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Study on Influencing Factors of Microbial Solidification of Soil

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Abstract

Microbial-induced calcium carbonate deposition technology (MICP) has the characteristics of low energy consumption and environmental friendliness, and have high technical value. The principle of this technology is that the metabolic activity of microorganisms in the soil can bind loose soil particles into a whole. In order to better understand this technology, this article systematically introduces and summarizes the soil reinforcement technology from the perspective of influencing factors. The research results indicate that the effective reinforcement range of soil particle size is 10-1000 μm; The temperature range of 30-40 ℃ is conducive to the formation of calcium carbonate precipitation; Alkaline environment is more suitable for the growth of microorganisms, and the reinforcement effect of soil is better when the pH value is 9-11; Using a step-by-step grouting method to treat soil can improve the uniformity of soil.

Keywords

Microorganisms; Factors Affecting Solidification; MICP.

1. Introduction

In recent years, the technique of microbially induced carbonate precipitation (MICP) has been proposed by combining geotechnical mechanics with microbiology. That is, the ability of microbial mineralization to produce calcium carbonate will be used to cement the soil and achieve soil reinforcement. Compared with the traditional grouting technology, this principle is universal in the natural environment and the formation speed and bonding strength are controllable. It has the characteristics of short time required for reinforcement and no need for maintenance, saving time and effort. This article summarizes the factors that affect the soil reinforcement effect. The influencing factors include soil environment, temperature, pH value, and grouting method.

2. Factors Affecting the Curing Effect

2.1 Soil Environment

Zhao Zhifeng[1] et al. took the Marine facies fill silt required by the reclamation project in Jiangsu as the research object. Yu Qingpeng et al. used silty sandy soil with particle size less than 0.25 mm and greater than 0.075 mm, which exceeded 50% of the total mass. Jiao Longxin et al. studied the interlayers of red clay in southwest China. Li Tao et al. Took the aeolian sand in desert areas as the research object. Table 1 shows the test methods under different soil environments. From this table, it can be seen that different soil environments have different properties, so each soil quality needs to be studied. The soil environment can affect the effect of microbial solidification of soil, and different soil types require different methods of testing.

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Table 1. Differences among the soil environments

Soil environment	Scheme 1	Scheme 2
Calcium sand	89.9 % $CaCO_3$, 7.4 % CaMg $(CO_3)_2$, most are granular and fragmentary	X-ray diffraction analysis (XRD), X-ray fluorescence spectrum analysis (XRF)
Liquefied sand soil	Grade poor fine sand	P wave velocity, S wave velocity and sample permeability coefficient
Brick masonry structure	Walls, stupas, temples, palaces, etc	Uniaxial compression resistance and uniaxial tensile strength test
Organic matter clay	Gs=2.7, the plasticity index Ip=25, and the optimal moisture content was 18.8%	MICP pressure grouting test, Ca^{2+} and NH^{4+} concentration determination, unlimited compressive strength test, etc

The differences in soil environment include the internal substance of soil, particle gradation, inter-particle density, and moisture content. These factors mainly affect the deposition rate of calcium carbonate. The high concentration of 2 mol/L chloride salt was mixed into the soil containing 0.255 mol/L NaCl. By observing the $CaCO_3$ content under different grouting rounds to verify the effect of high concentration of chloride salts, it was found that the $CaCO_3$ content increased with the increase of grouting rounds. The results showed that high concentration of NaCl can inhibit the activity of urease and affect the reinforcement effect of soil. Guo Hongxian et al. conducted consolidation compression tests on calcareous sand samples with relative densities of 70% and 30% under the conditions of bacterial solution and bacterial-free solution. The images showed that the samples with a relative density of 70% was more obvious, and the relative density had a greater impact on the compressibility of calcareous sand.

Among these differences, the effect of particle gradation on MICP was the most obvious. More studies were conducted on the reinforcement of coarse soil. However, because the microorganisms themselves have a certain size, it is not easy to transfer in fine grained soil, so the reinforcement of fine soil was less studied. This is because there is a certain distance between soil particles, and these tiny channels are called pore throats. The pore throats in coarse soil can allow microorganisms to transfer and spread between channels, making the soil evenly reinforced. The particle size of fine soil is small, and the microorganisms are easy to be blocked together, which greatly affects the reinforcement of soil. However, the large size of soil particle causes the calcium carbonate precipitation to basically stick to the soil particles, and the connectivity between particles is poor, affecting the reinforcement effect. Similarly, the small size of soil particle causes the calcium carbonate precipitation to concentrate together, and the reinforcement effect is poor. Therefore, the soil particle size is too large or too small for MICP reinforcement. The effective particle size range of MICP reinforced soil is 10~1000μm. Improving the relative density and gradation of soil particle size can achieve better reinforcement effect.

