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Preparation and Long-Term Treatment of Extreme-Soft Soil Using Lime and Polymer

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A B S T R A C T

Extreme-soft soil prevailed in the field, and preparing and testing such soil in the lab is not without physical challenges. Therefore, the present study aims to prepare extreme-soft soil using commercial bentonite and to treat such soil with different materials for evaluation of long-term performance. The extreme-soft soils, both untreated and treated, were experimentally evaluated by means of a modified vane undrained shear apparatus. Samples of extreme-soft soil are prepared from bentonite ranging from 2% to 10%, to reach this target. There is a separate treatment for the 10% prepared soft adding different lime percentages (up to 20%) and polymer (up to 5%). The soil samples from the treated samples were kept for curing period in open and closed-air conditions for up to 180 days. It has been observed in the study that untreated extreme-soft soil with untreated undrained shear strength between 0.001kPa to 0.0017 kPa correspondingly (bentonite 2% - 10%). Also, at 28 days curing time in a closed-air condition, the 20% lime-treated 10% bentonite extreme-soft soil had gained 1959% undrained shear strength. In addition, the extreme-soft soil treated with 10% bentonite and 5% polymer has 600% greater undrained shear strength than the open-air condition (28 days of curing). Also, at 28 days curing time of 180 days in a closed-air condition, the undrained shear strength of 10% lime-treated 10% bentonite extreme-soft soil has been increased by 1273%.

A R T I C L E I N F O

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1. Introduction

Population growth across the world is faced daily with limited land proper for putting up structures. Therefore, in areas where extreme soft soils with low undrained shear strength and extraordinary compressibility exist, replacement environments are required [1]. The main method to enhance soil for placing structures safely concerning engineering parameters is soil stabilization. Various methods were used in the improvement processes, including structural reinforcement, surcharge load, the use of vibration, admixtures, grouting and so on [2].

The features Importance soil improvement, including increased soil bearing capacity, reducing the potential of the settlement both differentially or total, speeding up the time of occurrence of total settlement, minimize the potential of liquefaction in saturated soils, reducing ground permeability, and squeezing the soil's water. An ancient way of soil enhancement is replacing the shale soil with appropriate fill material. Nonetheless, this method is usually extremely costly because of the price of excavation, expulsion of the supplant material when soil is too delicate. Different models for establishing shear strength value at corresponding liquid limit based on literature are proposed in Table 1. Table 2 identifies the correlations of tested soil shear strength versus physical properties.

Very broad-spectrum application has been used in the improvement of soft soil [3] and a family of solutions relied on cement, lime, fly ash [4][5][6][7]. As stated by [8],[9], cement column has been used for the improvement of soft ground. In addition, soil reinforcement has been utilized to expand the load-performance capacity of the underlying soil as described by [10],[11]. Lime and cement are then used for chemical stabilization [12], [13], [14], [15], [16], [17], [18], [19],[20],[21]. Nonetheless, such organic materials can provide acceptable stiffness with fragile functioning [20], [22].

Table 1. The relationship of tested soil shear strength versus soil liquid limit (LL) from literature.

Reference	Undrained soil shear strength (kPa) at corresponding LL	LL range	Name of test	Notes
[23]	0.7 to 1.75	30 to 97	Vane device	• Less than 1 kPa is the undrained shear strength. • Experimental work. • Undisturbed soil samples.
[24]	0.8 to 1.6 for British standards and 1.1 to 2.3 for American standards	40 to 72	Small Vane device	• Measured soil strength if 25% to 50% is more than ASTM. • Laboratory tests. • Undisturbed soil samples.
[25]	1.3 to 2.7	32 to 190	Vane device	• Higher than 1 kPa undrained shear strength is quantified. • Experimental work. • Undisturbed soil samples.
[26]	1 to 3	17 to 382	Vane device	• The undrained shear strength began from 1 kPa. • Laboratory work. • Both field and reproduction soil samples.
[27]	Average value of 1.7	26 to 190	Vane device	• The tested soil average value was 1.7 kPa. • Laboratory work. • Field soil samples.
[28]	1.7 to 2.8	36 to 159	Vane shear Test”	• The tested soil strength is higher than 1 kPa. • Laboratory work • Undisturbed soil samples.
[29]	0.5 to 5.6 0.8 to 4.8	27 to 526 30 to 328	Vane device	• The tested soil strength is lower than 1 kPa. • Laboratory work. • Both natural and artificial soil samples.
[30]	0.2 to 2.04	27.4 to 62.8	Viscometer device	• Less than 1 kPa is the undrained shear strength. • Laboratory work. • Artificial soil samples.
[31]	0.66 to 1.35	29.8 to 100.8	Viscometer device	• Lower than 1 kPa is the tested soil strength. • Laboratory work. • Natural and artificial soil samples.
[32]	1.2 to 12	26.4 to 83.6	Vane device	• Higher than 1 kPa is the undrained shear strength. • Laboratory work. • Undisturbed soil samples.
Notes	The range varied from a minimum value of 0.2 kPa to a maximum value of 5.6 kPa	Minimum 17% and maximum 526%	Mostly vane device	Tested soil strength is mostly less than 1 kPa. Most of the work is experimental. Infrequently offshore soil samples.

