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Study on the Unconfined Compressive Strength of Electricity-Modification Silicification Grouted Loess

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Silicification is one of the chemical methods of loess treatment. The mechanism of loess reinforced by electricity modified sodium silicate is studied for better silicification effect. Using unconfined compressive strength test, X-ray diffraction and SEM to explore the influence of the electric modified sodium silicate curing the loess. The results show that the mechanical strength of loess is basically improved with the higher voltage and the electricity time. The strength of loess first decreases and then increases with the increasing content of Na_2O and modulus basically. Amorphous phase peak groups appear in the X-ray diffraction patter. The SEM images show that the quanity of silica gel increased as the power voltage increasing, which covering the soil particles, bringing the soil grains closer and increasing the strength of the soil.

1. Introduction

The salicide method is the primary chemical method to treat the collapsible loess area, in which the physical and chemical reactions are made between the sodium silicate and loess. Chemical grouting has a long history. British engineer Hosagood built bridges in India using the chemical to consolidate the sand in 1884. Since then the experts and scholars from all over the world have studied silicification deeply. Lv et al., (2013, 2015) carried out the experimental study on temperature modified sodium silicate solidified loess; Zhao et al., (2004) found the sodium silicate slurry is mixed and finished to gel formation; Rzhanitsyn et al., (1969) used the CO_2-silicification grouted loess to strength the existing loess foundation; Zhou et al., (2014) analyzed the change mechanism of soil structure by measuring the change of resistivity in the process of double fluid silicification; Zhu et al., (1998) made the about the sodium silicate-bonded sand by silica sand surface modified in high temperature , and carried out the mechanism analysis; Ikeda et al., (2005) studied the properties of geological polymers excited by sodium silicate at different temperatures and analyzed the mechanism. At present, modified sodium silicate technology has achieved good results, but basically used for the foundation treatment of existing buildings. As one of the main methods of soil modification, the electroosmosis is widely used in soft clay and dredger fill projects which has the advantages of simple construction, high safety, etc. Electroosmosis was first discovered by Reussb in 1809, In 1887 the German engineer Jeziorsky created a silicification method and obtained a patent; Hu et al., (2010) analyzed the soft soil foundation by electroosmotic consolidation; Mohamad et al., (2011) compared the electroosmotic effects of iron, copper and aluminum electrodes; Turer and Genc, (2005) designed a horizontal one-dimensional Electroosmosis test instrument and conducted experiments; Fourie et al., (2007,2010) used electric synthetic material as the anode and conducted the electroosmotic consolidation test to the tailings for two months; Lockhart, (1983a, 1983b) investigated the effects of voltage, salinity, and exchangeable cations on the electroosmotic process; Casagrande, (1983) designed instruments to measure the changes of soil moisture content, fluid limit, shear strength, and other characteristics after applying the electric field; Burnotte et al., (2004) strengthened the soft soil by electro osmosis finding that the strength of soft soil increased obviously,

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and the consumption of electroosmosis only accounted for 7% of the total cost; Wang et al., (2014) conducted an electrochemical modification test on the silty silty clay. Therefore, the electric field was combined to modify the water glass to reinforce the Loess, and its mechanism, mineral composition and microstructure test were studied through the chemical composition.

2. Research Method

2.1 Equipment and Samples

Q3 remolded loess of Yan'an New Area was used in this experiment. The basic physical indexes of this silt uniform soil are given in Table 1. The soil was crushed and dried, then passed the 2mm sieve. A special mold was used to make 50mm×50mm standard samples of the loess. Then the samples were demolded immediately. After demolding, two stainless steel sheets were put on the both ends of the loess and the samples were electrified by voltage regulator. Preparation, demolding process of the samples had to be done fast, since the complete reaction between the water glass and loess led to the formation of silicate gel coating on soil particles, which would cause poor electrifying effect. After the electrifying, samples were covered with plastic film to keep its water content and were put into the constant temperature and constant humidity box for curing 28d. Later the samples were used in the unconfined compression test, chemical test and micro-examination at room temperature.

