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Recent Trends in Stabilization of Expansive Soil using Calcined Clay

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ABSTRACT

Expansive soils have the tendency to more swelling, shrinking and compressibility by variation in soil-water interaction affecting the alteration in the bearing capacity of soil. There are several methods used to stabilize the soils and promote sustainable development in the construction industry. In this, soil stabilization is prime and efficient techniques to improve the strength by altering the physical characteristics of the soil. In addition, admixtures improved the chemical characteristics of soil and also attained stability by improving the bonding between the soil structures. Soil stabilization has been experimented by many researchers and successfully used in several field applications especially using cement, lime, ashes, chemicals etc. An alternative to these options mentioned is using natural cementitious material such as calcined clay as an admixture. This work focuses on the effect, the development of the strength properties of treated soils with varying percentages of calcined clay as 2%, 4%, 6%, 8% and 10% under varying curing times. The enhanced strength behaviours of the expansive soil were determined by performing the unconfined compression test and also the microstructural studies like SEM and XRD for the selected samples. The results indicate that the maximum strength was attained on 8% admixture treated soil. Thus calcined clay acts as a natural cost-effective and eco-friendly stabilizer in place of replacement of cement to stabilize expansive soil which develops the strength characteristics of the expansive soil and also reduces environmental pollution.

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1. INTRODUCTION

Soil is one of the essential materials needed to decide the execution of construction. Rapid urbanization leads to the requirement of different forms of infrastructural development all over the world. Site feasibility plays major role in the selection of project; generally, prefer the soil with good bearing capacity [1]. Due to scarcity of land, it is impossible to obtain a construction field that meets the design requirements without ground modification in most geotechnical projects [2]. Under this circumstance it is necessary to give more importance to the subsurface which withstands the construction. Challenges arises to utilize the weak and problematic soil and converting them into the good soil by any suitable technology required to improve the behaviour of the soil which means for enhancing the properties of its original nature [3]. Expansive soil is one of the most problematic soil due to its volume change behaviour when interacting with the water and also due to the presence of montmorillonite clay minerals which is expansive in nature [4] and its spread covers around 12% of landmass. Ground improvement technique is the essential Techniques consist of several methods that vary based on the soil type and other factors which have been widely used to increase the load carrying capacity of the soil. One of the effective methods of enhancing the strength characteristics by addition of material along with the natural soil is called the stabilization method [5-7]. It plays an important part in the development of characteristics in a short period. Soil can be stabilized by means of physical, chemical and biological [8-11] methods to increase the weight bearing capabilities and performance of in-situ subsoil. The commonly used

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stabilization techniques are cement stabilization, lime stabilization, stabilization with flyash, bitumen stabilization etc. [12-15].

Many researchers involved in the field of soil stabilization using admixtures suggested this is one of the most widespread ground improvement techniques. The stabilized soil can be used in wide engineering applications in the field of earth structures, pavement, hydraulic structures etc. Several studies were done by adding soil with admixtures in any form, either powder or liquid to enhance the strength characteristics of the soil. Traditional admixtures like lime [16], cement [17] and its byproducts have stabilized the problematic nature of expansive soil and helped to improve the strength characteristics of soil but that leads to the depletion of natural resources. So upcoming research are done by adding industrial by-products such as GGBS [18, 19], flyash [15, 20, 21], phosphogypsum [22], Dolochar [23] etc and agriculture waste such as groundnut shell ash [24-26], bagasse ash [27, 28], etc. This admixture improves the strength, drainage, and permeability characteristics of the soil. However, this will be economical compared to other kinds of stabilization but long term usage of these wastes leads to the contamination of ground and groundwater. Hence it is necessary to adopt natural pozzolanic material which should provide a sustainable environment.

Calcined clay is one of the effective supplementary Cementitious materials for cement [29]. During the collection of literature, it was found that there are no traces of attempts made to stabilize the soil using calcined clay. In this research, experiments were conducted to examine the influence of the calcined clay on the strength behaviour of the expansive soil. This paper presents the influence of calcined clay (CC) on the engineering characteristics of expansive soils and their inherent ecological potential. A series of Unconfined Compression Test and Microstructural studies were performed on soil and soil treated with 2%, 4%, 6%, 8% and 10% percentages of Calcined clay. The laboratory test results of untreated and treated soils were compared and showed the increment in the strength properties of soil.