Table 2. Correlations of undrained shear strength versus physical soil properties.

Reference	Soil type	Relationship	Soil samples	Notes
[33]	Field CL soil	$\tau = 170e^{(-4.6I_L)}$	Onshore and laboratory soil samples	• τ versus I_L.
[34]	Field CL soil	$\tau = 1.6e^{4.23(1-I_L)}$	Onshore and laboratory soil samples	• τ versus IL. • Soaked clay samples. • Undrained shear strength is measured at 1.6 and 110 kPa for LL and PL, correspondingly.
[28]	Field CL & CH soils	$\tau = e^{5.26(1.161-w/w_L)}$	Onshore and experimental soil samples	• τ versus values of w/wL. • Water content is at high range. • Undrained shear strength is quantified using cone penetration method.
[35]	Field CL and CH soils	$\tau = \frac{1}{(I_L - 0.21)^2}$	Onshore and laboratory soil samples	• τ versus IL. • IL range is (0.5 to 2.5). • Undrained shear strength is predicted to be infinite at IL equals 0.21 and it cannot be expanded more than this value.
[30]	Artificial CH soil	$\tau = (19.81/I_L)^{2.64}$	Laboratory soil with onshore samples	• τ versus IL values. • IL values ≤6. • When IL range is (2 to 5), the soil strength was 90 to 5 Pa.
[36]	Mostly CL Field soils	$\tau = 3718.1(w_n)^{-1.18}$	Experimental onshore soil	• τ versus wn values. • The soil is low plastic clay. • Low unconfined soil shear strength value.
[37]	Field CL & CH soils	$\tau = 8.779e^{-2.3714(w/w_L)}$	Laboratory and onshore soil samples	• τ versus w/wL values. • Using degraded disturbed samples. • Soft soil with high compressibility.
[38]	Field CL soil	$\ln(\tau) = 11.5 - 2.21\ln(w)$	Laboratory and onshore soil samples	• τ versus w
[39]	Natural CL soil	$\tau = 144.9e^{(-1.72I_L)}$	Onshore and laboratory soil samples	• τ versus IL. • Various soil types. • The undrained soil shear strength was 35 kPa.
[39]	Field CL soil	$\tau = 191.4e^{(-0.03w_L)}$	Onshore and laboratory soil samples	• τ versus wL. • Various soil types. • Undrained soil shear strength less than35 kPa.
Notes	Predominantly CL soils.	Soil shear strength versus water content	Onshore and laboratory soil samples	• Various soil types. • Water content is less than LL. • Variety range of undrained soil shears strength.

Remarks: τ are described in given equations have kPa units, w_p is plastic limit, w_L is liquid limit, I_C consistency index, I_p is plasticity index, I_L is liquidity index, Several tests, including CBR, direct undrained shear, and unconfined compression, have also been conducted [40], [42], [43], [44], [45], [46], [47]. According to [48], the presence of fiber progressed the fracture decrease and hydraulic permeability of remolded compressed clayey soil.

Experimentation using admixtures for soil stabilization started between 1970 and 1980 in Japan. This technique penetrated into the ground during the injection and mixing stage by paddles, mixer shafts and jets. The improved soil strength will also be higher than the original soil and is of lower settlement and drop in hydraulic permeability [49]. The admixture may contain cement, lime, bitumen and oil where these materials are established and applied in soil improvement.

Deep mixing procedure could consider as a practical effective technique in low-strength clay. The formed column has different diameter range with a minimum value of 0.5 to a maximum value of 1.0 m with a total length of 25 m and the formed pillars are connected to achieve that cellular arrangement of constructed wall. Dry mixing is an effective procedure for ground improvement, where the strength achieved after the treatment can be varied by changing the amount of lime, cement and mixing additives [50],[51].

In general, however, grouts are used because they can usually gel faster and therefore penetration will be deeper. Before stopping, when grouting, the gelling shifts the ending grout to the exterior of the mass to fill small and large voids. Jet grouting is based on this principle, and it under all forms of deep mixing. It uses air and water (with/without grout) to mix the filed soft soil with the mixture of grout. Soft soil's stiffness with undrained soil shear strength is improved [52]. This technique was mainly framed towards a way to enhancing the efficiency of water storage through biochemical mortaring by corroding the soft soil that was later disposed of by filling cement slurry [53],[54].