Table 1: The physical parameters of soil samples

Relative density d_s	Plastic limit w_p (%)	Liquid limit W_L (%)	Maximum dry density ρ_{dmax}	Optimum moisture content w_{op} (%)
2.71	17.4	31.1	1.78	14.7

2.2 Experiment protocol

Four factors were taken into consideration, including the content of Na2O in sodium silicate (0.4%, 0.7%, 1.0%, 1.3%, 1.6% which were measured by mass ratio), the modulus (0(Directly add NaOH), 1.0, 1.8, 2.6, 3.4), the voltage (40v, 55v, 70v, 85v, 100v), and the conduction time (30s, 50s, 70s, 90s, 110s). NaOH was added to raise the content of Na_2O to adjust the modulus. The experiment was made up by three groups. Group1 was blank control, and the compactness of samples in this group was 75%, 80%, 85%, 90%, with the water content of 15.6%. Group2 was orthogonal group (Table 2) and the samples were made following the $L_{16}(4^5)$ orthogonal table 2. 16 sets of remodelling samples were prepared and each set of 4 which was 64 pieces in total. The compactness of Group2 was 85% and water content was kept at 15.6%.

3. Result Analysis and Discussion

3.1 Effects of compactness on unconfined compression strength

Figure 1 shows compression strength and compactness when the compactness of samples are 75%, 80%, 85 %, 90%.

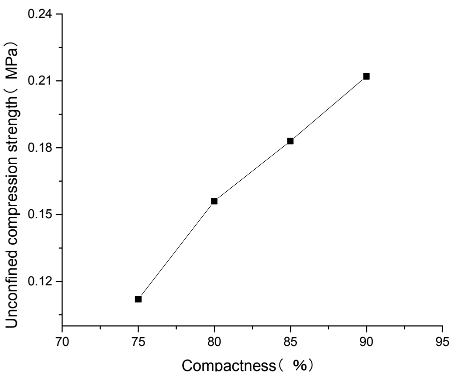


Figure 1: Relationships between unconfined compression strength and compactness

The figures 1 shows that the strength of the natural loess is less than the 0.212MPa when the water content is 90%, which is much lower than that of the high fill loess foundation. Therefore, it is very important to modify the loess.

3.2 Result Analysis of Orthogonal Test

Taking the orthogonal test method and the L16(45) orthogonal table into the test can reduce the amount of test, which would help determine the relationship between the various factors and laws with only 16 sets. The results are as follows Table 2:

Table 2: Orthogonal Test

Number	Na_2O (%)	Modulus (M)	Voltage (V)	Time (S)	Unconfined Compression Strength (MPa)						
1	0.4	0	40	30	475.8	17	1.3	1.0	100	70	678.4
2	0.4	1.0	55	50	498.6	18	1.3	1.8	40	90	486.1
3	0.4	1.8	70	70	643.2	19	1.3	2.6	55	110	714.2
4	0.4	2.6	85	90	912.4	20	1.3	3.4	70	30	789.4
5	0.4	3.4	100	110	699.8	21	1.6	0	100	90	681.6
6	0.7	0	55	70	469.8	22	1.6	1.0	40	110	778.1
7	0.7	1.0	70	90	562.7	23	1.6	1.8	55	30	721.4
8	0.7	1.8	85	110	538.4	24	1.6	2.6	70	50	834.9
9	0.7	2.6	100	30	668.1	25	1.6	3.4	85	70	978.3
10	0.7	3.4	40	50	643.5	K1	645.9	584.7	599.6	642.4	
11	1.0	0	70	110	572.9	K2	576.5	614.9	663.6	670.8	
12	1.0	1.0	85	30	557.1	K3	662.4	608.6	680.6	676.9	
13	1.0	1.8	100	50	653.7	K4	678.3	748.9	741.9	711.3	
14	1.0	2.6	40	70	614.7	K5	798.9	804.9	676.3	660.7	
15	1.0	3.4	70	90	913.8	range	222.4	220.3	142.3	68.9	
16	1.3	0	85	50	723.4	Optimal	5	5	4	4	

This paper uses "orthogonal test assistant" for data analysis. The larger the range is, the greater influence of this factor on the test-related indexes. Therefore, the strongest impact was caused by Na_2O content, the modulus and the voltage were following and the conduction time was the least one. In this circumstance, the optimal scheme was the set A5B5C4D4. Figures 5 to 8 show the unconfined compressive strength of each factor.