2. MATERIALS AND METHODOLOGY

In this study, the soil sample was collected from the site in Tharamani (Chennai, Tamil Nadu, India) at a depth of 1.2m from ground level. The series of test were carried out on the naturally dried and pulverized soil to find out the physical properties and Expansive nature of the soil as per the Bureau of Indian Standards (BIS). As per the IS: 2720 (Part 3) – 1987 the specific gravity of the soil is 2.5, and the particle size distribution showed that more than 50 % passes through 75 microns, the range of 4% sand, 9% silt and 87% clay. The consistency limits as per IS: 2720 (Part 5) – 1985 of the soil were 65% liquid limit and 22% plastic limit and 6% shrinkage limit, showing the soil is highly plastic which comes under the category of high compressible clay (CH) as per the IS: 1498 (Part 20) – 1970 specification and ASTM D2487 [30]. The free swell index value of the soil is 210% showing a very high expansiveness as per the IS: 2720 (Part 40) – 1977. The above test results showed that the virgin soil is highly expansive and more compressible. Hence, it requires soil stabilization in order to enhance the soil behaviour. The additive used for this soil treatment is calcined clay which possesses high pozzolanic natural material and is eco-friendly. The properties of the virgin soil are given in Table 1.

The unconfined compression test and its sample preparation for untreated and treated soil were carried out as per the IS: 2720 (Part 10) – 1973 code specification. The specimens were prepared in the standard dimension of size 38mm × 76mm with the slenderness ratio 2 as per the IS: 2720 (Part 7) – 1980 specification and mixed at the optimum moisture content (OMC) obtained from the standard proctor compaction test. After preparation, the sample was weighed and sealed with the polyethene wrap under the maintained temperature of 25° -30°C [34] and kept on moist saw dust and gunny bags to prevent moisture loss.

Figures 1 and 2 show the prepared UCC sample wrapped and kept in bed for the curing process. The same procedure is followed for the treated sample of different proportions of calcined clay and kept for 1, 3, 7, 14, 28, and 60 days curing by covering it with the gunny bags. The untreated and treated samples were tested at the strain rate of 1.2 mm/min as per the IS2729-Part 10.

Figure 1. UCC samples in polyethene wrapper

Figure 2. UCC samples under curing process

TABLE 1. Properties of the virgin soil

Specific Gravity, G	Particle Size Distribution (%)			Atterberg Limits (%)			Standard Proctor Test		Free swell Index (%)	UCS, (kPa)
	Sand, S	Silt, M	Clay, C	Liquid limit, WL	Plastic limit, WP	Shrinkage limit, WS	MDD (g/cc)	OMC (%)		
2.65	4	9	87	65	22	6	1.64	18.9	210	138

3. RESULTS and DISCUSSION

In this, the test results of the unconfined compression test and microstructural studies of the untreated soil then thesoil treated with 2%, 4%, 6%, 8% and 10% Calcined Clay (CC) were discussed and also analysed its changes in the strength characteristics of the soil.

3. 1. Unconfined Compression Test The test was conducted on the untreated and treated soil samples at the different curing periods and the typical stress-strain characteristics curve for the untreated and treated soil with 2, 4, 6, 8 and 10 % of Calcined clay under curing of 14days are given in Figure 3. The results show the increment in the unconfined compression strength value by increasing the percentage of calcined clay from 138kPa to 355kPa up to 8% calcined treated soil furthermore addition of 2% of calcined clay reduces the UCS value. It was observed that the rate of increment is more with an increase in the percentage of calcined clay. Many researchers reported that the reduction in the strength of soil once the stabilizer content has exceeded the optimum point [31-33]. This behaviour is similar for all other curing time periods of 1, 3, 7, 14, 28 and 60 days of the calcined clay treated soil. The more quantity of calcined clay provides more interaction between the soil and admixture and thus increasing the strength of the treated soil. The reduction in the compressive strength of soil once the stabilizer/binder content has exceeded a certain level has been reported by various researchers [34].

