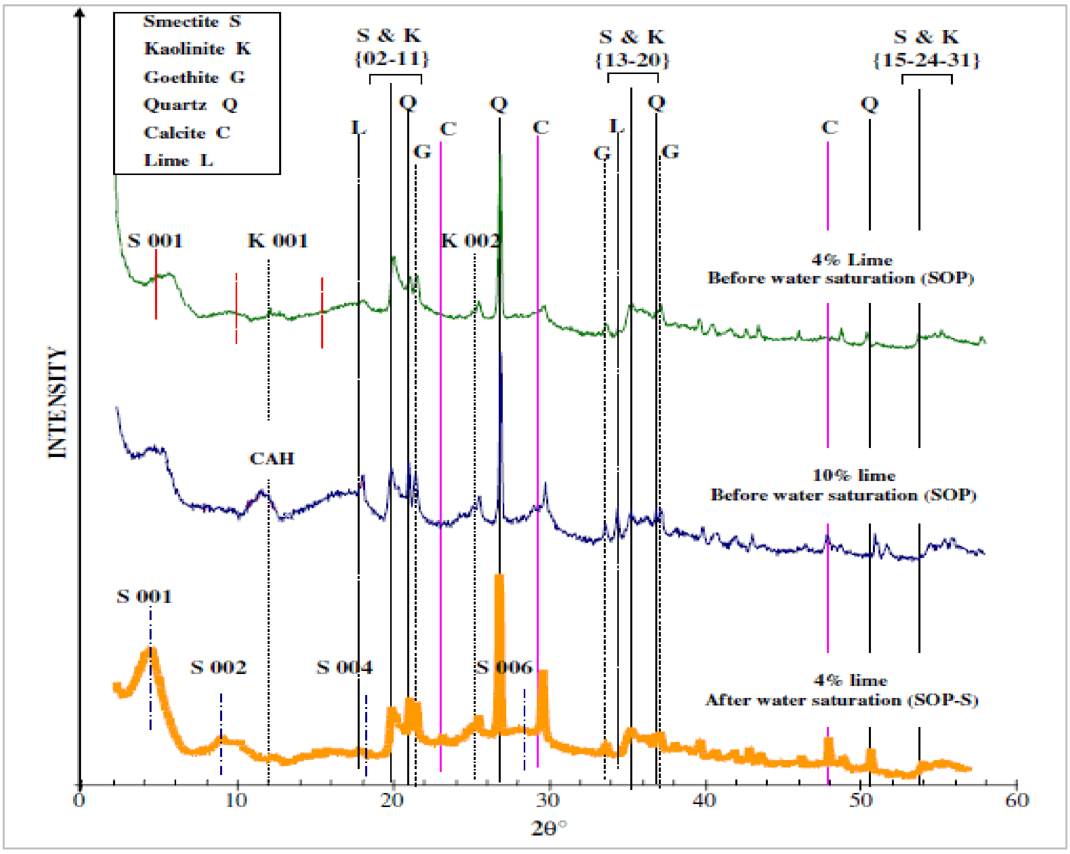


Figure 3 Water content-density relations with with different percentage of lime

[16] The changes in geotechnical characteristics such as UCS, plasticity, swelling pressure, and permeability along with the micro level composition of lime-treated and untreated compacted clay specimens were evaluated in this study. XRD, Thermogravimetric Analysis and SEM tests were conducted to the soil. Geotechnical properties changed immediately after the lime addition. Moreover, the treated soil lost its cohesiveness quality and function as a granular substance. The PI and swelling pressure decreased while permeability and UCS increased. Curing time also had a vital role in changing the soil geotechnical properties, as microscopic changes continued with the changes of the slow pozzolanic lime-clay reaction. Scanning Electrode Microscopic test showed morphological variations during treating clayey soil with lime, dense, thicker, but few large bits with interconnected holes. Figure 4 a and b shows The properties of the XRD, all treated and untreated specimens contain poorly made smectite-kaolinite, with some quartz and goethite. The shape and intensity of {hk} links: {02–11}, {13–20} showed partial disorientation of the clay bits. The determinations and observations clearly showed that the reaction of clay- lime improves the destruction of large clay crystals, beginning from the side of particle supported by the combination of CSAH (Ca++ of lime and the outputs of clay dissolution).



(a)



(b)

Fig 4 a: XRD of compacted, unsaturated (SOP) and saturated (SOP-S) virgin FoCa clay. b: XRD of treated (4%, 10% lime), compacted, unsaturated and saturated FoCa.