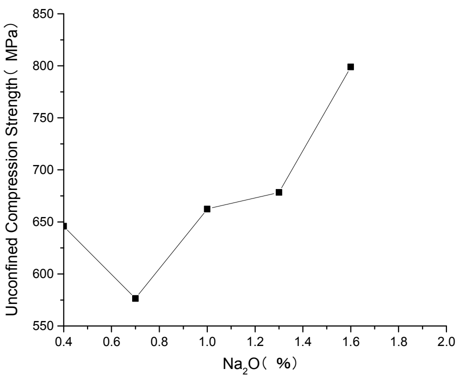


Figure 2: The effect curve of Na2O

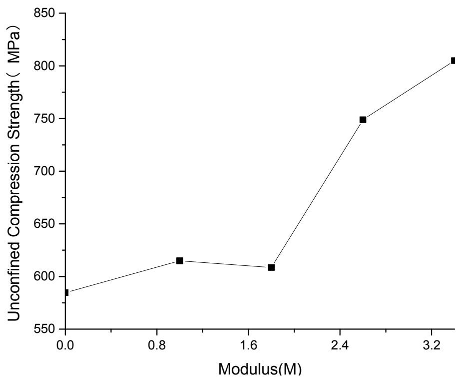


Figure 3: The effect curve of modulus

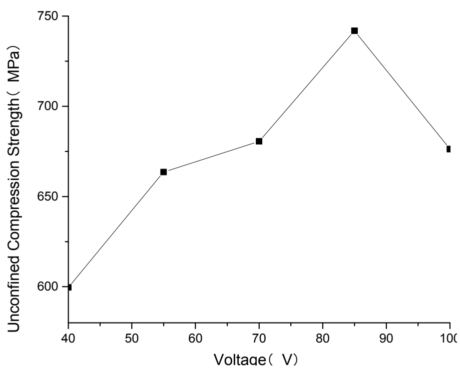


Figure 4: The effect curve of electricity voltage

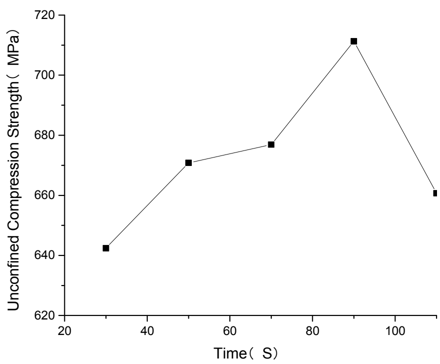
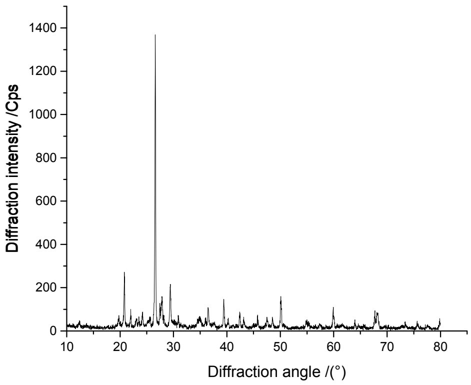


Figure 5: The effect curve of electricity time

It is shown by figure 2 that the unconfined compressive strength decreases first and then increases with the increase of Na_2O in the 0.4~1.0%. When the Na_2O content is more than 1.0%, the strength increased with the increase of the content. From the figure 3. When the modulus was 1.8, the strength was a little higher than the modulus was 1.0, higher than the modulus was 0. As the modulus increased, the strength increased and went to an extreme point. As shown by figure 4~5, with the increase of voltage and electrifying time, the intensity increases first and then decreases, and the turning points are at 100v and 110s respectively. This may be due to excessive discharge voltage or excessive electrifying time would cause damage to the soil, resulting in unconfined compressive strength reduction.

