Mix proportion design and curing mechanism of solidified soil

Shaohua Guo[a], Yipeng Wang*[a], Qi Yang[a], Tianqi Wang[b], Hanglin Yu[b]

[a]Liaoning Provincial Transportation Planning and Design Institute Co., Ltd, China
[b] School of Civil Engineering, Shengyang Jianzhu University, China

* Corresponding author: yipengw@163.com

Abstract. In order to study the type of soil stabilizers suitable for coarse-grained soils and their curing mechanism, a total of 12 sets of mixing ratios were designed in this paper. The unconfined compressive strength, water stabilization properties, and SEM tests were carried out, respectively. The test results show that the stabilization of coarse-grained soil according to the recommended dosage of the three curing agents does not meet the standards for the use of highway subgrade. However, additional cement and gravel dosages can be made to be applied in highway projects. One type of inorganic curing agent is more suitable for stabilizing gravel soils than the other two. Under the action of the curing agent, C-S-H and AFt have been transformed into $Ca(OH)_2$ and AFm, making the microstructure denser and forming a complete and solid curing whole. The macroscopic performance shows that the specimen has good strength and water stability.

Keywords: Soil stabilizer; Gravel; Unconfined compression strength; Water stability performance.

1 Introduction

With the accelerated pace of transportation development, there is an increasing demand for roadbeds' strength and ecological harmony. Soil stabilizer is made of powdered functional materials such as coagulation-promoting materials, reinforcing materials, micro-expansion materials, water-repellent materials, and so on through physical mixing. Fine-grained soil, medium-grained soil, coarse-grained soil, or construction solid waste are used as the stabilized material; after mixing and curing at room temperature, a solidifying mixture is formed with a certain strength, good resistance to water erosion, good resistance to salt freezing performance [1]. Common types of soil stabilizers are the following four: inorganic binder soil stabilizer, organic polymer soil stabilizer, ionic soil stabilizer, and biological enzyme soil stabilizer.

According to studies, the addition of soil stabilizers to cement-stabilized soil can better improve the strength of the soil. Yi et al. [2] conducted strength tests on the mixture of cement, fly ash, and other components with different mass fractions of waste soft clay . The results showed that the incorporation of water glass could im-

D. Li et al. (eds.), *Proceedings of the 2023 9th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2023)*, Advances in Engineering Research 228,
https://doi.org/10.2991/978-94-6463-336-8_35

prove the strength and water stability of the soil. Rajakumaran [3] found that the use of steel slag-fly ash to reinforce the expansion soil is very good, and the best mix ratio is obtained. According to the 4% steel slag + 6% fly ash mix ratio, the curing effect of the expansion soil is the most obvious. Zhang et al. [4] conducted an experimental analysis of cured sandy soil and found that cement is effective in improving the shear strength and resilient modulus of cured soil, and fiber is particularly effective in improving tensile strength. Li et al. [5] studied the influence of enzymes on the microstructure of marine soil using fractal dimensions. They believed that the main role of biological enzymes in soil is to enhance the orientation and order of soil particles, improve the degree of aggregation and pore uniformity of particles, make the soil more compact, and enhance the cementation between particles. Marto et al. [6] studied the curing effect of liquid polymer soil curing agent SS299 on laterite. They found that after the curing age of 7 days, the unlimited compressive strength and shear strength continuously increased with the curing time and curing agent. Thus, they concluded that the optimal dosage of SS299 was 9%. Sai and Rama [7] used 30% cast sand and 7.5% cement as curing agents to improve the durability of laterite. The improved laterite had 3342.02 kPa of unlimited compressive strength after 12 dry and wet cycles. They believed that the mixture of these two substances could be used as a substitute for natural river sand to improve laterite.

