Research on Strength and Microstructure Characteristics of Cement Solidified Cadmium Contaminated Expansive Soil

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Abstract: Depending on the laboratory test of consolidation expansive soil polluted by heavy metal Cd, we can use cement to cure expansive soil artificially polluted by cadmium nitrate in different concentration. The paper discussed how the heavy metal concentration, cement dosage and curing age influence the unconfined compressive strength by solidified expansive soil polluted by heavy metal and micro-structure properties were tested. The study results show that, as the curing age and cement concentration increases, the unconfined compressive strength increases; as the concentration of heavy metal increases, the unconfined compressive strength decreases; the effect of heavy metal concentration on strength is different, the effect of high concentration on strength is greater than the effect of low concentration; Through the change rules of the micro-structure characteristics, the results on micro-structure analyzing show that the reason of strength increases is the porosity decreases after adding cement.

1. Introduction

With the rapidly economic development and the strategies of urban industrial adjustment were implemented, the heavy metal left by industrial relocation was a big threat to the environment [1]. Therefore, it is necessary to cure heavy metal contaminated soil that can satisfy the safe of environmental, development and utilization. Cement solidification is a method for rapidly cure the heavy metal contaminated soil, scholars of domestic and foreign have done some studies about this issue [2-7]. Chen lei et al. [2] considered that the strength of cement solidified soil polluted by the Pb is increased with the increases of age and cement concentration. Wei mingli et al. [3] found that the concentration of Zn had a "critical value" on the strength and failure strain of contaminated soil. Cha pusheng et al[4] found that the unconfined compressive strength, cohesive force and internal friction angle of soil polluted by the Pb and Zn were increased with the increases of curing age and cement concentration. Shao li et al.[5] showed that the strength of cement solidified Ni contaminated soil was increased with the increases of age and cement concentration. Lee et al. [6] also found that as the content of Pb increases, the strength of cement solidified
material decreases. Gineys [7] believed that Pb can change the density and structure of CSH, enhance the unconfined compression strength of the curing age for 20 days. We all know that expansive soil is a special clay which has the characteristics of swelling and shrinkage upon changes in water content and stress conditions [9]. At present, the pollution of Cd is up to 7% [8] in China, and found that expansive soil had been polluted by Cd in Nan yang. The material will be changed and its strength will be affected when the expansive soil polluted by the heavy metal. Therefore, it is very important to cure the expansive soil polluted by the heavy metal Cd. In this paper, through unconfined compression test and microscopic experiment, the variation rules of Cd concentration, cement content, curing age on the strength and microstructure were analyzed.

2. Materials and test methods

2.1 The materials of test
Expansive soils were taken from Shi gang town of Nan yang city, and its color is brown red. The basic physical properties of undisturbed soil were obtained by tests, as shown in table 1.

Table 1. Basic physical properties of intact soils

| Moisture content (%) | Dry density (g/cm³) | Specific gravity | Liquid limit (%) | Plastic limit (%) | Optimum moisture content (%) | Maximum dry density (g/cm³) | Free expansion rate (%) |
|----------------------|--------------------|----------------|----------------|----------------|----------------------------|-----------------------------|------------------------|
| 25.31                | 1.38               | 2.68           | 48.8           | 28.33          | 23.1                       | 1.54                        | 58                     |

The heavy metal in the test is the cadmium nitrate, the reason is that contains more cations and has strong activity which makes it highly soluble in water. The disturbance to cement is very small after adding cement [10]. The concentrations of cadmium nitrate is chosen to be 1000 mg/kg, 3000 mg/kg and 6000 mg/kg that means 0.1%, 0.3% and 0.6% of the dry soil mass. It can be written as Cd 0.1, Cd 0.3 and Cd 0.6 in this paper, and Cd 0 means uncontaminated expensive soil. The cement is used as composite silicate cement, and the cement content is chosen to be 6%, 9%, 12% and that means 6%, 9% and 12% of the dry soil mass. It can be written as C 6, C 9 and C 12 in this paper.

2.2 Test methods of test
Heavy metal cadmium nitrate contaminated expansive soil is prepared by artificial: first, put the expansive soil in the oven to dry with the temperature is 105 degrees and the humidity is 22 degrees; adding cement to the expansive soil that through 2 mm sieve to filter; Then put cadmium nitrate in the water to prepare solution; stirring 5 minutes and put the solution in the cement expansive soil, mixing by artificial and samples are prepared after stewing. Last, using the static compaction to prepare samples for unconfined compressive (H 5 cm x Φ 5 cm), put the samples in the humidity chamber after demolding and the curing age is chosen to be 3 d, 7 d, 14 d and 28 d, starting XRD test and electron microscope scanning experiment when reach the curing age.

3. Test results

3.1. The influence of age on the strength
Curing age is very important to cement solidification because the length of time will affect the strength. FIG.1 shows the influence of curing age on the unconfined compressive strength at different concentration of cement and heavy metal.