4. XRD analysis

X-ray diffraction (XRD) is widely used in the determination of crystal structure, which shows the result by superposing the coherent scattering of atoms in the crystal. This machine could scan 10°~90° under a speed of 4(°)/min and step size of 0.02(°)/s. The natural loess and improved loess whose modulus was 3.4 and content of Na_2O was 0.4% and electrified for 70s were taken into operation to analyse the phase structure of the loess, and the experiment was carried out at the Logistical Engineering college.



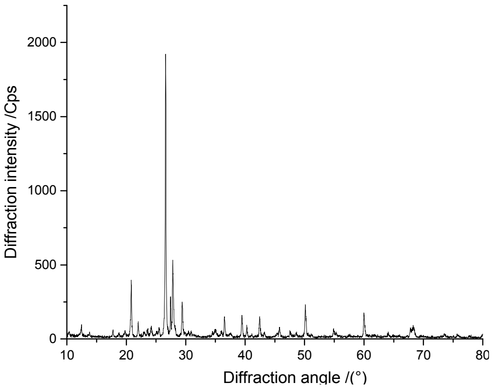


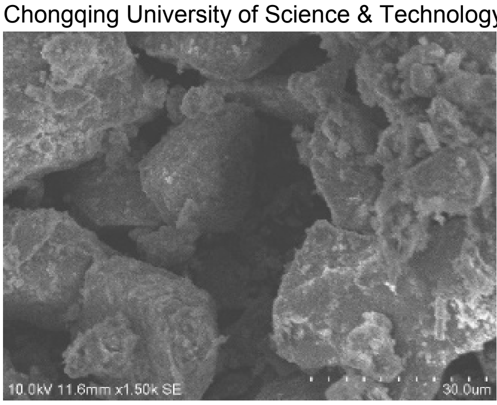
Figure 6: X-ray spectra of natural loess

Figure 7: X-ray spectra of improved loess

Comparing figure 6 with figure 7, the spectrum is basically consistent. There are some changes in the mineral part of the composition and a large number of amorphous phases low peaks show up densely. All these phenomenas indicate that the sodium silicate is reacting with the loess and causes the generation of silicate gel, resulting the stronger of the bond between minerals and the higher the strength of the soil.

5. Analysis of microstructure characteristics

The qualitative and quantitative analysis of soil microstructure is an important part of evaluating the engineering properties and mechanical properties of soil. In order to find out the mechanism electricity-modification silicification grouted loess, a scanning electron microscope (SEM), type S-3700N, was used to carried out the microstructure test of natural loess and modified loess samples, which the test was carried out in high vacuum while the samples were coated with a layer of metal film. This test was carried out in Chongqing University of Science & Technology.



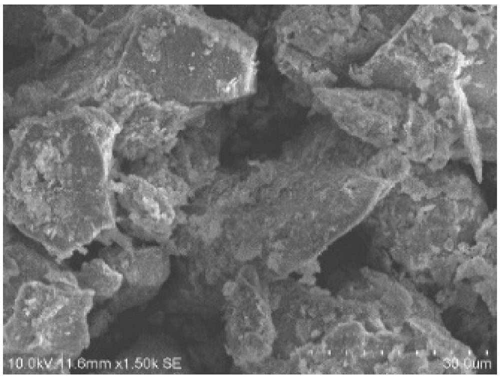
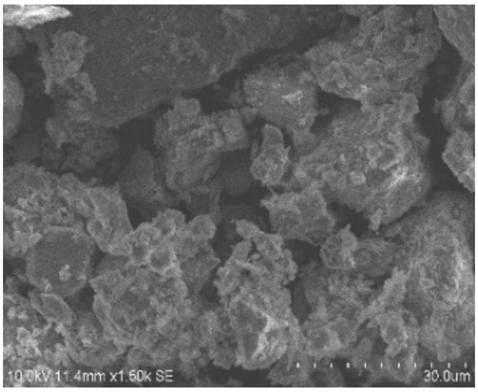