2 Test raw materials and solutions

2.1 Test materials

The experimental soil was taken from Linghai City, Jinzhou, Liaoning Province. The liquid limit of soil is 27.4, and the plastic limit is 17.1, which is coarse-grained soil. G-1 and G-3 are inorganic soil stabilizers, and G-2 is an ionic soil stabilizer. All three soil stabilizers meet the requirements of the standard CJJT286-2018 and have stable properties. The relevant properties and recommended dosage of soil stabilizer are shown in Table 1.

Table 1. Performance indicators of soil stabilizer

Type of soil stabilizer	Water content /%	80 μm Sieve margin /%	Recommended dosage
G-1(A)	0.32	8.2	Component A 6%
G-1(B)	0.17	7.8	Group B is divided into 1.5% of component A
G-2	——	——	Cement 5%, soil stabilizer 0.02%
G-3	0.22	5.1	Cement 5%, soil stabilizer 3%

The cement is ordinary P.O.42.5 cement. The crushed stone is naturally crushed and well well-graded. The particle size is 5-20 mm.

2.2 Test methods

Unconfined compression strength is an important parameter to characterize the strength of materials. It is also an important mechanical index for determining the bearing capacity of road-based materials. It is tested according to the standard JTGE 51-2009 (in Chinese). The water stability coefficient is calculated according to the specification CJJT286-2018 (in Chinese). The microscopic morphology of the solidified soil was used by SEM relationship to analyze the curing mechanism of the soil stabilizer.

The mixing ratios of solidified soil are listed in Table 2. In the specimen designation AGa-b-c, a indicates the type of soil stabilizer, b indicates the additional cement content, and c indicates the amount of gravel content, respectively. AG1-0, AG2-0, and AG3-0 compared the stability of test soil under the recommended dosage of different soil stabilizer types.

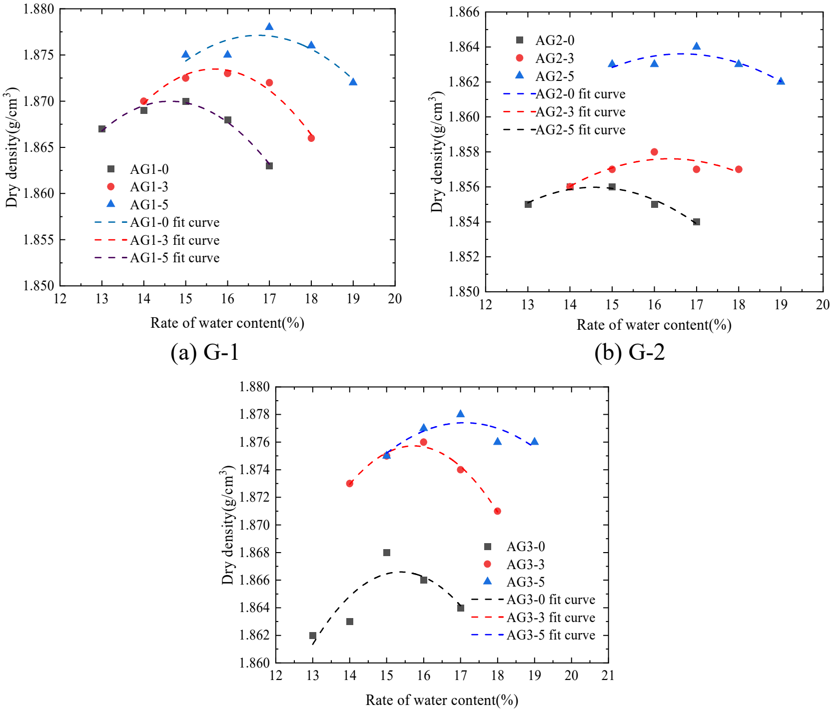
Table 2. Mix ratio design

Numbering	Type of soil stabilizer	Soil stabilizer dosage /%	Additional cement content /%	Gravel content /%
AG1-0	G-1	6% A + 1.5% A component B	0	0
AG1-3	G-1	6% A + 1.5% A component B	3	0
AG1-5	G-1	6% A + 1.5% A component B	5	0
AG2-0	G-2	0.02%+5% cement	0	0
AG2-3	G-2	0.02%+5% cement	3	0
AG2-5	G-2	0.02%+5% cement	5	0
AG3-0	G-3	3% +5% cement	0	0
AG3-3	G-3	3% +5% cement	3	0
AG3-5	G-3	3% +5% cement	5	0
AG3-0-10	G-3	3% +5% cement	0	10
AG3-0-20	G-3	3% +5% cement	0	20
AG3-0-30	G-3	3% +5% cement	0	30