Figures 4 and 5 show the stress-strain relationship graph for the soil treated with 6 and 8% calcined clay under 1, 3, 7, 14, 28 and 60days curing periods. The unconfined compression strength increases with an increase in curing period. Also, it was observed that the UCS value increased due to the influence of the curing period, but the percentage of increment is higher in the early days of curing compared with the later. The stress-strain behaviour is ductile in the early days of curing but the pattern changed to brittle at the later stage.

Figure 6 shows the UCC soil sample and their mode of failure pattern. This pattern is similarly maintained for all other percentages of the calcined clay. The variation is due to the pozzolanic materials is present in the calcined clay react with the soil minerals and alter the behaviour from ductile to brittleness compared with the virgin soil.

The unconfined compression strength value increases the strength upto 8% with the addition of calcined clay with soil due to more amounts cementitious components present in calcined clay reacting with the soil minerals. The effect of the admixture and curing period of the soil treated with varying percentages of calcined clay is given in Figures 7 and 8. The results show that the UCS value got rapidly increased in the order of 101-202 kPa with an

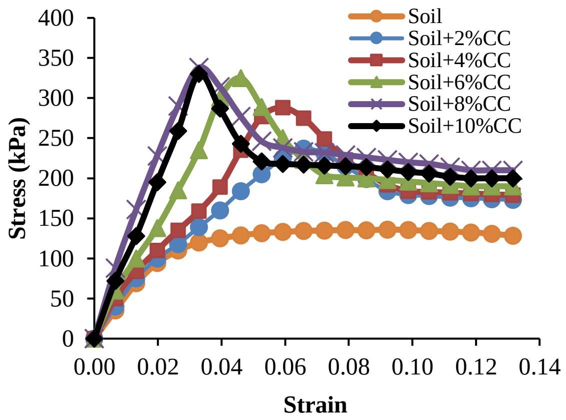


Figure 3. Stress strain Characteristics curve of the Untreated and 2%, 4%, 6%, 8% and 10% Calcined clay treated for 14 days curing period

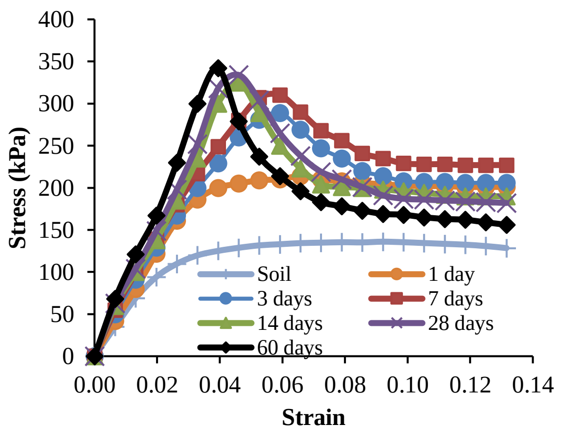


Figure 4. Stress strain characteristics graph for 6% Calcined clay treated soil under different curing period

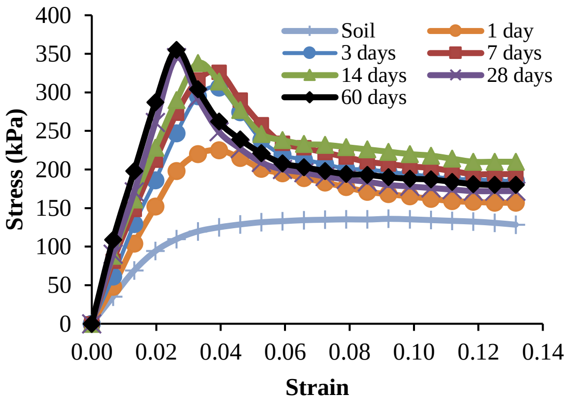


Figure 5. Stress strain characteristics graph for 8% Calcined clay treated soil under different curing period