[17] Many laboratory tests were conducted focusing the effects of delay in compaction and temperature on the mechanical, hydraulic and physical properties of lime added clayey soil. Samples held for a period of 0, 3, 6, 12, 24 and 48 h and 20°C, 40°C temperature earlier for compaction, curing time was 28 days for assessing the influences on long-term strength improvement. All prepared specimens had the same moisture content of 40% and dry unit weight of 12.16 KN/m^3. The findings showed that as the delaying period surged the dry unit weight declined remarkably at both 20°C, 40°C temperature, moreover, the greater decline was at 40°C temperature. Tremendous reduction (97%) observed in swelling pressure by compacting the soil at zerhour delaying period and issued to cure for 24 hours earlier to test. Mellowing the compaction of the specimen for 24hr at 40°C resulted in an increase in Permeability coefficient by 400%. Unconfined Compressive Strength increased with the delay of compaction. A surge of 234% and 282% of UCS observed after 24hr of mixing at 20°C and 40°C temperature respectively. according to the results of research work, mellowing the compaction process of lime added plastic clay soil should be avoided to protect the cementitious mixtures as it looks to be the main contributor for improving strength and decreasing swelling pressure of clayey soil.

[18]This investigation was about lime stabilized soil mixed by seawater. Influences of the seawater on the swelling reaction, consolidation and engineering characteristics of the soil were studied in this paper. Results showed that utilization of seawater leads to a reduction in swelling properties, consolidation and engineering behaviour of the soil. The seawater mixture ends to an increase in bearing
capacity of the soil. By mixing potable water and seawater (P.I) reduced by 59 % and 67% respectively.

B. Engineering properties of stabilized soil using GGBS

[19] The research has been done to see the effects of GBS on the properties of soft soil. Various percentages of GBS (3,6, 9, and 12%) was mixed with soil. Physical and strength performance tests namely, UCS, CBR, PI, free swelling index, and compaction swelling pressure was conducted to the GBS stabilized the soil. Moreover, the result indicated a significant improvement in the physical and strength properties of soft soil. A significant reduction in the swell-shrink properties of soft soil has been seen. OMC decreased while OMD increased when GBS was added to the soil. Based on the strength test results, 9% GBS was the optimum amount and showed maximum strength among the various percentages that were added to the soil. UCS and soaked CBR value increased 28%and 400% respectively by the addition of 9%GBS (Fig 5 and 6).