3 Analysis of results

3.1 Optimal moisture content

Figure 1 shows the inorganic binding material compaction curves for the three types of soil stabilizers. As can be seen from the figures, the inorganic binding material compaction curves of all kinds of soil stabilizers showed a tendency to increase first and then decrease. The maximum dry densities of ionic curing agent (G-2) were 1.856 g/cm^3, 1.858 g/cm^{3,} and 1.864 g/cm^3, smaller than those of inorganic type (G-1 and G-3) soil stabilizers. The growth and decline trends of the strike curves of ionic soil stabilizer (G-2) were slower. The trends of the strike curves of inorganic-type soil stabilizers (G-1 and G-3) were faster.



(a) G-1 (b) G-2

(c) G-3

Fig. 1. Compaction curve of inorganic binder

3.2 Unconfined compression strength

According to the test soil, the basic properties of the soil stabilizer, and the compaction test results, the stabilized soil mix ratio is designed, and the 7d unconfined compression strength is shown in Figure 2. It can be seen from Figure 2 that when the soil stabilizer is used according to the recommended dose, the 7d unconfined compression strength of solidified gravel soil with the G-3 soil stabilizer is the highest, which is 1.2 MPa. The three kinds of solidified gravel soil, according to the recommended dosage, did not meet the requirements of the use of highway subgrade. In Figure 3, when the additional cement content is 3%, the G-2 strength meets the strength standard of the subbase of expressway and first-class highways (≥1.5 MPa). The G-3 strength meets the strength standard of the base of secondary and lower-level highways (2~3 MPa). When the additional cement content is 5%, the 7d unconfined compression strength of G-1 is about 3.23 times that of the cement content of 3%. However, the error of parallel data reaches 18.9%, indicating that the performance of G-1 is unstable when the cement content is 5%. The strength values of G-2 and G-3 are lower than those of the additional cement incorporation. This indicates that the additional cement infusion is not as much as possible. There is a better dosage to meet the strength standards of the base of secondary and lower-level highways. In summary, by incorporating additional cement, three soil stabilizers can be used in highway engineering, and the curing effect of G-3 is better.

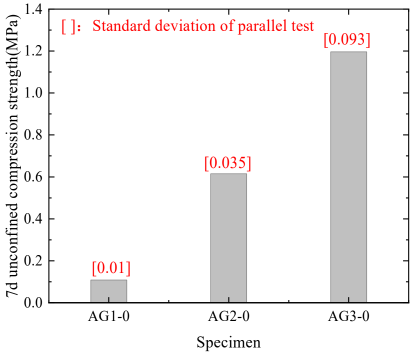


Fig. 2. 7d unconfined compression strength

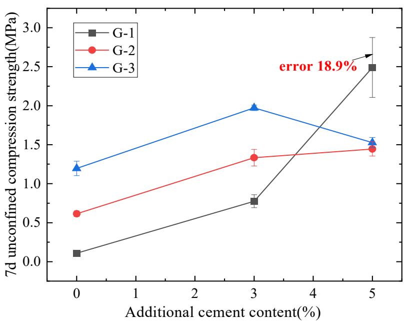


Fig. 3. Effect of additional cement content on strength

The addition of gravel to the recommended admixture of soil stabilizer G-3 can also be used to make the 7d unconfined compressive strength of G-3-cured gravel soils meet the requirements for highway use (Figure 4). When the gravel mixing amount is 30%, the 7d unconfined compressive strength is 1.68 MPa. This meets the strength standard of the sub-base of highway and first-class highway.