Figure 8: Natural loess

Figure 9: Electric voltage=40v



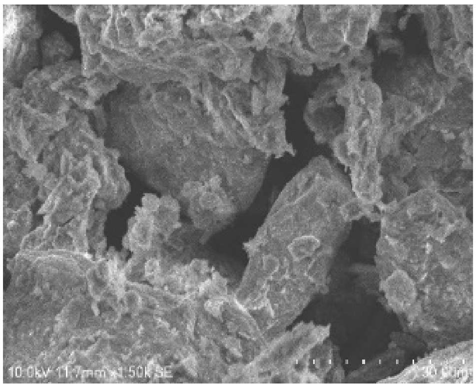
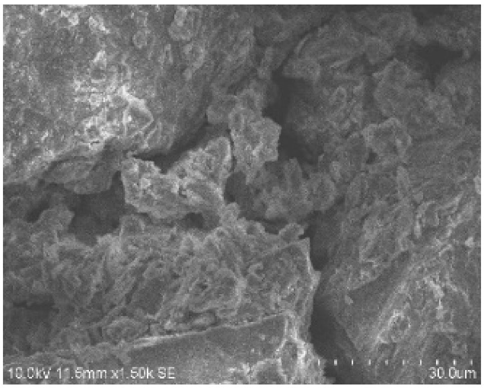


Figure 10: Electric voltage=55v *Figure 11: Electric voltage=70v*



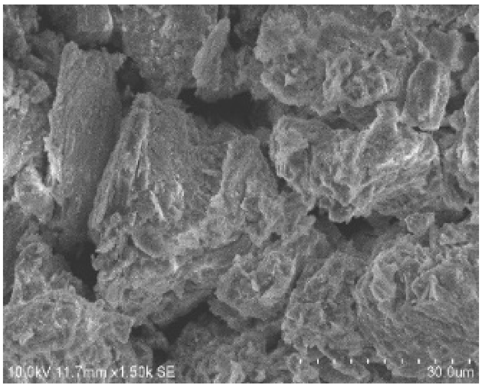


Figure 12: Electric voltage=85v *Figure 13: Electric voltage=100v*

Figure 8 is a natural loess SEM image, Figure 9~13 are the improved loess by the sodium silicate whose modulus was 3.4 and content of Na_2O was 0.2% and electrified for 30s with a voltage of 40v, 55v, 70v, 85v and 100v. The figures show that the structure of the natural loess is granular aerial structure or granular mosaic contact structure. The Loess particles and their pores are clear, and the main cements in the pores are clay minerals and calcium carbonate. Overall, after the modification, the pore spaces of loess particles were filled with the silicic acid gel created by the chemical reaction. Adsorption exists on the surface of loess particles. The contact changes from point contact to surface contact between the particles. The particles become big and the edge of the particles becomes rough because of agglomeration. In general, the soil particles hold together, the connection of loess become strong, the soil deformation is reduced and the strength increases gradually.

6. Conclusion

(1) The optimal scheme was the set A5B5C4D4. The unconfined compressive strength basically increases with the increase of the energization voltage and the electrifying time, however, in 100v and 110s, the soil is damaged due to too much voltage and time, which make the strength of the improved soil decreases.
(2) XRD test shows that under the condition of energization, the peak value of XRD changes, producing large number of amorphous phases low peaks, which indicating that more silicic acid gels are produced, and the strength of the improved soil is getting higher and higher. The surface attachment of modified loess particles increased.
(3) Under the energized condition, the silicic acid gel produced by chemical reaction is coated on the surface of soil particles, increasing the contact area between the particles, making the loess particles connected into a space mesh, and the unconfined compressive strength is increased macroscopically.

Acknowledgments

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