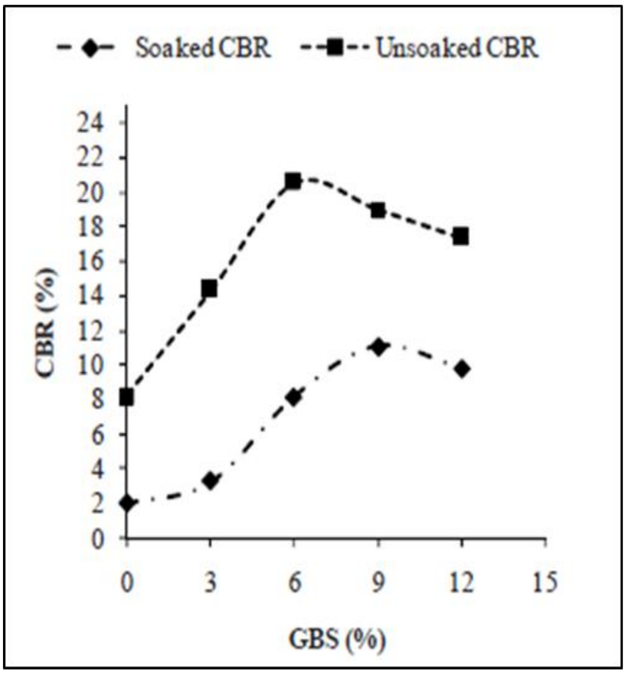


Fig 5 CBR of GGBS mixes

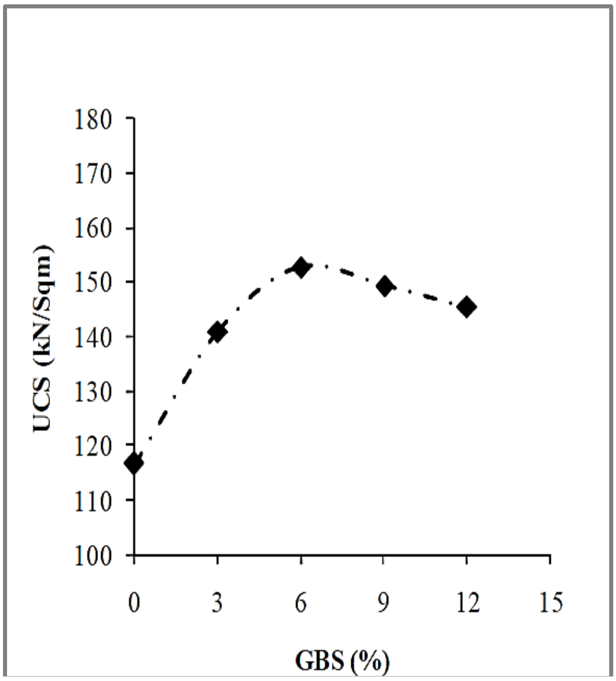


Fig 6 UCS of GGBS mixes

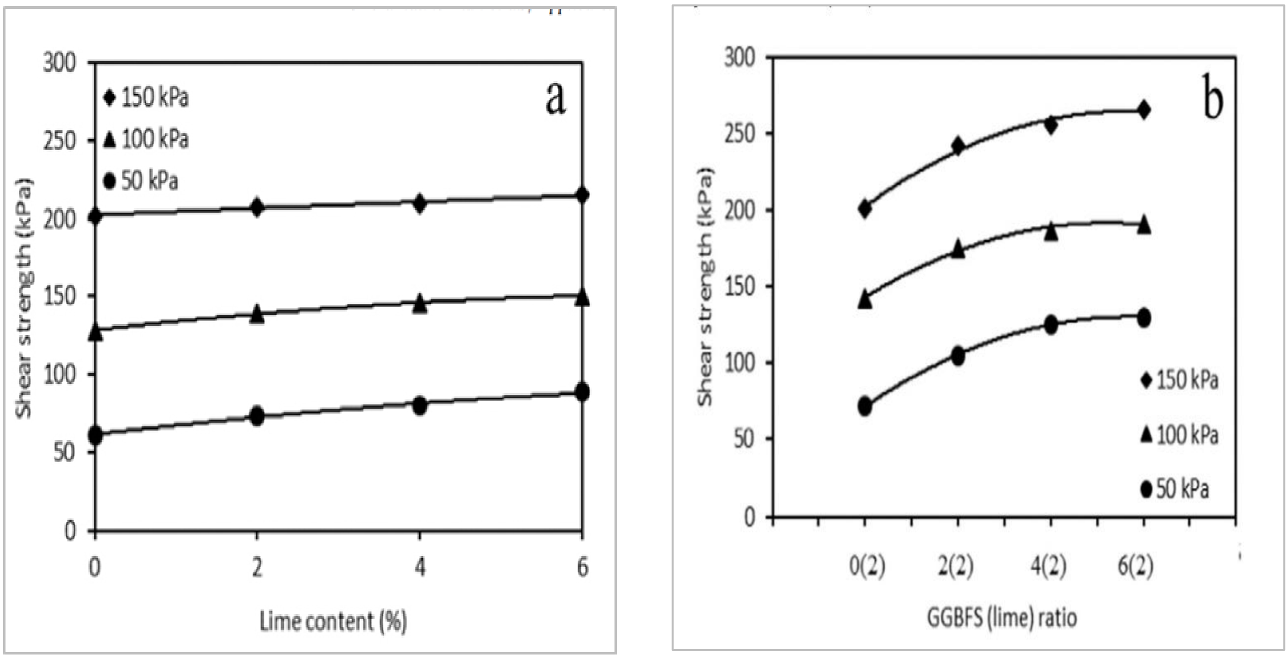
[20] In this paper, GGBS used for stabilizing the expansive soil. The utilization of waste material (GGBS) as a soil stabilizer in the construction of building and pavement in expansive soil was the goal of this research. Liquid limit and wet sieve analysis of the expansive soil studied in this research. Then a series of tests like, standard Proctor compaction and California bearing ratio have been conducted to find the optimum moisture content and strength of the stabilized soil. As the CBR value increased from 0.9 to 9% the result of this research showed that GGBS could effectively be as a soil stabilizer for pavement and building.