2.2 Temperature

Temperature greatly affects the activity of microorganisms. The suitable temperature for most microorganisms is 15-45 ℃, and the temperature for general soil environments is within the range of 10-25 ℃. This ensures that MICP technology can effectively reinforce soil in practical engineering, which is conducive to the promotion of this technology. However, it cannot guarantee the biochemical reaction of microorganisms in extreme environments (low temperatures). Huang Yan[2] et al. handled Bacillus Pasteur at 10 ℃, 20 ℃, 30 ℃ and 40 ℃, and found that the bacterial propagated the fastest when at 30 ℃. However, calcium carbonate precipitation could hardly be detected at 10 ℃. This is because the temperature is too low for bacteria to survive. Peng Jie et al. used Bacillus basi to conduct

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experiments at 10 ℃, 14 ℃, 18 ℃, 21 ℃ and 25 ℃ respectively. The results showed that the higher temperature, the faster the precipitation rate of calcium carbonate and the more calcium carbonate generated. However, Zhao Zhifeng et al. found that with the increase of temperature, calcium carbonate generation increased, but there was a peak value of unconfined compressive strength. Bacillus basi can react at 10 ℃, which verifies the feasibility of MICP at low temperature. Urease activity reached its maximum at 70 ℃, but the higher the temperature, the more unstable the urease activity was. Bacillus licheniformis is a bacterium with strong alkaline resistance and good activity in low-temperature environment. Yi Dan[3] et al. used this bacterium to explore the mineralization process of microorganisms in low-temperature environments at 10 ℃. They found that the bacteria grew slowly from 0 to 8h. The microorganism growth and multiplies rapidly at 8~40h. The number of bacteria was relatively stable from 40 to 60h, and the total number of bacteria reached its maximum. After 60h, the microorganisms died. In the outdoor construction process, controlling the temperature between 30~40 ℃ has little impact on the activity of microorganisms. The influence of low temperature environment should be avoided as far as possible in the future construction to ensure that the microbial activity is not affected.

2.3 PH Value

The alkaline environment is conducive to the growth and reproduction of most microorganisms (such as Bacillus pasteurii), but the PH too high will affect the reproduction of microorganisms or even direct death. Regarding the optimal reproductive environment of microorganisms, most microorganisms exist in the environment with a pH value of 5~9. But the pH of the environment in which different varieties of microbes are best suited to grow varies. Zhao Zhifeng et al. adjusted the pH value of soil samples to 9.92, 11.27 and 12.35 with different quantities and concentrations of NaOH solution to study the effects of different pH values on the strength of soil. They found that when the pH values were 9.92 and 11.27, the unconfined compressive strength was higher than the original soil sample. When the pH value was 12.35, the unconfined compressive strength was lower than the original soil sample (PH value was 9.06), as shown in Figure 2. It is concluded that MICP has a good reinforcement effect when the soil environment PH value is between 9 and 11, and a high PH value is not conducive to soil reinforcement. Wiley[4] et al. found that the most suitable PH value for the growth and reproduction of Bacillus pasteurii was 9.25, and the growth of bacteria stopped when the PH value was greater than 10. In order to obtain the optimal PH value for the metabolism and reproduction of urease bacteria, Zhang Haili et al. determined the bacterial growth and urease activity of Bacillus pasteurii at four gradients of PH values of 7, 8, 9, and 10. It was found that the bacterial growth was promoted when the PH value was 8, and the bacterial concentration and urease activity reached the maximum after 48h of culture. When the PH value was 10, the bacterial growth was inhibited by the over alkaline environment.

