Analysis of Strength and Compression Damage Characteristics of Soil Rock Mixture Based on Geopolymeric Reaction

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Abstract. Geopolymers was a common means of solidifying soil which can improve the overall strength of the soil. In order to further explore the strength and damage characteristics of the soil-rock mixture under the action of gel coagulation, this paper analyzed the compressive strength of the soil-rock mixture under different stone content through the unconfined compressive strength test. The results illustrated that when the amount of stone was small, the compressive strength decreases linearly with the increase of the amount of stone, and increased with the increase of the amount of geopolymer; According to discrete element method, using PFC2D software, to simulate the microscopic deformation and mechanical properties of the specimen during compression. The increase of stone content would magnify the damage of the soil when it reached the failure, but it did not necessarily increase the overall soil mass numerically. The strength of the soil would be greatly improved when the stone content reached a state that could form a skeleton structure.

1. Introduction
Geopolymer has several advantages of high strength, fast hardening, high temperature resistance, acid resistance and corrosion resistance, low carbon emission, energy saving, etc., and has been widely studied and applied. Fly ash is one of geopolymer gelling material that can be excited by hydrate activator. It is used as a soil solidification material by many scholars[1-2], Shen Bei[3] used geopolymer cementing materials to solidify sulfate saline soil, the solidification test shown that sodium silicate can better improve the strength characteristics of saline soil. When sodium silicate, lime, and fly ash are combined to solidify the soil, the lime content should not exceed 8%. Yu Jiajia[4] and others used geopolymer-cured soft clay, and through unconfined compressive strength test and SEM scanning, it was found that the increase of alkali activator content had a significant impact on the early strength improvement of geopolymer-cured soft clay, but it has little effect on the strength of 14 d and 28 d. The strength improvement efficiency would decrease as the content exceeds 5.0%.

Soil-rock mixed soil generally refers to a certain engineering scale with high strength rock, fine-grained soil, and pores, and extremely uneven loose rock-soil medium system with certain rock content[5-6]. It is widely used in foundation fillers. Because different projects have different requirements for the engineering characteristics of soil-rock mixtures, the research on the engineering properties of soil-rock mixtures is particularly important. Zou Haiwei[7] and others have studied the impact of soil to rock for soil-rock mixtures. The test result shown that CBR value and the modulus of resilience increased with the increase of the maximum particle size of the crushed stone, on the contrary, the optimal water content decreased with the increase of the maximum particle size of the
crushed stone; Through the discrete element simulation of the triaxial test of the soil-rock mixture under flexible loading of confining pressure Zhang Qiang [8], etc. analyzed that the friction angle in the excavated body increases linearly with the increase of rock content, while the cohesive force gradually decreases with the increase of rock content. However, there are relatively few studies on the characteristics of solidified soil-rock mixtures using geopolymers. Based on the above research, this paper adopted the mixing ratio scheme of water glass, lime and fly ash, through unconfined compressive strength test, combined with discrete element meso-analysis, the strength parameters and micro characteristics of different solidified samples were finally obtained. The changes in the microstructure characteristics of saline soil under the action of different curing materials and the effect of alkali-stimulated geopolymer curing saline soil from a microscopic point of view were analyzed in this paper.

2. Laboratory Test Analysis

2.1 Materials.

The test material used in this paper was a self-made mixed soil-rock mixture. The soil was silt from the Yellow River floodplain. Through the liquid-plastic limit test and compaction test of the soil, the specific physical properties of the soil were shown in Table 1:

| Relative density of soil | Liquid limit (%) | Plastic limit (%) | Plasticity index | Optimum moisture Content(%) | ρmax (g/cm³) |
|--------------------------|------------------|------------------|------------------|-----------------------------|--------------|
| 2.65                     | 34               | 22               | 12               | 13.84                       | 1.84         |

The geopolymer was mixed with water glass (powdered particles) and fly ash at a mass ratio of 1:1. The main chemical components of fly ash were SiO2, Al2O3, Fe2O3, etc. The physical and mechanical parameters of water glass were shown in the following table:

| Composition and attributes | SiO2 (%) | Na2O (%) | H2O (%) | Density(g/cm³) | modulus |
|----------------------------|----------|----------|---------|----------------|---------|
| numerical value            | 29.9     | 13.75    | 56.35   | 1.48           | 2.25    |

2.2 Preparation of Test Pieces.

The loading instrument for the unconfined compressive strength test adopts the YSH-2 unconfined pressure meter produced by Nanjing Ningxi Soil Instrument Co., Ltd., as shown in Figure 1. The test procedure refers to the "Highway Engineering Inorganic Binder Stabilizing Material Test Regulations", the unconfined compressive strength test is carried out on the solidified soil specimen. The size of the specimen is diameter×height=φ50mm*50mm. The maximum load when the specimen fails is obtained by loading the specimen at a uniform speed of 1mm/min, and the unconfined compressive strength of the solidified soil is calculated by Eq.1, Strength, as shown in Figure 2 is the specimen after loading failure.

\[ R_c = \frac{P}{A} \]  

(1)

In the formula, RC is the unconfined compressive strength of the specimen (MPa); P is the maximum pressure (N) when the specimen is broken, and A is the cross-sectional area of the specimen (mm²).
2.3 Strength Analysis.