C. Engineering properties of stabilized soil using lime and GGBS with other additives

[21] This paper, Studied the compressive strength of soil with stabilizer content (Fly ash, GGBS). This study is about the utilization of local fly ash and GGBS in construction in a way to reduce the amount of waste causing environmental pollution. 5,10,15 and 20% fly ash and GGBS used by dry weight of soil for stabilizing the soil. Various tests for evaluating the stabilized soil like specific gravity Atterberg limits, CBR and standard Proctor conducted on the soil. Based on CBR determination the optimal amount of GGBS and fly ash was 20% and 15% respectively. The results showed an increase in maximum dry density and compatibility of soil while the moisture content decreased by the increase of fly ash and GGBS%. Lastly, the result showed that the optimum value for GGBS is 20% and for fly ash is 15%.

[22] This investigation was about the usage of waste material like fly ash and GGBS and their effects on the engineering properties of soil plus improving the subgrade construction of roads. The main target was the reduction of waste materials in the open area. After mixing the stabilizer content (fly ash, GGBS) different tests like PL, PI, LL, OMC, MDD, UCS, CBR both soaked and Un- soaked was conducted to the modified soil. The various percentage of fly ash up to 10% and a fixed amount of 10% GGBS was added to soil sample and the result showed an increase in MDD from 1.73 gr/cm^3 to 177 gr/cm^3 and a decrease of OMC from 16.5% to 15.8% further mixing of fly ash was led to vice versa result. The laboratory results have been shown that the 10% amount of stabilizer content (fly ash, GGBS) increase the amount of soaked and un-soaked from 1.6 Kg/cm2 to 4.17Kg/cm^2 and 2.35Kgr/cm to 4.51 K gr/cm^2 respectively. Finally, the recommended value of fly ash and GGBS that should be used in soil denoted a value of about 10%.

[23] This study was about the partial replacement of lime with GGBS. Also, a comparison between lime stabilized soil and GGBS substitution by conducting the (VSS)volumetric shrinkage strain, UCS and (SR)share strength tests. The results of VSS showed that the usage of GGBS with lime led to an effective reduction in volumetric shrinkage. The (UCS) results showed that the partial replacement of lime with GGBS ended with higher compressive strength and share strength (fig 7). Microstructural studies like (SEM), energy dispersive X-ray spectroscopy (EDS) carried out on modified lime stabilized soil shows that the mixture of GGBS in lime-stabilized clay led to the production of cementations material. XRD test showed that calcium silicate hydrates (CSH) are the primary hydration production in the lime.



(a) (b)

Fig 7 (a) Outcomes of shear strength tests on mixtures of clay with different S/L ratios under 50 k Pa stress. (b) Results of shear strength tests on blends of clay with various S/L ratios under 100 k Pa stress.

[9] This study was about the utilization of lime and rice husk ash in clayey soil. Agriculture waste such as rice husk ash (RHA) and lime added to the soil for improving the weak subgrade. The combined percentage of lime and RHA to the soil was 5,10,15 and 20% by the weight of soil. Making a strong foundation by using cheaply available lime and rice husk ash was the primary objective of this paper. A reduction in maximum dry density to 1.325gr/cm3 from 1.382 gr/cm3 with lime addition and to 133gr/cm3 from 1.382gr/cm3 with RHA has seen in this research. The optimum amount of (RHA) and lime was 15%. An increase in OMC from 22% to 28.8% with lime and up to 25.5% with RHA found during this investigation. By the addition of stabilizer content (lime, RHA) specific gravity CBR and UCS increased while liquid limit, plasticity limit and permeability of soil decreased. This paper shows that lime is a better stabilizer than RHA for improving the engineering properties of soil.

[24] Bagasse fibre and lime added to the expansive nature soil for reinforcing the soil particles. Bagasse fibre is an industrial waste, a residual of sugar cane juice left after extraction. The chosen soil had been collected from Queensland, Australia. The expansive soil had been added by 0.5%,1% and 2% Bagasse fibre and lime for stabilisation purposes. UCS and linear shrinkage tests undertook for 3,7 and 28-day curing period the paper has shown that linear shrinkage dip while UCS values of treated soil surge with the increase of stabilizer's percentage (Fig 8 and 9). This research found that a blend of hydrated lime-bagasse fibre has a better result in case of strength than bagasse fibre alone.