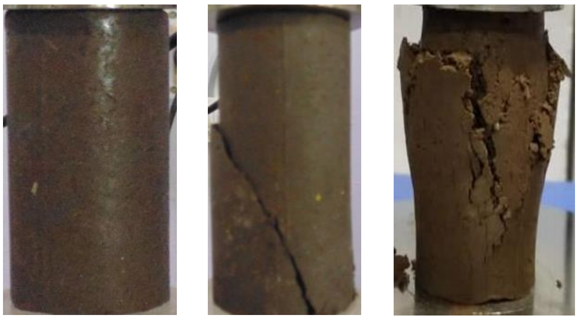


Figure 6. UCC soil sample with failure mode

increase in the percentage of calcined clay of 2 to 8% at the age of 14 days curing period. However, an increase in calcined clay declined with increasing in curing period of 60 days was 17-39kPa. It was observed that the percentage increment in strength is more in the early days of curing due to the occurrence of high reactive siliceous and alumina content compared to that of the later days due to the slowdown of the reaction of additives.

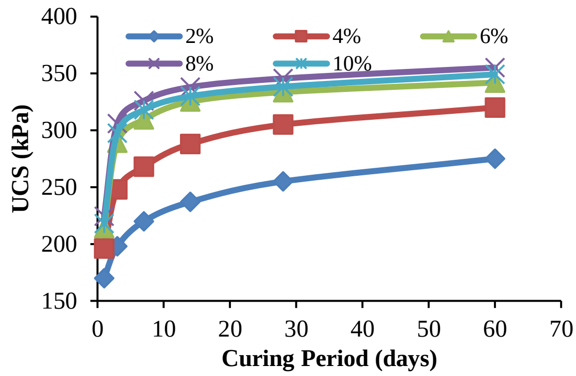


Figure 7. Effect of admixture on the Calcined clay treated soil for varying curing period

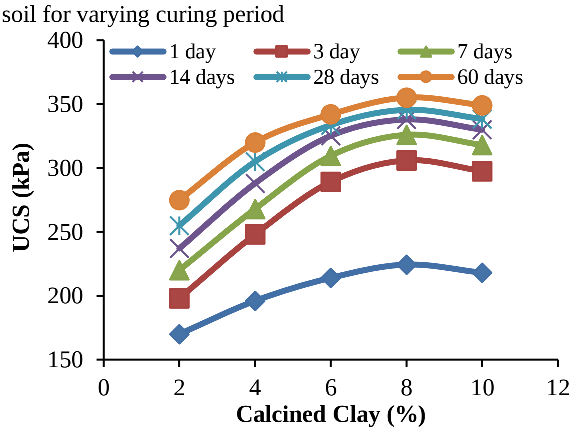
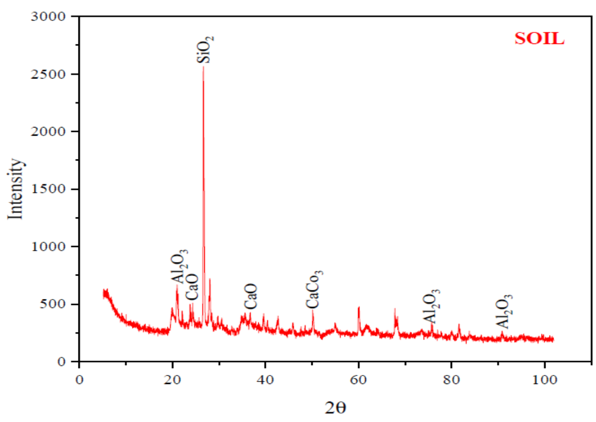
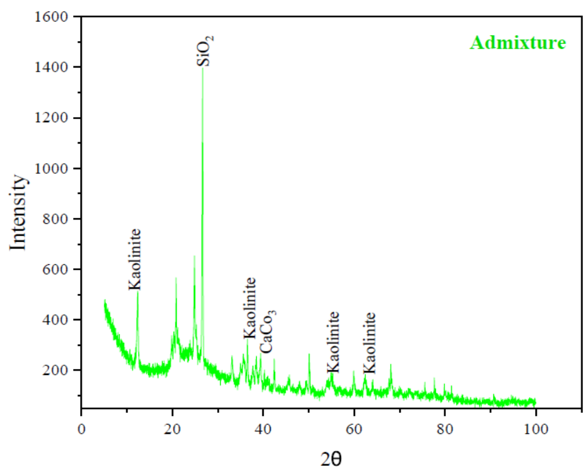


