Effect of Sulphate on Compressive Strength of Cement Stabilized Soil

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***Abstract*—Salt types and concentration have important effect on the performance of cement stabilized soil. In this paper, two kinds of sulfate were added into cement based material to prepare two kinds composite curing agents. Unconfined compressive strength of stabilized soil was studied. Then sulfate hydration products and micro morphology stabilized soil were analyzed. The results of the study show that, when cement based curing agent contained small amount of sulfate, strength of solidified soil is improved greatly; a preliminary analysis of the reasons may be formation of hydrated calcium sulphoaluminate in stabilized soil, which can fill in the pores and improve compactness of the stabilized soil structure, and thus improve the strength of the stabilized soil.**

***Index Terms*—sulfate, cement, curing agent, soil stabilization**

I. INTRODUCTION

Chemical stabilization/solidification treatment is one of rapid and efficient methods in foundation treatment [1]-[3]. At present there are lots of types curing agents and stabilization effect is also great difference [4]. In practical engineering curing agent used widely includes cement based and lime based curing agent [3]. Some industrial waste or organic matter material can also be as soil curing agent, but application is not widely [5]-[8]. By physical and chemical reaction, cement based or lime based curing agent can generate some cementitous hydration products, which make stabilized soil form solid structure and improve stabilized soil strength [3], [9]. Based on principle of cement chemistry [10], many factors would affect the hydration process of cement and lime to change types and quantities of hydration products. Effect of salts on the hydration of cement is great, and there are lots of study results [10]-[12].

For soft soil, especially saline soil, when cement based material was used as curing agent, salts would have great effect on strength of the stabilized soil [13]. While development rule of strength and reason are not clear. This paper preliminary studied influence of sulfate on the strength of cement stabilized soil.

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II. EXPERIMENTAL MATERIALS, METHODS

A. Raw Materials

Cement: cement used in this paper is P•O32.5, an ordinary Portland cement produced by Qiangli Cement Plant. 3d and 28d of compressive strength is 14.2MPa and 39.7Mpa, and chemical composition is shown in Table I.

TABLE I. CHEMICAL COMPOSITION OF CEMENT/%

Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Others
2.45	24.14	7.46	3.35	58.12	2.68	2.0

Soil: Two kinds of soils samples were used and the main physical and mechanical indexes of soil samples are shown in Table II.

Other materials: Na_2SO_4, $CaSO_4$ and $Ca(OH)_2$ powder were produced by Tianjin Fuchen chemical reagent factory, and purity are more than 99%.

B. Experimental Methods

1) Preparation of stabilized soil test block

The stabilized soil blocks for these experiments were prepared in 50mm compacted cubes, similar to GB/T 17671-1999, as follows:

The soils and curing agents were weighed then mixed using the SJ-160 mortar mixer for 60r/min for 30s, then mixed at 120 r/min for 3 minutes, pausing after the first minute to scratch the mixture off the blade and mixer wall.

The mixture was compacted into a cubic steel mold with a side length of 50mm into three layers. Using a mortar vibrator platform, each layer was vibrated for 60s in the steel model to compact. The excessive mixture of the top layer was removed, and the upper surface was covered with a plastic film to prevent evaporation.

Models with compacted mixture were placed into a standard curing room kept at 95% RH at 20±2 ℃. The stabilized soil cubes were extracted after 24 hours and continued curing for the designed curing period of 7 and 28 days.

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TABLE II. PHYSICAL AND MECHANICAL INDEXES OF SOIL SAMPLES

Index name \ Soil sample	Soil A	Soil B
e	0.87	0.96
w/%	45	49.7
w_L/%	28.6	46.7
w_P/%	19.7	27.6
r/kN/m^3	15.3	14
c/kPa	12.1	40.6
φ/ °	23.5	17
pH	7.3	6.4
activated silicon and aluminum amount /%	6.7	10.5

For strength tests, the soil cubic were tested directly without any further treatment. After the strength test, small cubic specimens (10 mm) were cut from the soil cubic sample and soaked in anhydrous alcohol for 2 days to stop the hydration and were subsequently dried in a vacuum desiccator at room temperature. Power specimens were prepared by grinding small portions of the dried specimens and passing the ground material through a 0.075 mm sieve.