This article was to explore the strength characteristics of the soil-rock mixture under the solidification of geopolymers. 3%, 5%, and 7% of the total weight of the soil were used as the test dosage. The stone was mixed internally while the stone was set at different dosage of 0%, 6%, 12%, 18%, 24%, 30% of the total mass. Because the strength of the geopolymer required a certain period of health preservation, the specimens in this test were cured under a sealed room temperature, and the preservation time was 7 days. The experimental data obtained was sorted as shown in Figure 3:

![Figure 3. compressive strength](image)

It can be seen that with the gradual increase of the amount of rock, the unconfined compressive strength basically decreases linearly, mainly due to the small increase in the amount of rock, which fails to form a good skeleton structure and reduces the contact between soil particles, so that the strength decreases with the increase of the content. In conclusion, the higher the content of the geopolymer, the stronger the compressive strength is.

3. Discrete Element Model Establishment

The contact model between the soil particles was simulated by the parallel bond model (linear bond model), and the contact between the stone particles was simulated by the linear contact model. After the soil was solidified by the geopolymer, the interior is gelled, the contact model of soil and stone was quite different from the linear stiffness model, so the parallel bonding model was still used for simulation, and the fixed content of geopolymer was determined at 5%. Refer to related literature [9-11]. With further improvement, the parameters of the calibrated soil-rock particle meso-contact model were listed in the following table:
| Type       | $\rho$ (kg·cm$^{-3}$) | Contact stiffness (N·m$^{-1}$) | Bond strength (N) | Fric  |
|------------|------------------------|-------------------------------|-------------------|-------|
|            |                        | normal | shear | normal | shear |       |
| Soil       | 1700                   | $8\times10^6$ | $8\times10^6$ | $3\times10^2$ | $3\times10^2$ | 0.57   |
| Rock       | 2700                   | $1\times10^8$ | $1\times10^8$ | -          | -      | 1.0    |
| Soil-Rock  | -                      | $3\times10^6$ | $1\times10^6$ | $2\times10^2$ | $2\times10^2$ | 0.45   |

Because the stone particles were relatively fine and the mixing amount was relatively small, and its angularity had little influence on the soil, round particles were used to directly simulate stone particles and soil particles. The particle size of the stone particles was set to 2.36mm-4.75mm. Among them, the particle size of the soil particles was set between 0.6mm-0.7mm, as shown in the figure was a virtual specimen of unconfined compressive strength of soil-rock mixture: the gray particles were stone particles, and the yellow particles were soil particles:

Figure 4. virtual specimen of soil rock mixture

A virtual loading test was performed on the soil-rock mixture mixed with rocks, and the virtual test of the soil-rock mixture after loading failure was shown in Figure 5 below:

Figure 5. loading destroy state

Perform virtual tests were carried through on soil-rock mixtures with 0%, 20%, 50%, and 80% stone content, and the virtual test soil-rock mixture after loading failure was shown in the figure below:
It could be concluded from Figure 6 that when the content of stone inside the soil was less, a better skeleton structure cannot be formed, and the specimen would crack under pressure under relatively complete conditions. When the content of stone reached 80%, the stone could be more adequate filled in the soil and basically formed a skeleton prototype. Therefore, when the entire specimen was damaged during the pressurization process, the internal skeleton structure could still continue to resist compression until the damage was large, and the final damage could be seen from Figure 7. It was found that at 80% of the content, the force chains with larger force values extended from top to bottom along the skeleton structure, which also shown that the stone can better resist when the content of the stone reached the conditions that could form the skeleton structure.

4. Conclusion

(1) For the soil and rock mixture with gelation reaction curing, the content of geopolymer is 3%, 5%, 7%, and the content of stone is 0%, 6%, 12%, 18%, 24%, 30%, the unconfined compressive strength
test was carried out, and the results showed that with the gradual increase of rock mass, the unconfined compressive strength basically decreased linearly; the higher the content of geopolymer, the stronger the compressive strength.

(2) Through the discrete element virtual test analysis, it is obtained that the increase of the stone material content will promote the damage degree of the soil body when it is destroyed, but the overall strength of the soil body may not be increased numerically. When the amount of stone material reaches a state that can form a skeleton structure, the strength of the soil will be greatly improved.

5. References
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