Research on the Mechanical Properties of the Improved Tin Tailing Silty Sand (TTSS) based on the Unconfined Compressive Strength Test

Chaoyun Hu[1], Qiang Tan[1*], Songtao Zhang[1], Baiyu Li[1], Jianguo Hu[1], Haiming Liu[2] and Hongwei Li[2]

[1] Yunnan Construction Investment Holding Group Co., LTD., Kunming 650501, China
[2] School of Civil Engineering, Kunming University of Science and Technology, Kunming 650500, China
273170619@qq.com

Abstract. Tailings are an industrial waste residue. If effectively improved, not only is it beneficial to improve the stability of the tailings dams, but also it can also convert tailings into valuable resources and achieve the resource utilization of waste. This article obtains the strength characteristics of the Tin Tailing Silty Sand (TTSS) improved by the inorganic composite curing agent, epoxy resin curing agent and Supplementary Coat Additive (SCA) curing agent through unconfined compressive strength test. It is studied that the compressive strength of the TTSS improved by three curing agents has been improved with the increase of curing time, but there are differences in the magnitude of the increase in sample strength and the required curing time. As the ratio of three curing agents increases, the compressive strength of the samples is also improved to varying degrees. Among them, the influence of slag and cement in inorganic composite curing agents on the strength characteristics of the TTSS is more significant.

Keywords: Tin Tailing Silty Sand (TTSS); Curing agent; confined compression strength; Unconfined compressive strength test; Curing mechanism.

1 Introduction

Tin tailings are often regarded as waste. However, by deeply exploring their mechanical properties and making improvements, these originally valueless materials can be rejuvenated, reducing the dependence on new raw materials and thereby alleviating the damage to the environment caused by the exploitation of new resources. For example, in the field of construction engineering, the improved tin tailings powder and sand can be applied in filling and foundation treatment, effectively achieving the purpose of saving natural sand resources. Secondly, Improving and utilizing them can reduce the storage volume of tailings, lower

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environmental risks, and prevent harmful components in the tailings from seeping into underground water bodies through rainwater, thereby protecting the surrounding ecological environment.

Tailings are a solid waste with low useful component content generated during the beneficiation process[1]. Tailings belong to artificial sand and are usually discharged into tailings dams through pipelines[2]. The use of curing agent to improve the strength characteristics of tailings has important theoretical and practical significance in terms of the safety of the tailings dam, ecological environment and resource waste. On the one hand, tailings with higher strength can effectively improve the safety factor of tailings dams, enhance their stability, and enhance their ability to resist natural disasters. On the other hand, the improved tailings can have greater recycling and reuse value in the engineering field.A large number of scholars have applied inorganic curing agents to the reinforcement and improvement of soil. Li et al.[3] conducted the strength characteristics test on high viscosity iron tailings and analyzed the effects of basalt fiber content and wet-dry cycles on the strength of solidified tailings using high calcium geopolymer. Ou et al.[4] revealed the changes in the strength and microstructure characteristics of the product through shear, compression tests and microscopic analysis. Wei et al.[5] conducted experimental research on the mechanical properties of tailings improved by polymer materials through the indoor experiment.

This article takes the Tin Tailing Silty Sand (TTSS) as the research object, and uses three different types of curing agents, namely inorganic, epoxy resin and ionic to improve it. The strength characteristics of the improved TTSS are measured through the unconfined compressive strength test, and the effects of different curing agent dosages on the strength of the improved TTSS are compared and analyzed.

2 Test materials and test plans

2.1 Tin tailing silty sand (TTSS)

The tailings selected for the experiment are from the Kafang tailings dam in Gejiu, Yunnan, which belongs to tin tailings. According to the standard of Geotechnical Testing Methods (GB/T 50123-2019)[6], relevant tests are carried out on the physical properties of the TTSS, and the physical property parameters are shown in Table 1.

Table 1. The physical properties of the TTSS.