Present mortaring began in the digging ventures connected with the gushing and quality power in the stores, shaft and tunnels then it was utilized in common building. Depending on the application, the condition of the field and purpose of grouting, there are several functions of grouting. This career includes penetration grouting, compaction cementing, hydro crack mortaring, rock filling, jet fracture, grouting and cement filling. The difference between the grout features and the field soil type was accessed due to unique grouting functions. Chemical grouts are different from cementitious grout and are sent into soil voids containing particles in a fluid medium. The chemical grout can also occupy voids up to 10 to 15 μm in size. The main grout properties are the setting time, rheology, toxicity, strength, stability, penetration and water tightness [55].

The principal target of the work is to prepare the low undrained shear strength bentonite extreme-soft soil utilizing a newly modified experimental device. Specifically, 28 days curing time in open and confined-air conditions is required for the prepared extreme-soft soil treated using various percentages of lime and polymer. Moreover, the lime treatment of extreme-soft soil must be checked in closed-air conditions after 180 days.

2. Materials and Methods

2.1. Bentonite

Laboratory bentonite extreme-soft soil 2% and 10% bentonite was prepared using general light gray industrial sodium bentonite. For the used bentonite, the liquid limit (LL) value was 500 while the plastic limit (PL) value was 100. The density of bentonite varies from 2.65 kN/m^3 to 2.75 kN/m^3. This bentonite can be used to prepare artificial extreme-soft soil with sufficient viscosity and undrained shear strength to achieve a low filtrate loss.

2.2. Lime

Lime is utilized for the treating of extreme-soft soil in either the type of quick-lime known as (CaO) or hydrated lime recognized as ($Ca(OH)_2$). The quick-lime is produced depending on organic processes that change the calcium-carbonate known as (limestone-$CaCO_3$) to calcium-oxide identified as (CaO). As the quick lime mixes using water, it becomes hydrated-lime. The obtained hydrated-lime alters and modifies extreme-soft clay constituents.

2.3. Polymer

Acrylamide polymer: the mix consists of 15% polymer, 0.5% catalyst, and 0.5% catalyst, and 84% water. Hence, the obtained polymer was the one with 15% of dissolved polymer. The value of pH for the polymer solution was 15. So, 0.05% active polymer content is obtained, which should be used for the treatment of extreme-soft soil using 10% of the polymer solution.

3. Modified Vane Undrained Shear Device

Concept of vane undrained shear device was created and tested in (Sweden) at the late of (1940s). The soft soil shear strength is determined based on vane undrained shear test computing spin force (T_{max}) and cycles [56]. The device contains four tinny rectangular fins or arms attached at the ends of a lengthened circular small rod [57]. Particularly, the vane device is approximately two widths in height. The performed test is conducted by embedding the vane for double the vane height in the soil and then spinning it at a steady angle amount between 0.1 to 0.2 grades, pending the soil test to failure. The value of highest spin force required to get soil undrained sheared is subsequently altered to the soil shear strength (undrained condition) of the cylinder-shape plane. The torque mobilized to undrained soil shear strength being tested is calculated using the degree of rotation. Figure 1 shows a vane undrained shear device.

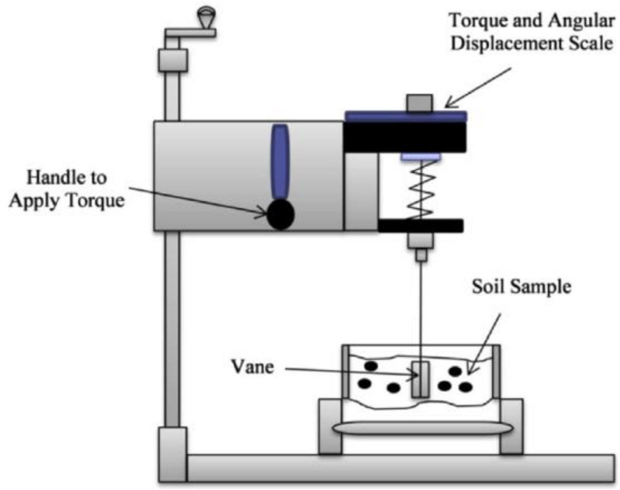

Fig. 1. The vane undrained shear device.

4. Results and Analysis

4.1. Pure Extreme-Soft Soil

Samples of extreme-soft soil were arranged in the research laboratory through addition of various proportions (2% to 10%) of locally available bentonite with tap water at ambient temperature for almost ten minutes till they reached uniform moisture. Prepared samples were taken slurry having a diameter of 50 mm and a height of 100 mm in cylinder-shape flexible types. The undrained soil shear strength for the prepared samples was evaluated using vane undrained shear device. A major challenge of laboratory testing or even field testing is the proper evaluation of extreme-soft soil undrained shear strength, thus; we utilize the modified vane undrained shear apparatus to quantitate the excessive-low undrained shear strength of the untreated extreme-soft soil. Figure 2 infers both undrained soil shear strength in addition to water content value of extreme-soft soil prepared using different percentage of bentonite. The undrained soil shear strength value extended from 0.0001kPa to 0.0017 kPa as the water content value was reduced from 98% to 90% through increasing bentonite solid substances from 2% to 10%, correspondingly.