![Graph showing the influence of curing age on the unconfined compressive strength at different cement and heavy metal concentrations.](image)

Figure 1. The influence of curing age on the strength

It can be seen from figure 1, the strength of the cement solidified heavy metal cadmium nitrate contaminated expansive soil are increased with the time of curing age, but the rate of change is different. In the short curing time of 3 d and 7 d, the rate of strength change is fast and the turning point is obvious at the heavy metal concentration of 1000 mg/kg and 3000 mg/kg; the slope of the curve is gentle after 14 days and that means the rate of change in strength begins to slow down. At any ages, the slope of curve is gentle at the heavy metal concentration of 6000 mg/kg, that means the influence of age in strength change is small. The curing age of turning point is different at different concentration of heavy metal and cement. We can conclude that short curing times has a big effect in strength change, and it is not obvious more than a certain curing age; The reason is that the hydration will be occurred in a short time after adding cement, and ion of Cd will form colloidal precipitates at the solution with alkaline, it can improve the strength; With the passage of time, the hydration reaction is blocked and the growth of strength slows down, it can indicate that the strength of cement solidified increases at a highly rate after curing within the first few days [11].

3.2. The influence of heavy metal concentration on the strength

In our life, the concentration of heavy metal in the place is different from the others. So we should talk about the influence of heavy metal concentration on the unconfined compressive strength. The tree map
shows the effect of heavy metal concentration on the unconfined compressive strength at the different curing age and cement concentration.

![Diagram showing the effect of heavy metal concentration on unconfined compressive strength at different curing ages and cement concentrations.](image)

**Figure 2. Influence of different concentrations on strength**

According to the tree map of fig.2, the unconfined compressive strength of the cement solidified Cd contaminated expansive soil are decreased with heavy metal concentration increases, but the reduction is different in the different heavy metal concentration. In the concentration of 1000 mg/kg, the strength is always slightly lower than the expansive soil after adding cement at different curing age. As the concentration increases, the strength decreases more and more, the extent of decrease is larger in the concentration of 6000 mg/kg than the concentration of 3000 mg/kg. The results show that at low heavy metal concentration, the ion of Cd would not prevent the hydrate reaction and the cement material would be generated, improved strength would be used to compensate the decreased strength of expansive soil caused by pollutant. At high heavy metal concentration, the ions will hinder or delay the hydration reaction and promote the strength of expansive soil to decrease.

### 3.3. The influence of cement content on the strength

The cement content is very important to cure expansive soil because we should consider the curing result and economic. Above figure 1 and 2, we can see that the strength of the expansive soil polluted by Cd are increased with the increases of the cement content. The reason is that the cement continuously increases which can accelerate the hydration reaction and the ions of Cd will be contained in C-S-H at the form of Cd(OH)$_2$ [12]. At 28d age, the strength can reach 2 MPa that is higher than conventional packing, so it can
satisfy the requirements of engineering. Considering the economy, we can select the suitable content of cement to cure Cd contaminated expansive soil.

4. Microstructure characteristics

4.1. XRD

In order to study the solidification mechanism of cement consolidate Cd contaminated expansive soil, XRD and electron microscopy are tested. The results are as follows:

![Figure 3. XRD](image)

The figure above shows the XRD diagram of Cd contaminated expansive soil in different cement concentration. It can be seen from the figure that the peak value decreases after adding cadmium nitrate; With the addition of cement, the peak value increases with the cement content increases. It indicate that the crystallinity of the material increases continuously with the addition of cement, so that the strength will be increased continuously.

4.2. SEM

The scanning electron microscopy are conducted under the concentration of 0.6% and cement content of 6% and 12%, the amplification times is 5000 and 10000. The results are as follows:
At a magnification of 5000 times, there are many gaps in the cement content of 6%, the gap is significantly reduce in the cement content of 12%. At a magnification of 10000 times, gaps decreases with the increases of cement content. No matter how many times zoom, it has the same rules that the gaps of the expansive soil decreases with the cement content increases. It indicates that the hydration reaction of cement will be accelerated, gelling substance will be generated and internal pores of expansive soil will be filled by the materials, it can promote the porosity decreases and strength will be increased.

According to the change rules of XRD and SEM, we can conclude that the law of microscopic characteristic change is agree with the law of experiment.

5. Conclusion
(1) The unconfined compressive strength of cement solidified Cd contaminated expansive soil are increased constantly with the increases of curing age. The influence of the curing age on strength is
different, strength changes greatly in the first few days after adding cement and the change of strength is gentle after 14 days.

(2) The unconfined compressive strength of cement solidified Cd contaminated expansive soil are decreased with the heavy metal concentration increases. The effect of strength change is different, the strength will be reduce greatly in the high concentration.

(3) The strength of cement cured Cd contaminated expansive soil will be gradually improved with the increase of the cement.

(4) The diffraction strength of the viscous material increases constantly after adding cement, and the products will reduce porosity of the expansive soil and then promote the strength improve.

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