Tailings category	Particle specific gravity G_S	Porosity ratio e	Permeability efficient k/cm•s-1	Plastic limit W_P/%	Liquid limit W_L/%	Optimal moisture content W_{OP}/%	Maximum dry density $\rho_{d\,max}$/g•cm-3
The TTSS	3.07	0.92	2.30×10-3	15.9	24.4	19.3	1.78

2.2 Curing agent

The experiment selected three types of curing agents, namely inorganic, epoxy resin and ionic. The inorganic solidifying agents mainly use the cement, hydrated lime and slag powder as the main solidifying agents, and sodium silicate, whose molecular formula is $Na_2SiO_3 \cdot 9H_2O$, as the admixture. The epoxy resin curing agent is composed of epoxy resin E51 and epoxy resin T31 curing agent. The ionic curing agent is selected as Supplemental Coloant Additive (SCA) curing agents produced by Qingdao Zhuo-neng-da Construction Technology Co. Ltd. What's more, appropriate cement and hydrated lime are added. The specific physical properties of each curing agent material are as follows.

(1) Epoxy resin E51 :The epoxy resin E51 is a transparent colloid with an epoxy value of 184-195 g/mol, a viscosity of 10000-16000 mPa.s, and hydrolyzed chlorine which is less than or equal to 0.5%.

(2) Epoxy resin T31 curing agent :The epoxy resin T31 is a reddish brown viscous liquid with a viscosity of 0.2-0.3 Pa.s and an amine value of 460±20 mgKOH/g. It belongs to phenolic amine compounds and is a curing agent with excellent comprehensive performance. Due to its active group structure such as hydroxide and amine groups, it can significantly improve the heat resistance, corrosion resistance and shear strength of the sample.

After mixing epoxy resin E51 and epoxy resin T31 in proportion, they form a yellow colloid.

(3) SCA curing agent: The SCA curing agent is a light yellow semi transparent liquid produced by Qingdao Zhuo-neng-da Construction Technology Co. Ltd.

2.3 Determination of cement ratio of the curing agent

Group A: Inorganic composite curing agent. The inorganic composite curing agent is mainly composed of cement, hydrated lime and slag powder, with sodium silicate ($Na_2SiO_3 \cdot 9H_2O$) as the admixture. The dosage is designed using an orthogonal table, and the specific cement ratio of each component is shown in Table 4.

Group B: Epoxy resin curing agent. According to the research of other scholars[7] and the recommended dosage from manufacturers, the epoxy resin E51 and epoxy resin T31 curing agent are mixed in a 4:1 ratio. The ratio of the mixed reagent is proposed to be 3%-9%, and the specific ratio is shown in Table 2.

Table 2. The cement ratio of the epoxy resin curing.

Experimental group	Epoxy resin E51 /%	T31 curing agent /%	Mixed dosage /%
Blank group	0	0	0
B1	2.4	0.6	3
B2	4.8	1.2	6
B3	7.2	1.8	9

Group C: SCA curing agent. Referring to the recommended dosage from the manufacturer, combined with the actual application of ionic curing agents, a constant amount of cement and hydrated lime are combined to improve the strength characteristics of the TTSS on the basis of adding SCA curing agents. The specific addition is shown in Table 3.

Table 3. The cement ratio of the SCA curing agent.

Experimental group	Cement /%	Hydrated lime /%	SCA curing agent /%
1	6	4	0
C2	6	4	0.1
C3	6	4	0.2
C4	6	4	0.3

3 Effect of cement ratio of curing agent on compressive strength

3.1 The effect of cemen ratio of inorganic composite curing agents on compressive strength

In this experiment, the improved TTSS with inorganic composite curing agent is a four factor and four level orthogonal experiment, and the experimental results are shown in Table 4.

Table 4. Experimental results of unconfined compressive strength of the TTSS improved by inorganic composite curing agent.