4.2. Long-Term Extreme-Soft Treatment

The ability of any employed treating agent is computed by its capability of sustained long-term action. Therefore, there is a need to inspect the efficiency of lime and polymer in treating extreme-soft soil in their long-term performance. It is a necessity to find out which factors are having a significant influence in the individual effect of lime and polymer in the ratio of 10% bentonite with respect to undrained shear strength and water content study after 28 days. Methods Different treating conditions such as air-closed (closed curing) and air-opened (air-curing) schemes have been maintained.

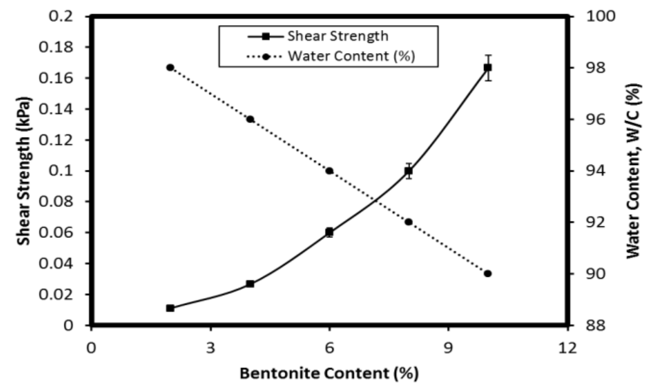

Fig. 2. The association of undrained soil shears strength and water content change versus bentonite substance for untreated extreme-soft soil.

Figure 3 depicts the relationship of undrained soil shear strength as a function of lime content added to 10% extreme-soft soil in closed curing condition. Overall, the undrained soil shear strength of the 10% extreme-soft soil, is enhanced for increasing lime content amount, where it can be higher for further curing duration. The rise in the undrained shear strength by 95% for 0% lime content and 1959% for 20% lime content is achieved when the preserving time ranged from 0 day to 28 days. Moreover, for the addition of lime with a minimum value of 0% to a maximum value of 20%, the undrained soil shear strength is raised by 14%, and 1103% after 0 day, and 28 days curing period, correspondingly.

Figure 4 identifies the relation of water content value vs lime substance added to 10% extreme-soft soil during long-term change in closed cure conditions. Specifically, when the substance of lime is increased, the water substance of the 10% bentonite extreme-soft soil is reduced because of growth of solid contents in the prepared sample. The decrease in water content, when the curing interval is increased from 0 to 28 days, is 7 and 37% for 0% and 20% lime substances, correspondingly. In addition, increasing the lime substance from a minimum value of 0% to a maximum value of 20% reduces the water content values by 22%, and 47% at 0 day, and 28 days curing duration, correspondingly.

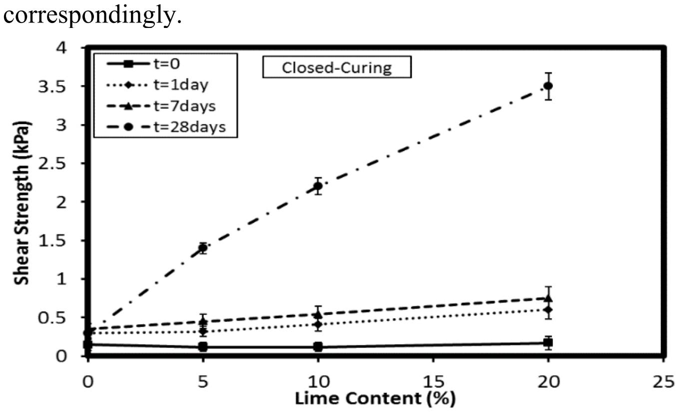

Fig. 3. The long-term undrained soil shear strength changes versus lime substance for 10% bentonite extreme-soft soil cured in closed-air condition.

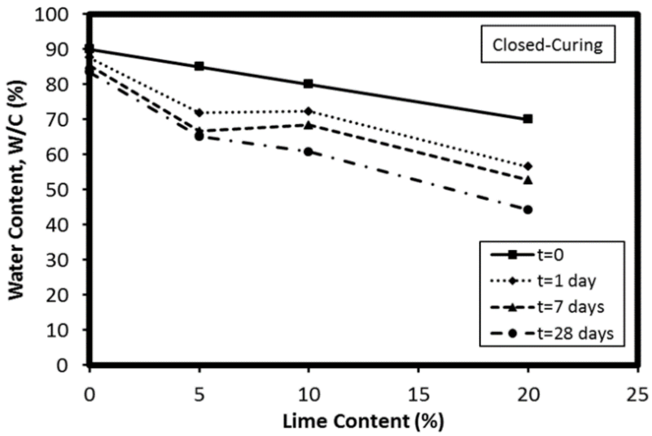

Fig. 4. The long-term water content change versus lime substance for 10% bentonite extreme-soft soil cured with lime in closed-air condition.