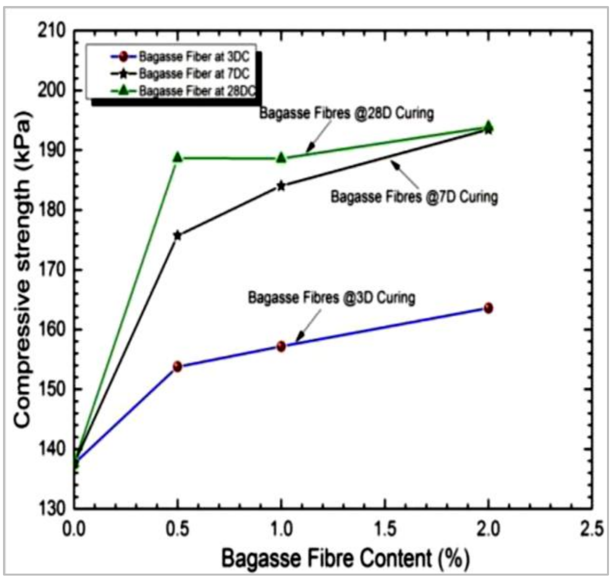


Figure 8: Effects of fibre content on UCS values of treated expansive soil.

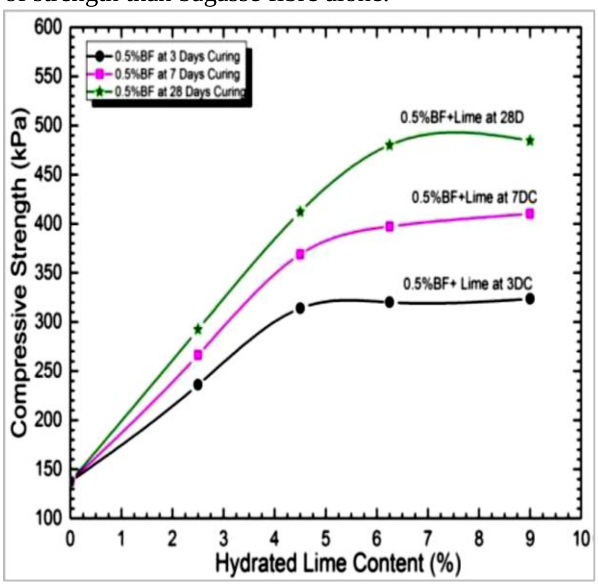


Figure 9: Effects of 0.5% fibre against different hydrated lime percentage on UCS values of treated expansive soil.

[25] The study was about the treatment of highly expansive and very plastic clay soil, pozzolanic reaction progress of clayey soil has been evaluated in 50 C temperature and different curing periods. By conducting different laboratory tests on soil, this has been observed that a large quantity of lime (>5%), is required to defeat with the silicate layer and destroy them to create the various hydrates in the processed soil. Addition of lime above the needed amount (5%) to the treated soil for the cation transfer cause the pozzolanic reaction formation of a new form: CAH and CSH at high temperatures, curing time and high lime content. A significant development in the UCS test is achieved by lime addition. Rising curing temperature from 20° to 50° increased the rate of pozzolanic reaction by 600%.

[26] Investigated the effects of waste aluminium beverage can (WBC) pieces on the swelling and strength characteristics of the lean clay soil. An amount of 2, 4, 6, 8, and 10 % (WBC) mixed with soil. Compaction, CBR and free swelling tests carried out to investigate the effects of the stabilizers on the soil engineering properties. The results showed that the addition of (WBC) leads to an increase in MDD and a decrease in the OMC of the soil. These stirrups are considered as environmentally friendly materials and the effective amount of stabilizer was found as 6%.
[27] This research investigated the GGBS and cement stabilized earth blocks (CSEB). Two different types and locally available soil, Dakshina of Kannada district and Karnataka, India was selected for the investigation. Firs, an optimum amount of GGBS discovered after that different amounts of cement added to the soil for the generation of the size of 305 mm *143 mm *105 mm compacted (CSEBs). After 28 days curing, the results revealed that the GBBS and cement made (CSEBs) can be used as load-bearing walls in buildings. The excellent percentage of GBFS denoted as 25% and 20% for stabilizing the lithomargic clay and lateritic soil. By adding 25% and 20% GGBS, an enhancement of about 53% and 40% in the strength of lithomargic and lateritic made blocks has seen in the results see Fig 10 and 11. An amount of 10% cement along with optimum of GGBS raised the strength of blocks by 390%.