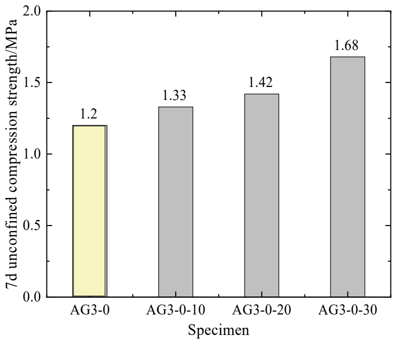


Fig. 4. Effect of gravel on 7d unconfined compressive strength

3.3 Water stability performance

The water stability coefficients of stabilized gravel soils by soil stabilizer at the recommended dosage are shown in Figure. 5. The specification "Technical Standard for the Application of Soil Curing Agent" (CJJT286-2018) stipulates that when the water stability coefficient is 0.8, the requirements for highway use are met. It can be seen from Figure 5 that none of the three types of soil stabilizers meet the requirements. AG3-0 is 0.78, which is better than AG1-0 and AG2-0. When the additional cement content is 5%, the AG1-5 water stability coefficient is 0.86. When the additional cement content is 3%, the AG3-3 water stability coefficient is 0.83, which can meet the requirements of highway use (Figure 6).

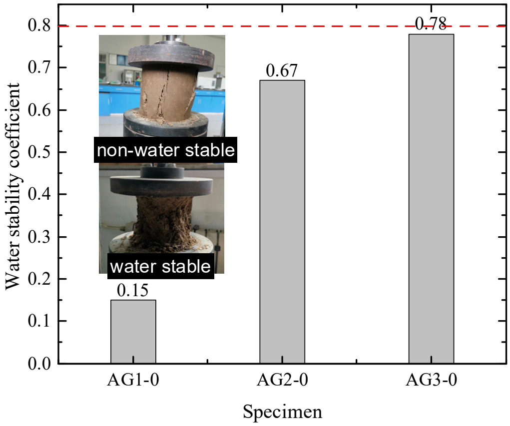


Fig. 5. Water stability coefficient at the recommended dosage

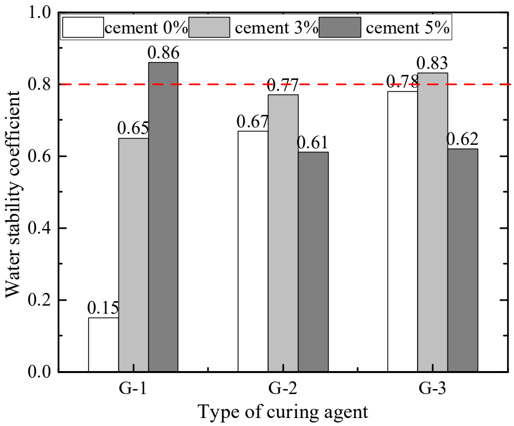


Fig. 6. Effect of additional cement content on water stability coefficient

Figure 7 shows the influence of gravel on the water stability coefficient. On the basis of the recommended amount of G-3, by adding gravel, the water stability coefficient of G-3 solidified gravel soil can also meet the requirements of highway use. When the dosage of gravel is 10% and 20%, the water stability coefficients are 0.8 and 0.81, respectively. Figure 8 shows the strength loss rate. Except for the high strength loss rate of the recommended G-1 stabilized gravel soil, the strength loss rate of each other specimen is less than 40%.