Figure 5 illustrates the long-term relationship of the undrained soil shear strength using lime substance treating 10% extreme-soft soil under air curing condition. It is demonstrated from the literature that increasing the lime proportion will also increase the undrained shear strength which is higher for a longer curing duration. The undrained shear strengths were raised by 487% and 3005% for 0% and 20% lime substances correspondingly, when increasing the curing period from 0 day to 28 days. Furthermore, for the improvement in lime substance from a minimum value of 0 % to a maximum value of 20 %, the undrained soil shear strength was increased as 14 % and 504% at the curing time of 0 day and 28 days, correspondingly.

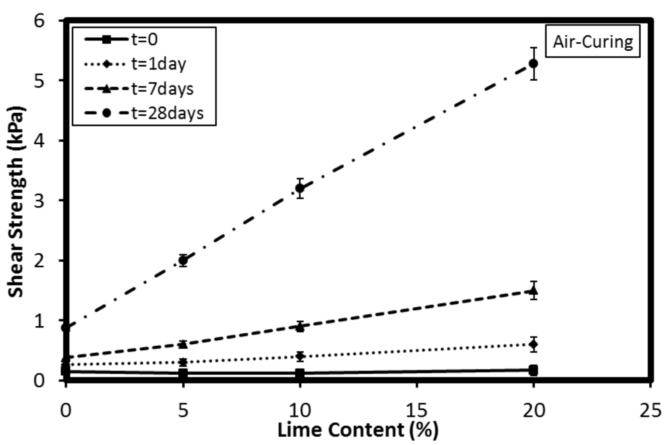

Fig. 5. The long-term change of undrained soil shear strength versus lime substance for 10% bentonite extreme-soft soil cured in air-curing condition.

Figure 6 presents the long-term change of water content value for 10% bentonite extreme-soft soil treating with different lime content in air-curing condition. Increasing in lime content is resulted in reducing the water content value of the 10% bentonite extreme-soft soil as the solid substance in the tested medium is increased. The amount of water is reduced 33% and 73% for lime contents of 0% and 20% correspondingly for the increment of curing time from 0 day up to 28 days. Also, by increasing the lime amount from 0% to 20%, the water content is reduced up to 68% and 87% for curing duration of 0 day and 28 days, correspondingly. Remarkably, the undrained shear strength increases up to 200% and 51% with air-curing instead of closed-curing with 0% and 20% lime substances at a curing time of 28 days, correspondingly. In addition, when changing the curing conditions from close-cured to air-cured, the reduction in water content was 27% and 57% for a minimum value of 0% and a maximum value of 20% lime substances correspondingly at a curing time of 28 day.

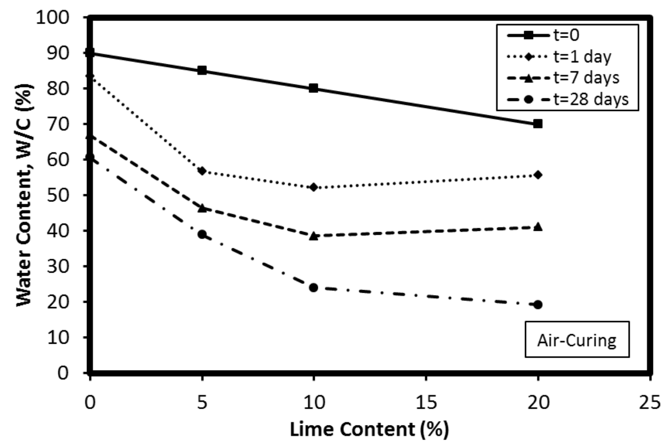

Fig. 6. The long-term change of water content values versus lime substance of 10% bentonite extreme-soft soil cured in air-curing condition.

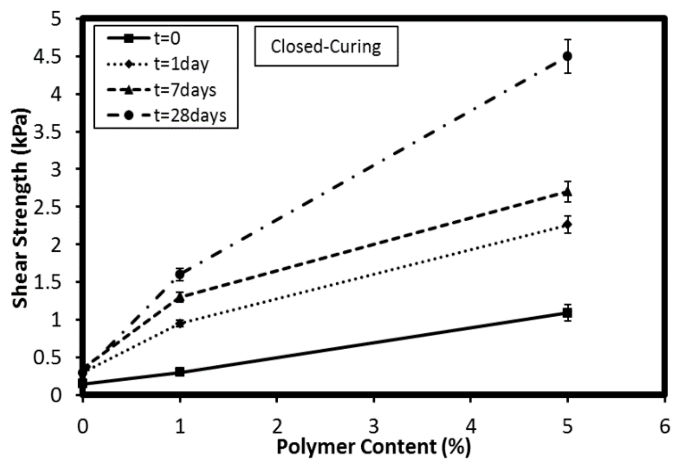

Fig. 7. The long-term change of undrained soil shear strength versus polymer substance for 10% bentonite extreme-soft soil cured in closed-air condition.