Figure 8. Effect of curing period on the soil treated with varying percentage of Calcined clay



Soil Sample



Admixture Calcined clay

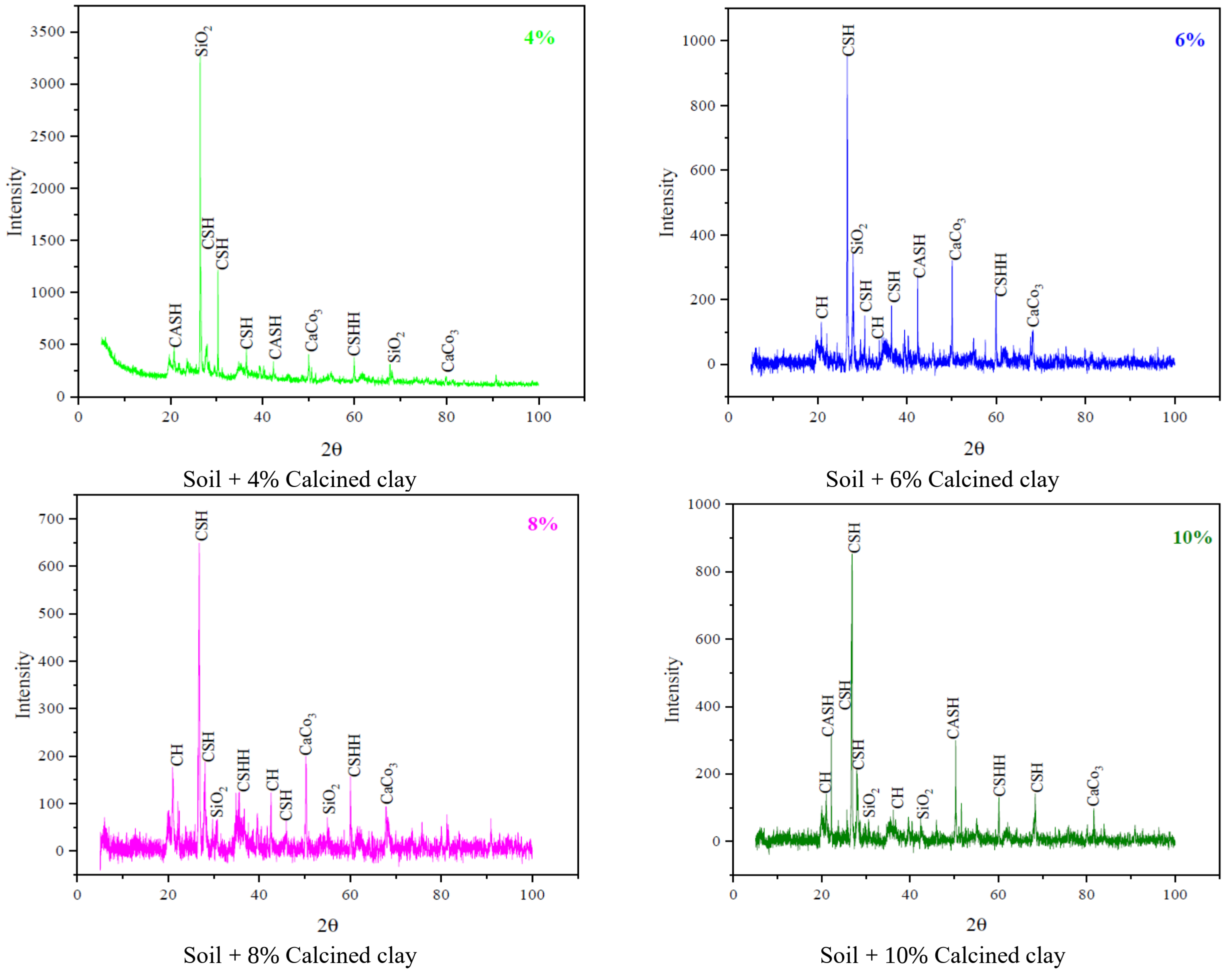
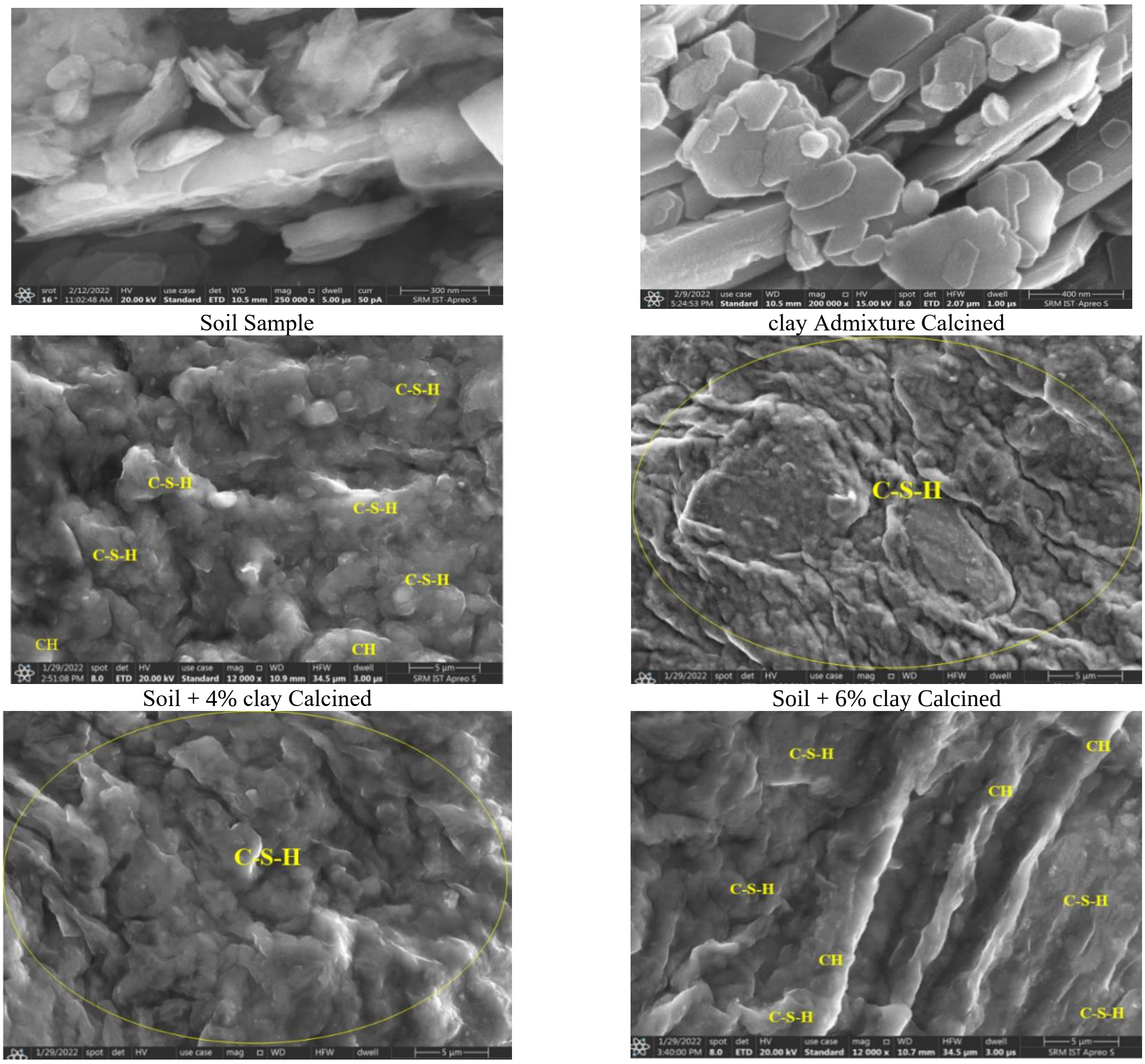


Figure 9. XRD patterns of virgin soil, calcined clay and soil added with different percentage of calcined clay (4%, 6%, 8% and 10%) for 14 days curing period

3. 2. Microstructural Studies The XRD analysis and SEM studies were conducted for the expansive soil, calcined clay and soil treated with varying percentage of calcined clay at 14 days curing to observe the reason for the change in the soil to know the mineralogical composition of the materials of untreated and treated soil.