Experimental group	Water glass/%	Cement/%	Slag powder/%	Hydrated lime/%	Unconfined compressive strength/kPa
A1	1	2	2	2	86.8
A2	1	4	4	4	205.3
A3	1	6	6	6	298.1
A4	1	8	8	8	367.9
A5	2	2	4	6	227.3
A6	2	4	2	8	187.3
A7	2	6	8	2	281.2
A8	2	8	6	4	307.1
A9	3	2	6	8	236
A10	3	4	8	6	290.4
A11	3	6	2	4	232.9
A12	3	8	4	2	266.2
A13	4	2	8	4	255.3
A14	4	4	6	2	278.1
A15	4	6	4	8	271
A16	4	8	2	6	233.8

Using the range analysis of orthogonal experiments, statistical analysis is conducted on the experimental results indicators. The specific process and conclusions are as follows.

The calculations during the range analysis process are shown in Table 5.

Table 5. Range analysis of the unconfined compressive strength.

Calculation indicators	Water glass /kPa	Cement /kPa	Slag powder /kPa	Hydrated lime /kPa
K_1	958.10	805.40	740.80	912.30
K_2	1002.90	961.10	969.80	1000.60
K_3	1025.50	1083.20	1119.30	1049.60
K_4	1038.20	1175.00	1194.80	1062.20
K_1	239.53	201.35	185.20	228.08
K_2	250.73	240.28	242.45	250.15
K_3	256.38	270.80	279.83	262.40
K_4	259.55	293.75	298.70	265.55
Range R	20.03	92.40	113.50	37.48

In order to analyze the influence trend of the cement ratio of each component on the unconfined compressive strength more intuitively and clearly, the cement ratio of each component is taken as the abscissa, and the average value of the corresponding test result index is taken as the ordinate. The influence trend diagram of the compressive strength of each component is drawn as Figure 1.

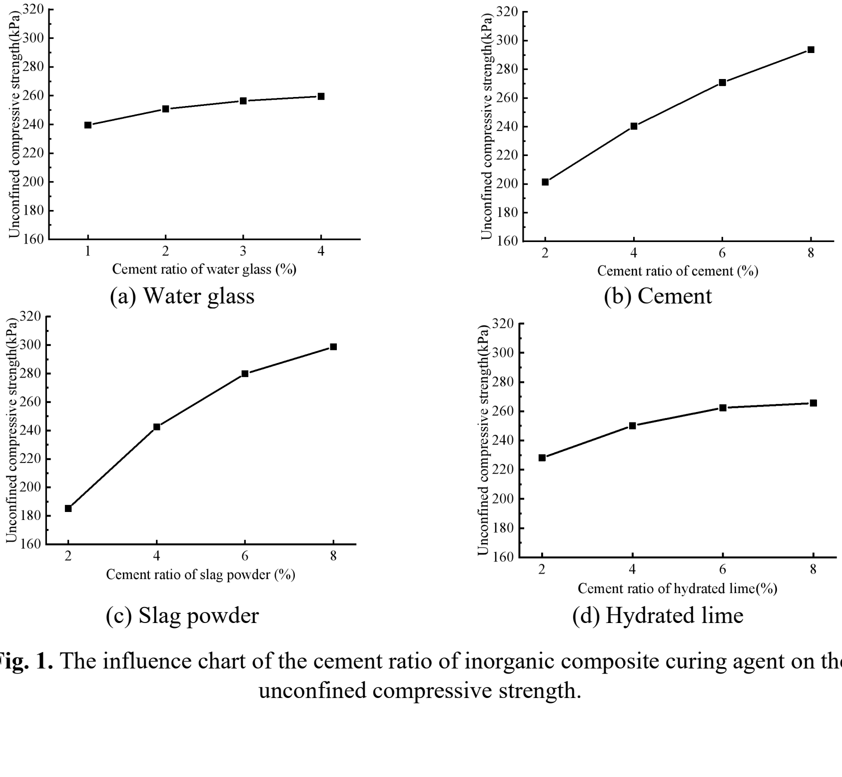

Fig. 1. The influence chart of the cement ratio of inorganic composite curing agent on the unconfined compressive strength.