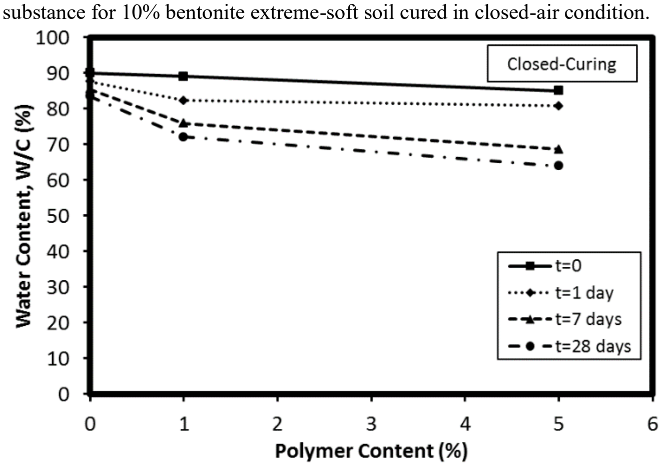

Fig. 8. The long-term change of water content value versus polymer substance for 10% bentonite extreme-soft soil cured in closed-air condition.

Figure 7 shows the long-term evolution of undrained soil shear strength treated with polymer substance of 10% bentonite extreme-soft soil cured under closed condition. Increase in the polymer substance increases the undrained soil shear strength of the 10% bentonite extreme-soft soil where high undrained values are observed for extended curing time. The undrained shear strength increases by 95% and 313% comparing 0 day and 28 days curing time for 0% and 5% polymer content, correspondingly. Moreover, the undrained soil shear strength of the extreme-soft soil is increased by 632% and 1446% at a curing time of 0 day and 28 days correspondingly for polymer increase from 0% to 5%. It is indicated in Figure 8 as the long-term relationship of water content value vs polymer substance for the closed-curing condition of the treated 10% bentonite extreme-soft soil. The water content values of 10% bentonite extreme-soft soil decreases with the increasing solid content. Moreover, further increase of curing duration from 0 day to 28 days, the water content value is reduced with 7% and 25% for 0% and 5% polymer substances correspondingly. In addition, as the polymer substance increases from 0% to 5%, the water content decreases by 6% and 23% at 0 day and 28 curing period, correspondingly.

It is obvious that in closed-curing condition when treatment agent is altered from 20% lime to 5% polymer, the undrained shear strength shows to be increased by 541% and 29% at curing time of 0 day and 28 days, correspondingly. However, when 20% lime is switched with 5% polymer substance in closed curing condition, the water content value decreases by 21% and 44%, at the curing time of 0 day and 28 days, correspondingly.

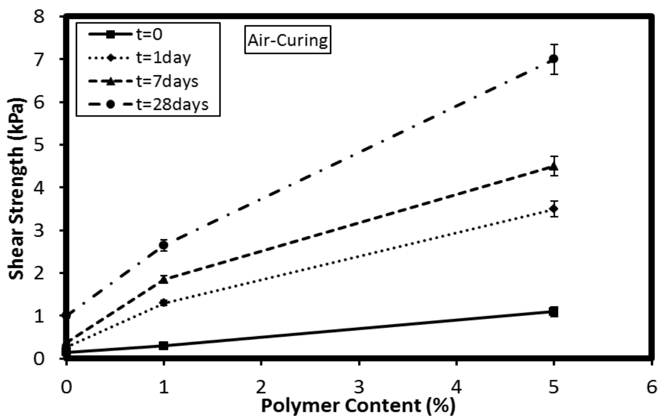

Fig. 9. The long-term change of undrained soil shear strength versus polymer substance for 10% bentonite extreme-soft soil cured in air-curing condition.