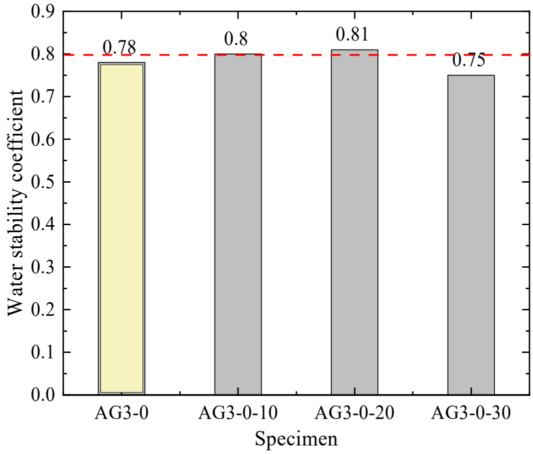


Fig. 7. Influence of gravel on water stability coefficient

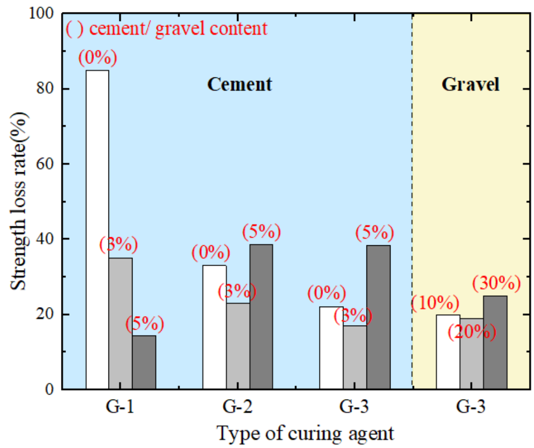
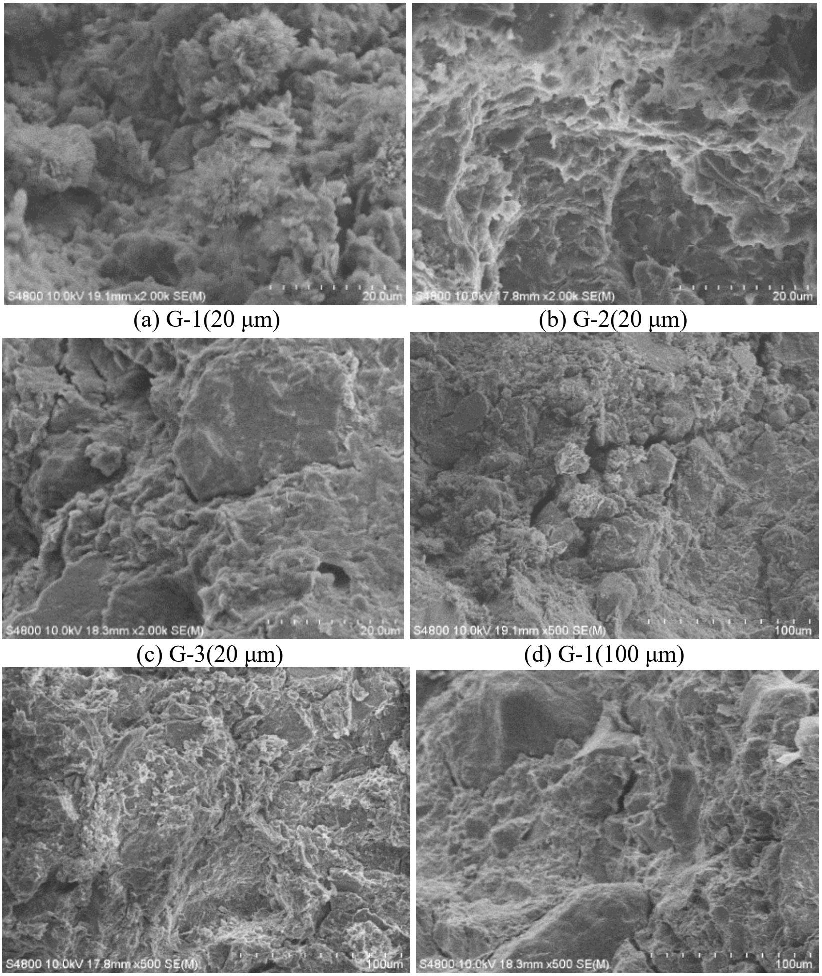


Fig. 8. Strength loss rate

3.4 Curing mechanism

The SEM test images were used to visualize the changes in pore structure and material composition of different types of stabilized gravel soils. The micromorphology of the three types of curing agent-stabilized gravels is shown in Figure 9.