According to the above analysis, it can be seen that the unconfined compressive strength increases with the proportion of each component added. The growth trend of water glass and hydrated lime is relatively gentle, while the cement ratio of cement and slag powder has a significant impact on the growth trend of the compressive strength. When the cement ratio of water glass is between 1% and 4%, the improvement trend of compressive strength tends to be gentle as the cement ratio increases. The compressive strength of cement increases linearly with the increase of cement ratio within the range of 2%-8%. The growth trend of compressive strength of slag powder is also very obvious. Although the trend of strength improvement slows down after the cement ratio of slag powder increases, the absolute value of strength improvement is still relatively significant. When the cement ratio of hydrated lime is in the range of 2%-6%, the improvement trend of compressive strength is relatively obvious, and the improvement of compressive strength in the range of 6%-8% is very limited.

Based on the range analysis of indicators for the unconfined compressive strength test results of each component, the range R at different levels can be obtained. This indicator reflects the influence order of each component on the unconfined compressive strength of the improved TTSS. Among them, the range of water glass is 20.03 kPa, the range of cement is 92.40 kPa, the range of slag powder is 113.50 kPa, and the range of hydrated lime is 37.48 kPa. Therefore, based on the magnitude of the range, the influence order of each component of inorganic composite curing agent on the unconfined compressive strength of the TTSS is slag powder, cement, hydrated lime, and water glass in descending order.

Based on the range analysis results of the orthogonal experiment, it can be concluded that the influence of the four components on the test results in descending order is as follows, slag powder, cement, hydrated lime and water glass, based on the unconfined compressive strength test of inorganic composite curing agent of the improved TTSS. Among them, the slag powder has a high significant impact, cement has a significant impact, and hydrated lime and water glass have no significant impact.

3.2 The effect of the addition ratio of epoxy resin curing agent on compressive strength

The Epoxy resin E51 and epoxy resin T31 curing agent are prepared in a 4:1 ratio, and epoxy resin curing agents with different mixing ratios are used to improve the unconfined compressive strength of TTSS. The test results obtained are shown in Figure 2.

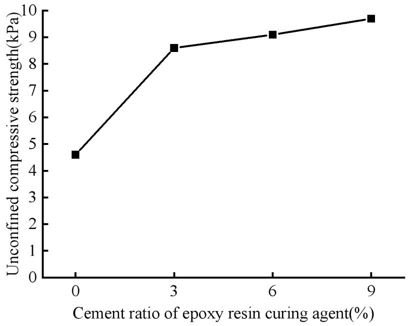

Fig. 2. The effect of the addition ratio of the epoxy resin curing agent on unconfined compressive. strength.

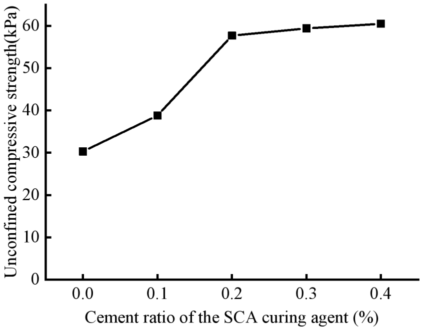

Fig. 3. The effect of the addition ratio of the SCA curing agent on unconfined compressive strength.

From Figure 2 and Figure 3, it can be seen that the unconfined compressive strength of the improved TTSS is promoted with the increase of the ratio of epoxy resin curing agent from the overall trend. When the epoxy resin curing agent is not added, the original compressive strength of the TTSS is 4.6kPa. After adding 3% epoxy resin, the compressive strength of the TTSS increased to 8.6kPa, which is 1.87 times higher than before. When the addition ratio is 6% and 9%, the compressive strength of the TTSS is increased by 5.8% and 12.8% respectively, compared to 3%. It can still improve the compressive strength of the TTSS to a certain extent, but the improvement effect is not significant compared to when the addition ratio is 3%. Therefore, when the mixing ratio of epoxy resin curing agent is 3%, it has good economic and safety benefits from an economic perspective.