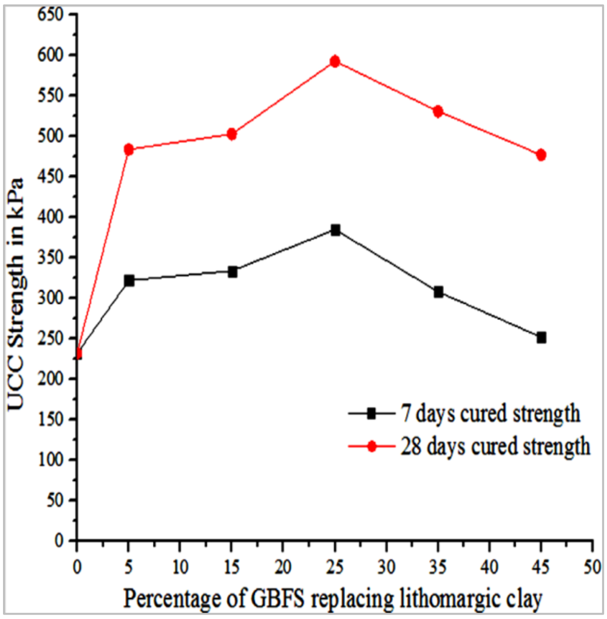


Fig 10 Effects of GGBS on UCS of lithomargic clay

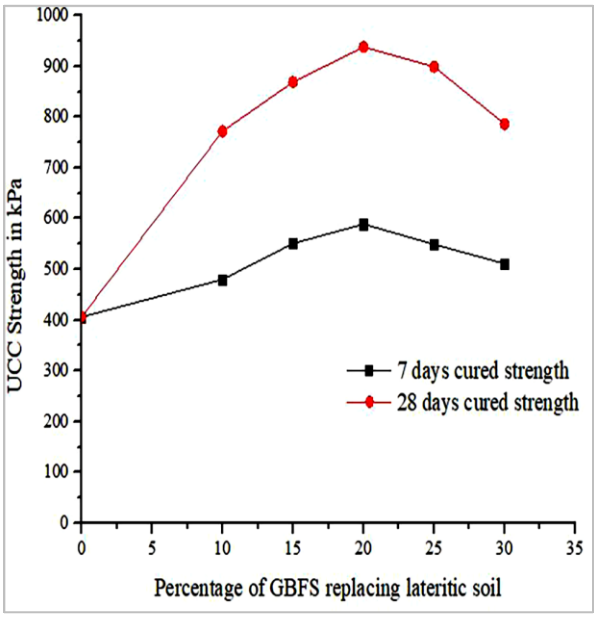


Fig 11 Effects of GGBS on UCS of lateritic clay

III. CONCLUSION

This investigation summarized the results of various studies on stabilization of clay soil. Effects of lime and GGBS on geotechnical properties of soil investigated separately. Combination of stabilizer (GGBS+ lime) for stabilizing clayey soil found flawless for improving the engineering performance of expansive soil. Using these materials as stabilizer inferring the following points: -

1) Effects of GGBS on soil: By the increment of GGBS%, the LL, PL and consequently the plasticity index moves on declining, which causes the soil lower plastic, on the other hand, MDD value rises while OMC fall with the increasing of GGBS proportion in the mix. The swelling degree of soil plummets down by a large ratio. Because GGBS release calcium ions in the blend which comes around the clay particles and surround the surface of the grains, therefore causing soil capability of moisture attraction down. Furthermore, pozzolanic integrations can tighten the soil bits. Hence growing the strength and decline the potential to swell.
2) Effects of lime on soil: By the increment of lime%, the LL and PI go on decreasing, on the other hand, OMC value rises while MDD fall with the increasing of lime proportion in the mix. In case of swelling, less amount of lime can

treat the soil very well. By evaluating the researches, this has been observed that the maximum amount of lime that gives the best results is 8% lime.

3) XRD and SEM- Micrographs showed that both stabilizers (lime, GGBS) form a cementitious substance with soil. The fabric of the treated soil depicted that GGBS and lime which resulted in pozzolanic reactions contributed to the growth of strength parameters of stabilized soil.
4) In most cases, all strength characteristics of treated soils namely UCS, CBR and BTS etc. improve with the lime and GGBS addition, moreover, strength properties of soil develop with the curing time and it played a vital role in this case.

Overall, it remarks that the combination of GGBS and lime on the engineering performance of clayey soil has a great result than using them separately.

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