2) Method for unconfined compressive strength (UCS) of stabilized soil

The stabilized soil cubes prepared using the above procedures were used to conduct the UCS after 7 and 28 days of curing. Three replicate specimens were tested as in JTJ 057-94, and the average of the results was used for analyses. The UCS was performed using a LQ-100S pavement material strength testing instrument manufactured by Beijing Tool Factory at a strain rate of 1mm/min.

Calculate the UCS of the specimens by formula (1)

$$R_C=P/A \quad (1)$$

where R_c is the UCS (MPa), *P* is the breaking load (N), and *A* is area (mm^2).

3) XRD experiment

A D/MAX-RC X-Ray diffraction determination instrument manufactured by Rigaku was used to perform X-ray diffraction analyses to evaluate hydrates types in stabilized soil. Instrument was set to maximum power 12KW, scanning angle range from 2.5° to 120°, and a 0.02°step size.

4) SEM experiment

Use an S-530 type scanning electron microscopy to test the microstructure of solidified soil. Electric current was set to 75mA and the voltage to 10～20KV.

III. EXPERIMENTAL RESULTS

A. UCS Test Results

Reference [4] have shown that, when $Ca(OH)_2$ was added into cement to form curing agent, UCS of stabilized soil would improve greatly. Therefore, in this paper cement based curing agent is mixed with a small amount of $Ca(OH)_2$. Detailed curing agent mixture ratio is shown in Table III and Table IV. The number in both of Tables is mass percentage of wet soil samples.

TABLE III. CURING AGENT MIXTURE RATIO/%

No.	Cement	$Ca(OH)_2$	Na_2SO_4	$CaSO_4$
A1	11.5	2	-	-
A11	11.4	2	0.1	-
A12	11.5	2	0.2	-
A13	11.6	2	0.3	-
A14	11.1	2	0.4	-
A15	11.4	2	-	0.1
A16	11.3	2	-	0.2
A17	11.2	2	-	0.3
A18	11.1	2	-	0.4
A2	7.5	2	-	-
A21	7.4	2	0.1	-
A22	7.3	2	0.2	-
A23	7.2	2	0.3	-
A24	7.1	2	0.4	-
A25	7.4	2	-	0.1
A26	7.3	2	-	0.2
A27	7.2	2	-	0.3
A28	7.1	2	-	0.4

TABLE IV. CURING AGENT MIXTURE RATIO/%

No.	Cement	$Ca(OH)_2$	Na_2SO_4	$CaSO_4$
B1	11.5	2	-	-
B11	11.4	2	0.1	-
B12	11.5	2	0.2	-
B13	11.6	2	0.3	-
B14	11.1	2	0.4	-
B15	11.4	2	-	0.1
B16	11.3	2	-	0.2
B17	11.2	2	-	0.3
B18	11.1	2	-	0.4
B2	7.5	2	-	-
B21	7.4	2	0.1	-
B22	7.3	2	0.2	-
B23	7.2	2	0.3	-
B24	7.1	2	0.4	-
B25	7.4	2	-	0.1
B26	7.3	2	-	0.2
B27	7.2	2	-	0.3
B28	7.1	2	-	0.4

The UCS of 7d and 28d curing period are shown from Fig. 1-Fig. 4.

Based on the above four figures, the following experimental results can be obtained: (1) For the two kinds of stabilized soil samples, when curing agent contained a certain amount of sulfate, UCS of all of stabilized soil samples were more higher compared with the reference group. For example for the soil samples of A, when the content of Na_2SO_4 increased from 0.1% to 0.4%, the UCS of 7d increased about 3.8%-38.5% and the UCS of 28d increased about 5.8%-30.8% compared with the UCS of stabilized soil sample A1. The UCS of stabilized soil sample B showed the similar law; (2) the strength increment of 7d was higher than that of 28d. For example for the soil samples of B, maximum strength of 7d is 36.4%, while maximum strength of 28d is 21%; (3) when the types and content of curing agent is same, the UCS of stabilized soil sample B is higher than that of A.