(a) G-1(20 μm)
(b) G-2(20 μm)
(c) G-3(20 μm)
(d) G-1(100 μm)
(e) G-2(100 μm)
(f) G-3(100 μm)

Fig. 9. Stabilizer gravel soil SEM diagram

It can be seen from Figure 9 that there are a large number of hydration products in the micromorphology of the stable gravel of the soil stabilizer G-1 and the soil stabilizer G-2, including flocculent hydrated calcium silicate gel C-S-H, calcium alum crystal AFt, etc. These hydration products are bonded to each other to form a stable spatial structure. At the same time, the hydration products distributed in the pores are bonded, wrapping the surrounding soil particles and playing a role in filling the pores. Still, some tiny cracks and some large pores can also be observed from the figure, which is due to the decomposition of C-S-H and AFt with the hydration process.

The AFt originally filled in the pores decreases in volume with the hydration process. The pores between soil particles are re-exposed, and the compactness is weakened. At the same time, under the action of soil stabilizer G-3, it can be observed from the figure that the flocculent C-S-H and calcium alum AFt have been transformed into calcium hydroxide $Ca(OH)_2$ and AFm. This makes the mesostructure denser, forming a complete and solid curing whole. The macroscopic performance is that the sample has better strength performance and water stability performance.

4 Conclusion

(1) The maximum dry density and optimum moisture content of the inorganic curing agent were greater than those of the ionic soil stabilizer from the compaction test. The trend of the compaction curves for the ionic soil stabilizer was slower than that for the inorganic soil stabilizer. The optimum moisture content was not significantly correlated with the type of soil stabilizer. Yet, it was mainly related to the cement dosage in the binding material and the type of soil sample.

(2) The three soil stabilizers solidified according to the recommended amount of gravel soil do not meet the requirements of highway use. With the addition of cement, three soil stabilizers can be used in highway projects, and the G-3 has a better stabilization effect. On the basis of the recommended amount of G-3, by adding the gravel, the 7d unconfined compression strength of G-3 solidified gravel soil can also meet the requirements of highway use. The superior macadam content is 30%. The water stability of hardener gravel soils can be improved by incorporating additional cement or macadam.

(3) Under the action of soil stabilizer G-3, flocculent C-S-H and alumina AFt have been transformed into calcium hydroxide $Ca(OH)_2$ and AFm. This makes the mesostructure denser and forms a complete and solid solidified whole. The macroscopic performance is that the sample has good strength performance and water stability performance.

References

1. Liu X J, Wu C F, Zhen X D, et al. Analysis of the research status of soil stabilizer and cured soil durability[J]. Hunan Communications Science and Technology,2023,49(01):43-47.
2. Yi X Z, Luo R D, Gao Y, et al. Study on strength characteristics and water stability of solidified waste soft clay[J]. Bulletin of the Chinese Ceramic Society,2022,41(03):976-984.
3. Rajakumaran K. An Experimental analysis on stabilization of expansive soil [J]. International Journal of Advances in Engineering & Technology, 2015, 7(6):1745-1752.
4. Zhang J, Weng X Z, Liu J Z, et al. Experimental study on mechanics and water stability performance of composite solidified sand[J]. Materials Reports,2014,28(24):115-119+124.
5. Li J, Wang W, Huang H. Materials Science and Engineering, 2020, 23: 740-742.
6. Marto A, Latifi N, Sohaei H. Stabilization of laterite soil using GKS soil stabilizer [J]. Electronic Journal of Geotechnical Engineering, 2013, 18:521-532.
7. Sai Chandu A, Rama S R G V. Strength and Durability Characteristics of Red Soil Stabilised with Foundry Sand and Cement[J]. Arabian Journal for Science and Engineering, 2021, 46(5):5171-5178.