Figure 9 shows the correlation of long-term undrained soil shear strength with polymer substance of 10% bentonite extreme-soft soil as cured in air-condition. When the content of polymer increases, undrained shearing resistance of the 10% bentonite raw soil rises sharply and the greater undrained shear strength is observed for extended curing duration. Final results denoted that the undrained soil shear strength was increased by 571% and 537% for 0% and 5% polymer substances, correspondingly, via curing time increase from 0 day to 28 days. At a curing time of "0 day and 28 days", when the polymer substance increases from 0% to 5%, the undrained shear strength increases by 636% and 600%, correspondingly. In the figure, the long-term evolution of the water content value vs polymer substance for the 10% bentonite extreme-soft soil in air-curing condition is identified. By increasing the polymer substance, they reduce the content of water. The proportion of water is reduced up to 0% and 5% polymer contents as the curing time increases to 28 days as 33% and 46%. The increase in polymer from 0% to 5% leads to decrease in water content by 6% and 25% at curing time of 0 day and 28 days correspondingly. For 28 days of curing time, the undrained shear strength value is increased by 244% and 56% when the curing circumstance is altered from closed-air to air-curing and the water content value is reduced by 27% and 28% for 0% and 5% polymer substances, correspondingly. By changing the conduct cause from 20% lime content to 5% polymer content in air-curing condition, 545% and 33% increase in undrained shear strength and 8% and 137% decrease in water content at the curing duration of 0 day and 28 days, correspondingly.

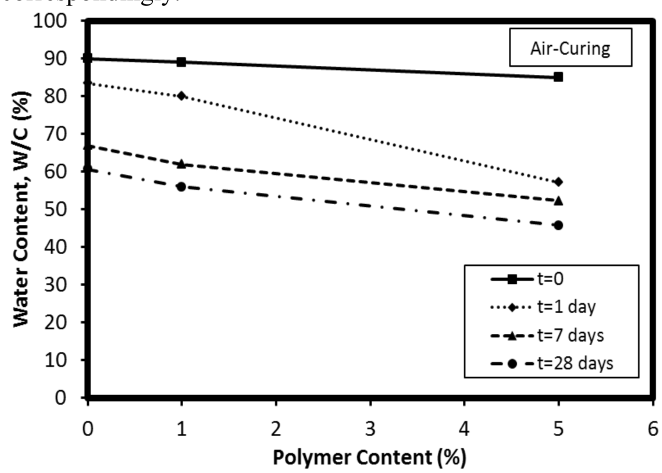

Fig. 10. The long-term change of water content value versus polymer substance for 10% bentonite extreme-soft soil cured in air-curing condition.

Because of the high-approval of utilizing lime as one of the soil modification agents, an investigation of 10% of bentonite extreme-soft soil treated with lime content up to 180 days with closed-curing condition is proposed. Soil's undrained shear strength and moisture content value at 10% usage of bentonite extreme-soft soil from lime are studied. In Figure 11, the association of undrained shear strength in all samples, and the long and short-term change (long term 10%, 6-month, short term 3, 7, 14, 21 days), with 10% lime contents of bentonite extreme-soft soil samples treated under closed-curing conditions is showed. The growth in undrained soil shear strength when curing duration increased from 0 day to 28 days are 645% and 10% lime substance is 10125%. At 0 day curing time, the undrained soil shear strength is almost constant in case of lime substance increases from 0% to 10%. When the lime is increased from a minimum value of 0% to a maximum value of 10% the undrained soil shear strength increases by 1273% at curing duration of 180 days. Figure 12 identifies the relationship of the short-term and long-term changes of the water content value and undrained shear strength of 10% bentonite extreme-soft soil modified by lime substance in closed-curing mode. When the lime substance increases from 0% to 10%, the water content value is reduced by 69% at the 180-day curing period. The long-term outcomes have indicated that the cured extreme-soft soil undrained shear strength has been growing with time and its moisture content value has been reducing with time. Additionally, the research has shown that polymer is more effective treatment agent compared to lime.

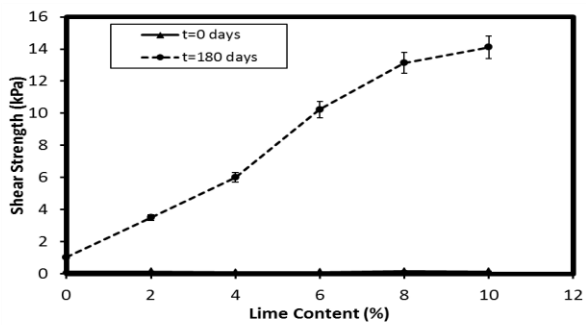

Fig. 11. The relationship of the short and long-period change of the undrained soil shear strength with the lime substance for the 10% bentonite extreme-soft soil cured in closed-curing condition.