3. 2. 1. X- Ray Diffraction Analysis The geological properties of the soils are largely depend on the phases/minerals present in the soil rather than the chemical composition, type of minerals present or structure. The identification of the minerals is largely predicting the swelling and expansive behavior of the soil. The XRD pattern of the expansive soil used in this study is evident that the expansive soil consists of the clay mineral like montmorillonite and non-clay mineral of quartz (SiO_2). The expansive soil is also identified with the mixed layer minerals such as illite–smectite and illite-montmorilloniteis. The peaks at the 2θ value of 26.6, 20.8, 50.1, 55.3, 59.9, 64, 67.7 and 68 are attributed to the presence of quartz mineral. The mixed layered phases identified in the present soil attribute to the swelling potential of soil with increasing liquid limit value. XRD pattern of the calcined clay shows the amorphous halo in the range of 18-28° 2θ represents the reorganized aluminosilicates of the kaolin as a result of the amorphisation during the calcination. The inserted image clearly shows the amorphous hump clearly. In addition to this, the crystalline phases of quartz, $CaCO_3$, kaolinite ($Al_2Si_2O_5(OH)_4$) etc are also present. Some of the remaining kaolinite peaks represent the incomplete decomposition of kaolinite after the calcination.

The absence of montmorillonite minerals and the formation of illite phases indicates the complete decomposition of the montmorillonte mineral before calcination. XRD Analysis X-ray diffraction analyses were conducted on samples of the four various percentages of 4, 6, 8, and 10 % at curing period of 14 days to study the phase nature of the materials and identified the main reacting compounds like CH, CASH, $CaCo_3$, C-S-H and SiO_2.



Soil Sample | clay Admixture Calcined | Soil + 4% clay Calcined | Soil + 6% clay Calcined | Soil + 8% clay Calcined | Soil + 10% clay Calcined

Figure 10. SEM images of virgin soil, calcined clay and soil added with different percentage of calcined clay (4, 6, 8 and 10%) for 14 days curing period.

The XRD pattern of the soil, calcined clay and soil stabilized with 4, 6, 8 and 10% calcined clay treated soil at 14 days curing period are presented in Figure 9. The weight percent is calculated based on the dry weight of the soil sample. The mineralogical composition of the treated soil represents that the calcined clay treated sample showed significant phase changes when simply mixing soil and calcined clay. That may be due to the fact that the calcined clay requires alkaline/acid condition to dissolute the reactive silica and alumina to form the alumino silicate hydrate type gel. The calcined clay treated soil reveals the formation new mineral of calcium silicate hydrate (CSH) in the diffraction peak angle 2 theta value of 29°. Also, additional calcite peaks ($CaCO_3$) at the diffraction angle of 38° formed due to cementitious reactions [35]. These hydration products are formed due to the pozzolanic reaction of the compounds in the soil and calcined clay.

3. 2. 2. Scanning Electron Microscope The soil samples were analyzed for morphology changes with the addition of admixtures using a high-resolution field emission electron microscope FEI's Quanta 200 FEG FESEM with elemental mapping and EDAX. SEM imaging essentially provides a visual characterization of the sample surface, making meaningful inferences from the image is harder. SEM Analysis to get the evolution images for the samples on the treated soil of four different percentages, such as 4, 6, 8 and 10% at 14 days curing period. SEM was carried out and illustrated. Since very fine particles are used for taking images after the magnification and sizes may be adjusted by the operator without being aware of it and without knowing the significance of the images, it can be noted that some factors that affect the soil moisture system starting from the sample preparation up to the images taken by the operators. It was discovered that a minor adjustment and move results in two distinct images, one of which depicts appropriately moistened soils and the other, from the same sample, depicting improperly moistened soil; hence it can be stated that the SEM images are taken from the sample. Their corresponding inferences should be considered with respect to that particular image and not extrapolated to other regions.