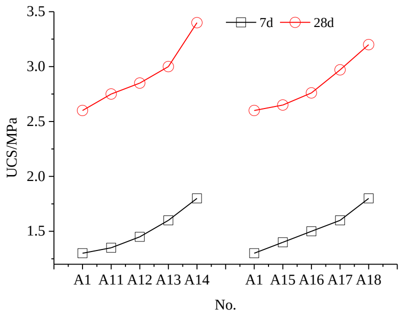


Figure 1. UCS experiment results of stabilized soil A when curing agent content is 14%

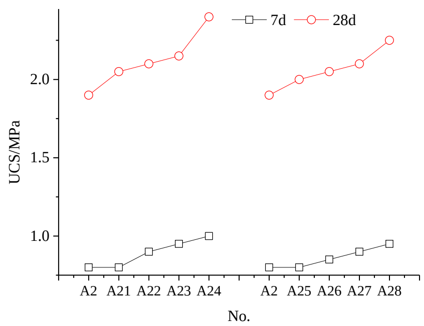


Figure 2. UCS experiment results of stabilized soil A when curing agent content is 10%

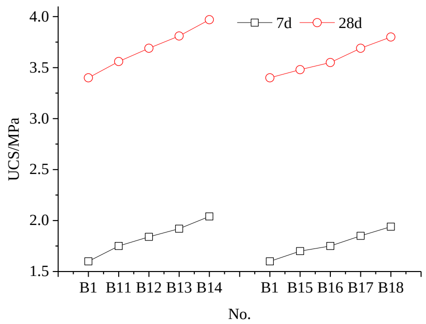


Figure 3. UCS experiment results of stabilized soil B when curing agent content is 14%

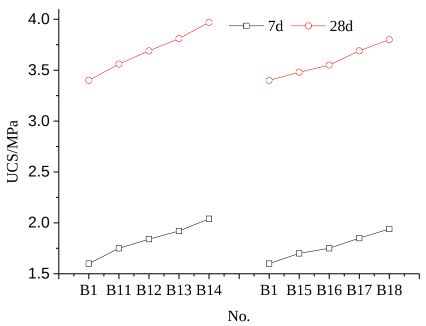


Figure 4. UCS experiment results of stabilized soil B when curing agent content is 10%

B. Results of the XRD Experiment

In order to study the above experiment law, XRD experiments were tested. This paper mainly study types and relative content of hydrates that is related with sulfur. The results of the study shows that, when the cement based curing agent contained some sulfate, sulfate would react with other component of cement and produce hydrated calcium sulphoaluminate; and with the increase of sulfate content, the peak value of hydrated calcium sulphoaluminate in XRD pattern. This indicated that amount of hydrated calcium sulphoaluminate increased with the sulfate content. Fig. 5 represents only the XRD test results of stabilized soil samples B1, B11, B12, B13, and B14. The other groups of stabilized soil sample had similar results with Fig. 5. In Fig. 5, ☆ represents diffraction peaks of hydrated calcium sulphoaluminate.

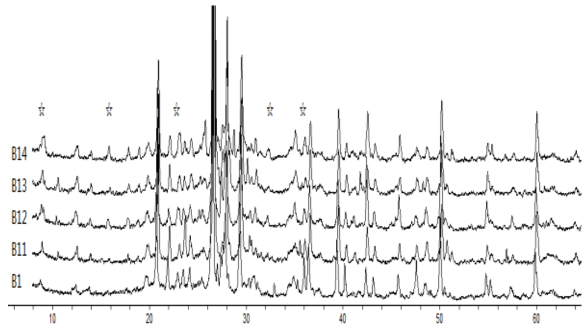


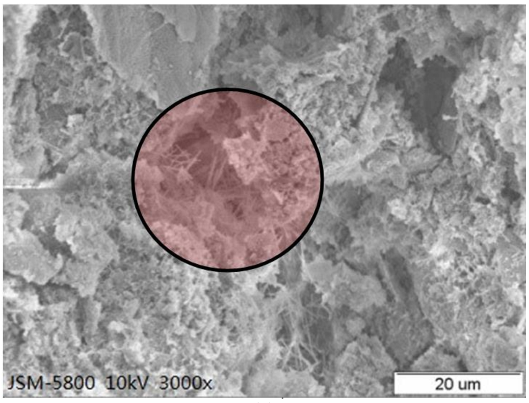
Figure 5. XRD test results of stabilized soil samples B1, B11, B12, B13, B14