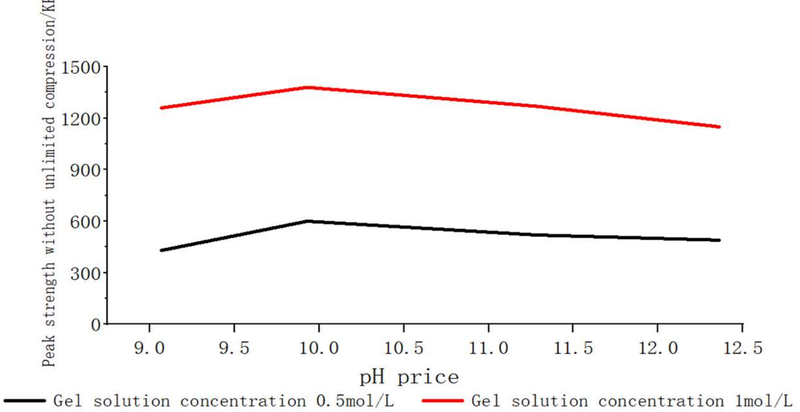

Figure 1. Effect of pH value on unconfined compressive strength

2.4 Grouting Method

Different grouting methods determine the amount of calcium carbonate deposition and the uniformity of distribution after grouting. The main grouting methods are indirect grouting, step grouting, surface spraying, pressure grouting, etc. The existing grouting methods are mainly gravity infiltration grouting and surface spraying. The grouting method often used in the past is to directly pour a single concentration of cementing liquid into the soil. This method is relatively simple, but the utilization rate of cementing liquid is too low and the soil is not reinforced uniformly. In addition, drainage grouting is mainly used in larger volumes of soil, such as in practical engineering. In order to establish a three - dimensional MICP model of convection-diffusion-reaction, Peng et al. combined the grouting method (MICP grouting pipe) with calcium carbonate reaction, and found that the content of calcium carbonate was the highest near the grouting pipe hole and gradually decreased to the outer edge of the model. Han Zhiguang et al. used indirect grouting method when dealing with liquefiable sand: (1) select one end of the sample as the grouting entrance, inject bacterial solution and then inject cementing solution; (2) select the other end of the sample as the grouting entrance, and repeat step (1). The grouting method can ensure the uniformity of liquefied sand reinforcement as much as possible. The separate perfusion of bacterial solution and cementing solution is related to the step grouting method. The step grouting method can make the bacterial solution and cementing solution react fully and improve the uniformity.

The most direct reason for the uneven distribution of calcium carbonate is the uneven distribution of calcium ions. The content of calcium ions can be used as an indicator to monitor the generation of calcium carbonate precipitation. The increase in the uniformity of calcium ion distribution is accompanied by the loss of calcium salts. Therefore, the improvement of the uniformity of calcium carbonate precipitation will lead to the reduction of the utilization rate of nutrient salts. Yang Zhuan et al. adopted the step grouting method. The test was performed three times by filling the bacterial solution. After each filling of the bacterial solution, the gel with the same molar concentration of $CaCl_2$ and urea was refilled 5 times, and the interval between the two successive mineralizing salts was guaranteed to be about 24h (standing for a long enough time can make the cementing solution and the bacterial solution react completely). Andres Quiros[5] et al. compared the saturated soil samples treated by the grouting method and the unsaturated soil samples treated by the infiltration method. Through SEM test, it was found that the strength of the unsaturated soil samples treated by the infiltration method was lower; the calcium carbonate deposition of the saturated soil samples treated by the grouting method was partly located in the key position and partly around the sand particles. The unconfined compressive strength test shows that the strength of unsaturated soil treated by infiltration method is higher than that of saturated soil treated by grouting method. The infiltration method can obtain samples with higher strength, but poor ductility. The application of MICP technology to the seepage control and repair of dam slope, namely the biological film coating technology, is based on the principle of adhering to the surface of concrete to form surface protection, which is suitable for large-scale construction site operation. Tsai[6] et al. conducted tests on the treatment of beach sand by surface spraying method and surface spraying injection method, and concluded that the best treatment method is the two-phase surface spraying method, which can achieve better reinforcement effect. Liu Lu et al. used an adjustable spraying cleaning bottle to evenly spray bacterial solution or a mixture of calcium chloride and urea on the surface of the dam model sample, and improved the utilization rate of calcium ions in the mixture by adding excess urea solution. The dam model treated by MICP was put outside to dry, and then a flume test was carried out with the untreated control group model. It was found that the untreated dam model was soon washed away, and the dam model treated by surface spraying method washed away by water with a flow rate of 10 cm/s for several days, but its integrity remained intact. The existing MICP grouting technology is mainly gravity infiltration grouting or surface spraying.

3. Conclusion

The reinforcement effect of microbial geotechnical technology is affected by many factors, including soil environment, temperature, PH value and so on. In addition, the grouting rate and the treatment interval of bacterial solution also affect the reinforcement effect to a certain extent. The research results indicate that the effective reinforcement range of soil particle size is 10-1000 μm; The temperature range of 30-40 ℃ is conducive to the formation of calcium carbonate precipitation; Alkaline environment is more suitable for the growth of microorganisms, and the reinforcement effect of soil is better when the pH value is 9-11; Using a step-by-step grouting method to treat soil can improve the uniformity of soil.

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References

[1] Zhao Zhifeng, Kong Fanhao: Study on the influence of soil environment on microbial induced calcium carbonate deposition and reinforcement of marine silt [J], Journal of Disaster Prevention and Reduction Engineering, Vol.38(2018) No.4,p.608-614+692.

[2] Huang Yan, Luo Xuegang, Du Fei: Factors affecting microbial induced calcite deposition reinforcement [J], Journal of Southwest University of Science and Technology,Vol.24(2009) No.3, p.87-93.

[3] Yi Dan, Yang Guojun. Research on low-temperature microbial induced calcium carbonate deposition and its application in concrete crack repair [J], Silicate Bulletin, Vol.41(2022) No.3, p.959-968.

[4] R W W,L J S. Requirement of an alkaline pH and ammonia for substrate oxidation by Bacillus pasteurii.[J],Journal of bacteriology,Vol.84(1962).

[5] Quiros A, Zhang Shuai, Cheng Xiaohui. Research on Strengthening Unsaturated Sand Soil by Microbial Infiltration Grouting Method [J], Industrial Architecture, Vol.45(2015) No.7, p.28-30+175.

[6] Tsai C-P, Ye J-H, Ko C-H, Lin Y-R. An Experimental Investigation of Microbial-Induced Carbonate Precipitation on Mitigating Beach Erosion, Sustainability,Vol.14(2022) No,5, p.2513.