SEM showed the microstructures of calcined clay, supporting the earlier assertion. Figure 10 shows the soil, admixture and 4, 6, 8, 10 % of treated soil under 14 days of curing and the dispersion of calcined clay is highlighted above. It indicates that the particles are randomly dispersed and incorporated within clay and hydration-product matrix. The interface between the calcined clay and stabilized clay matrix is also shown in the figures, illustrating that calcined clay particles are not required to participate in the hydration and pozzolanic interactions between hydrated products and clay minerals. It should be highlighted that sand and silt particles are only included in a clay matrix that has been stabilized when hydration process products, like CSH, adhere to the clay surface and bind sand particles to create a stabilizing paste. As previously indicated, the clay/silt particles should only interact in a safe and solid way.

4. CONCLUSION

From the test results the following observation on the strength and microstructural behaviour of the untreated and 2, 4, 6, 8 and 10% of Calcined clay treated soil under 1, 3, 7, 14, 28 and 60 days of curing were obtained

From the study of the unconfined compression test, it was examined that the UCS values increased from 138 to 355 kPa at 8% optimum calcined clay for 60 days of curing. An increase in the strength of UCS value is due to the development of cementitious compounds in the treated soil. The incremental strength is directly proportional to an increase in the proportion of admixture and curing phase up to optimum content.

The mineralogical studies show the formation of calcium hydroxide and CSH gel formation is more on the later days of curing compared to the earlier. Also, it shows the chemical reaction between the compounds present in the admixture and soil that forms the Cementitious bonding of the treated soil.

Thus, calcined clay acts as a natural pozzolanic material for the replacement of cement that improves the strength characteristics of the expansive soil in the ground improvement techniques and also reduces environmental pollution.

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Persian Abstract

چکیده

خاک‌های گسترده تمایل به تورم، انقباض و تراکم‌پذیری بیشتر با تغییر در برهمکنش خاک و آب دارند که بر تغییر ظرفیت باربری خاک تأثیر می‌گذارد. روش های مختلفی برای تثبیت خاک و ترویج توسعه پایدار در صنعت ساختمان استفاده می شود. در این زمینه، تثبیت خاک، تکنیک اصلی و کارآمد برای بهبود استحکام با تغییر خصوصیات فیزیکی خاک است. علاوه بر این، افزودنی‌ها ویژگی‌های شیمیایی خاک را بهبود بخشیدند و همچنین با بهبود پیوند بین ساختارهای خاک، به پایداری رسیدند. تثبیت خاک توسط بسیاری از محققین آزمایش شده است و با موفقیت در چندین کاربرد میدانی به ویژه با استفاده از سیمان، آهک، خاکستر، مواد شیمیایی و غیره استفاده شده است. این کار بر روی تأثیر، توسعه ویژگی‌های مقاومتی خاک‌های تیمار شده با درصدهای مختلف خاک رس کلسینه شده به صورت ۲، ٤، ٦، ۸ و ۱۰ درصد در زمان‌های مختلف پخت تمرکز دارد. رفتارهای مقاومتی افزایش یافته خاک منبسط با انجام آزمایش فشار نامحدود و همچنین مطالعات ریزساختاری مانند SEM و XRD برای نمونه‌های انتخاب شده تعیین شد. نتایج نشان می دهد که حداکثر مقاومت در خاک تیمار شده با مخلوط ۸ درصد به دست آمد. بنابراین خاک رس کلسینه شده به عنوان یک تثبیت کننده طبیعی مقرون به صرفه و سازگار با محیط زیست به جای جایگزینی سیمان برای تثبیت خاک گسترده عمل می کند که ویژگی های مقاومتی خاک گسترده را توسعه می دهد و همچنین آلودگی محیطی را کاهش می دهد.