C Results of the SEM Experiment

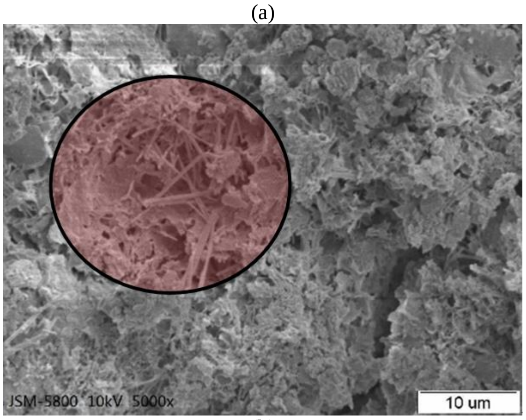
For further research the law of the UCS, the microstructure of stabilized soil samples were tested. SEM test results of B12 stabilized soil sample are shown in Fig. 6. The figure shows that: (1) when the cement based curing agent contained some amount of sulfate, stabilized soil sample would produce a certain amount of needle bar hydras-hydrated calcium sulphoaluminate; (2) the needle bar hydras will fill in the pores of stabilized soil samples(as shown in the drawing area in Fig. 6). This can improve the structure compactness and then improve the UCS of stabilized soil sample. This paper lists only the results of the SEM of B12 stabilized soil sample, meanwhile the other stabilized soil samples had the similar experimental phenomenon.

IV. Analysis

Reference [4] shows that when curing agent contained only cementitous components (such as cement), stabilized soil sample will produce only cementitious hydration products, which can only cement soil particle as a whole and make the stabilized soil sample generate a certain strength. However, in stabilized soil structure, there are some inevitable pores among soil particles. Cementitous hydration products can only cement soil particles, but cannot fill the pores. Thus when curing agent contained only cementitous component, stabilized soil had certain strength, but strength is not high. When the curing agent contains a certain amount of expansive component (such as sulfate), sulfate will react with the hydras of cement to produce a certain amount of hydration calcium sulfate (as shown in Fig. 5 and Fig. 6. According to the principle of the cement chemistry [10], solid volume will increase 127% in the process of formation of hydrated calcium sulphoaluminate. Therefore, the additional volume increment will be filled in the pores of stabilized soil, as shown in Fig. 6 there are lots of the hydrated calcium sulphoaluminate in the pores. The porosity decreased and UCS increase.



(a)



(b)

Figure 6. SEM test results of B12

Of course, based on the principle of the cement chemistry [10], excess of hydrated calcium sulphoaluminate may decrease the strength of concrete. And so on, excess of hydrated calcium sulphoaluminate may also decrease UCS of stabilized soil. In this study, the maximum content of sulfate was relative low and only 0.4% of wet soil samples, amount of excess of hydrated calcium sulphoaluminate are relative low. If continue to increase the amount of sulfate, whether UCS of stabilized soil would decrease or not is uncertain, and this is the next research.

V. Conclusion

According to the results of this study and analysis, we can get the following conclusions:

1) Compared with cement curing agent without any sulfate, when the cement curing agent containing a small amount of sulfate, the UCS of stabilized soil can be improved and the maximum UCS increment 28d is up to 30%.

2) When curing agent containing cement based material and sulfate were used to stabilize soil sample, stabilized soil would generate expansive hydras-hydrate calcium sulphoaluminate, which can fill in the pores of stabilized soil, dense structure of the stabilized soil and improve the UCS.

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