3.3 The effect of the addition ratio of SCA curing agent on compressive strength

Under the conditions of the cement addition ratio of 6% and hydrated lime addition ratio of 4%, the variation of unconfined compressive strength of the improved TTSS with the addition ratio of SCA curing agent is shown in Figure 3.

According to the analysis in Figure 3, it can be seen that the unconfined compressive strength of the improved TTSS increases with the addition ratio of SCA curing agent, while the cement and hydrated lime addition ratio remains unchanged. After adding 6% cement and 4% hydrated lime to the improve TTSS, the compressive strength increases from 4.6kPa to 30.3kPa, and the effect is significant. After adding 0.1%, 0.2%, 0.3% and 0.4% SCA curing agents, the compressive strength increases to 38.8kPa, 57.7kPa, 59.4kPa and 60.5kPa, respectively. Compared with only adding cement and hydrated lime, this strength index increases by 28.1%, 90.4%, 96.0% and 99.7%. It can be concluded that the compressive strength of the TTSS is significantly improved when different amounts of SCA curing agents are added. Among them, the most prominent cement ratio of SCA curing agent to improve the compressive strength of the TTSS is 0.2 %, followed by 0.1 %, and 0.3%-0.4% can also improve the compressive strength of the sample to a certain extent, where the increase rate is relatively slow.

4 Conclusion

This chapter conducts unconfined compressive strength tests on modified TTSS with the inorganic composite curing agents, epoxy resin curing agents, and SCA curing agents, and studies the variation law of unconfined compressive strength of the improved TTSS under different curing times and curing agent ratios. After comprehensive analysis and comparison of the unconfined compressive strength test results of three curing agents for improving TTSS, it is believed that SCA curing agent is very beneficial for improving the early strength of the TTSS. Although epoxy resin curing agent can complete curing quickly, the unconfined compressive strength is relatively low and the effect is average. The improved inorganic composite curing agent has the highest compressive strength of the TTSS, but at the same time, the proportion of each component added is relatively high. In practical applications, the addition ratio may limit the extent to which the compressive strength of the TTSS can be improved.

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References

1. YANG, C H., ZHANG, C., LI, Q M., et al.: Disaster mechanism and prevention methods of large-scale high tailings dam[J]. Rock and Soil Mechanics 42(01), 1-17 2021.
2. SUN, X., CHEN, Z., GUO, K., et al.: Geopolymeric flocculation-solidification of tail slurry of shield tunnelling spoil after sand separation[J]. Construction & Building Materials 374, 2023(Apr.17).
3. LI, Y., WEI, M L., LIU, L., et al.: Strength characteristics and mechanism analysis of fiber reinforced highly cohesive tailings solidified using high-calcium geopolymer[J]. Rock and Soil Mechanics 44(01), 43-53 2023. DOI:10.16285/j.rsm.2022.0252.
4. OU, X D., HUANG, Z Z., LUO, B X., et al.: Model test study on treatment of baucite tailing slurry by adding sand step by step combined with quicklime drainage and solidification[J]. Journal of Engineering Geology 31(01), 318-326 2023. DOI: 10.13544/j.cnki.jeg.2020-347.
5. WEI, Z A., ZHAO, J K., QIN H., et al.: Effects of polymer materials on the mechanical properties of tailings[J]. Chinese Journal of Rock Mechanics and Engineering 39(S1), 3095-3102 2020. DOI: 10.13722/j.cnki.jrme.2019.1096.
6. Ministry of Housing and Urban Rural Development of the People's Republic of China, State Administration for Market Regulation. Standard for Soil Test Methods (GB/T 50123-2019) [S]. China Planning Press, 2019.09.、
7. WANG, Y J., LIN, W Y., HUANG, Y S., et al.: Analysis of durability performance of ionic soil stabilizer improving soil[J]. Key Engineering Materials 667, 335-340 2015.