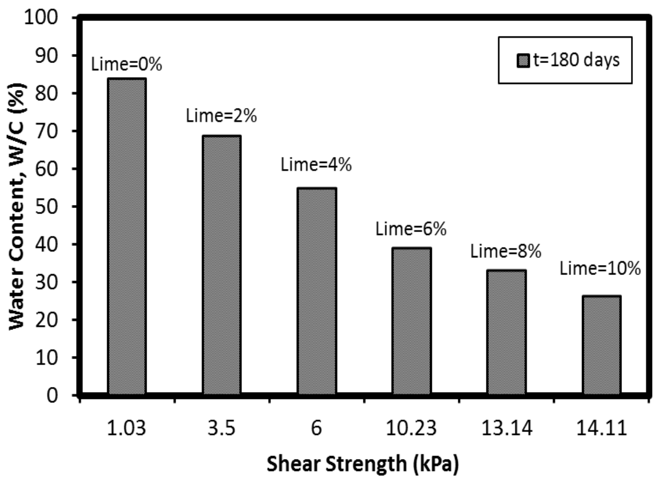

Fig. 12. The relationship of the short and long-period changes of the water content values versus undrained soil shear strength for the 10% bentonite extreme-soft soil cured with lime in closed-curing condition.

5. Conclusions

A laboratory sample of extreme-soft soil is prepared in the laboratory from bentonite with 2 to 10% increase in percentage. The treatment of prepared 10% bentonite extreme-soft soil are performed separately with various fractions of lime and polymer and are then cured in open and closed-air conditions and cured of 28 days. A modified vane undrained shear device has been utilized to test all untreated and treated extreme-soft soils. The work found the following:

1. The undrained soil shear strength value of prepared bentonite extreme-soft soil (≥ 0.0001 kPa to ≤ 0.0017 kPa) when the bentonite solid substance range is 2% to 10%.
2. Undrained shear strength of lime-treated 10% bentonite extreme-soft soil under closed-air curing condition is improved by 95% and 1959% when the curing duration is increased from 0 to 28 days for 0% and 20% lime substances, correspondingly.
3. In the closed-air curing condition, the water content of lime treated 10% bentonite extreme-soft soil decreased by 7% and 37% as the curing period increased from 0 to the 28 days for the 0 and 20% lime substance.
4. Under open-air curing condition, the undrained shear strength of 10% lime-treated bentonite extreme-soft soil increased by 487% and 3005% for 0% and 20% lime substances in 0 to 28 days curing.
5. Different lime contents produce equivalent AWC with varied moisture retention for speculating lime stability for opened cure 0 to 28 days: extremely low 33% and 73% water retained for 0% and 20% lime substances correspondingly, with respect to the 10% bentonite extreme-soft soil.
6. The undrained soil shear strength of lime-stabilized 10% bentonite extreme-soft soil is improved by 200% and 51% with 0% and 20% lime substances with 28 days for curing, when the curing state changes from closed-curing to opened-curing.
7. The water content value of lime-treated 10% bentonite extreme-soft soil is decreased by 27% and 57% for 0% and 20% lime substances, correspondingly, at a curing duration of 28 days when the curing condition is switched from closed-curing to opened-curing.
8. Under closed-air curing scenario, the undrained shear strength of polymer-fixed 10% bentonite extreme-soft soil increased by 95.2% and 313.9% as the curing period grew from 0 to 28 days for polymer content of 0% and 5%, correspondingly.
9. Under closed-air conditions, the water content of polymer-stabilized 10% bentonite extreme-soft soil decreases 7% and 25% by increasing the curing duration from 0 to 28 days for 0% and 5% polymer substances, correspondingly.
10. The increase in undrained shear strength is 541% and 29% when the conduct cause changes from 20% lime to 5% polymer cured in closed condition for 10% bentonite extreme-soft soil at the same curing period of 0 and 28 days.
11. A 50% reduction in water content is achieved by reducing the conduct cause from 20% lime to 5% polymer cured in closed condition for 10% bentonite extreme-soft soil after 0 and 28 days.
12. Under the opened-air curing condition, the undrained soil shear strength of 10% bentonite extreme-soft soil treated with polymer increases by about 571% and 537%, correspondingly, as the curing duration increased from 0 to 28 days for 0% and 5% polymer substances.
13. Under the condition of opened curing, for 10% bentonite extreme-soft soil treated with polymer, when 0% and 5% polymer substances in soil cures from 0 days to 28 days, its water content values are reduced by 33% and 46%, correspondingly.
14. The undrained shear strength is incremented (with respect to 20% lime) by 244% and 56%, for a curing time of 0 and 28 days, correspondingly, as the conduct cause is changed in 30% bentonite extreme-soft soil in opened-curing condition from 20% lime to 5% polymer.
15. The water content reduced by 27% and 28% at the curing durations of 0 and 28 days, correspondingly, with the aims of 20% lime changing to 5% polymer for high extreme-soft soil in an opened-curing condition.
16. For 10% lime content, the undrained soil shear strength of lime treated 10% bentonite extreme-soft soil is enhanced by 1273% for the closed-air curing condition when the curing time is increased to 180 days.
17. Under the closed-air curing condition, the water content values of lime-treated 10% bentonite extreme-soft soil is reduced by 69% for 10% lime content when the curing time is extended to 180 days.

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