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The Solidification Mechanism of Cement and Fly Ash Towards Contaminated Soil

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This paper aims at analyzing the solidification mechanism of fly ash and cement towards the contaminated soil. The man-made contaminated soil was chosen as the research object, and the curing agent, a mixture of fly ash and cement, was used to solidify it. It is concluded that the soil without the addition of curing agent will produce exposed overhead structures after compression and have lower strength and stability. However, the connection way of the original particles of the soil with fly ash-cement curing agent changes, and its strength is also greatly enhanced. Besides, different curing agents have different impacts on the soil. Therefore, the fly ash-cement curing agent has certain application value in solidifying the contaminated soil.

1. Introduction

While the modernization of urban areas is accelerating, most buildings have waste materials or engineering pollution to be disposed during their construction. As the pollution itself contains complex ingredients and higher organic content, it will inevitably form contaminated soil in the process of numerous pollution landfills. To promote the urban development, these contaminated soils must be treated centrally. From the current research on contaminated soil, we can see that there are few researches about the solidified process of contaminated soil.

In solidifying the contaminated soil, the fly ash-cement curing agent has certain application value. This paper uses the man-made contaminated soil as the research object to explore the impact of cement, fly ash and gypsum on the strength of the contaminated soil. It also investigates the curing age of curing agent based on unconfined compressive strength (UCS).

Figure 1: Construction of contaminated soil at site in a city

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2. Literature review

Cement soil is a mixture formed by injecting cement slurry (or cement dry powder) into soft soil and stirring. The soft soil is strengthened by cement, and its physical and mechanical properties are improved. It has the advantages of water hardness, low compressibility and low permeability. However, the compressive strength of cement soil is still far lower than that of concrete, and the composite foundation formed later has larger deformation. For such defects, many experts and scholars usually use cement admixtures or mineral admixtures to overcome them. At present, common admixtures and mineral admixtures include silica powder, lime, mineral powder, fly ash, gypsum and sulphate, fiber, water glass, surface active agent, compound admixture and so on. The unconfined compressive strength of cement soil is an important index to reflect the strength and deformation characteristics of cement soil, so the unconfined compressive strength is generally used to study the strength of cement soil. The research shows that the addition of fly ash can enhance the strength of cement soil to a certain extent. Zhou Chenggang and Gao Jun Liang indicated that when the amount of fly ash was equal to that of cement, the strength of cement mixed soil material increased by about 10% compared with that of cement alone. The main factors affecting the strength of fly ash cement soil include cement content, curing age and fly ash content. Among them, the cement dosage and age have the greatest influence on the strength of cement soil, followed by the amount of fly ash. When the content of fly ash is fixed, the unconfined compressive strength of cement soil increased with the increase of cement content. However, when the cement content increased to a certain extent, the effect of cement addition on strength was not obvious.

There are also many experts hoping to predict the compressive strength of fly ash cement soil by three main factors, including cement content, curing age and fly ash content. Many domestic scholars have obtained the strength prediction formula of the fly ash cement soil through the experiment. By using the proposed formula, the unconfined compressive strength of cement soil with different cement content and fly ash content can be calculated. More scholars have established a functional relationship between strength and age, amount of cement and dosage of fly ash. The strength of fly ash cement soil is influenced by many factors, and the compressive strength is predicted by three main factors. However, these prediction formulas are only obtained in one or two regions and one or two soft soil tests. The general applicability of the formula remains to be tested by more experiments and engineering practice. In order to improve the theoretical and practical system of fly ash and cement soil, the strength prediction of fly ash and cement soil can also be used as a research direction.

LópezDelgado and so on, by analyzing and summarizing the research results of fly ash cement soil in recent years, summed up the strength law of fly ash cement soil when different cement content, fly ash content and age, the stress strain relationship of fly ash cement soil tended to brittle failure. The shape effect, micro aggregate effect and volcanic ash effect of fly ash had a positive effect on the improvement of strength and mechanical properties of cement soil (LópezDelgado et al., 2012); Zhou and others studied the active cementitious materials to solidify lead contaminated soil, and the alkali activated cementitious material with rich silicon material was used to study the stabilization of lead in the soil. 500 mg/kg Pb contaminated soil was treated with fly ash, silica fume and rice husk ash cementitious materials, respectively. The treatment effect was evaluated by unconstrained compression strength (UCS) and toxicity characteristic leaching program (TCLP) for 14 and 28 days (Zhou et al., 2017); Yuebing evaluated the immobilization of sepiolite on cadmium contaminated soil, indicating that sepiolite affected cadmium contaminated soil (Yuebing, 2012); Li and so on compared solidification / stability of lead contaminated soil of magnesium aluminum cement (MPC) and ordinary Portland cement (OPC) with the same dose, and the leaching mechanism of Pb in the solidified body was analyzed. They pointed out that the effect of MPC in the stabilization of Pb was better than that of OPC. The leaching mechanism of Pb in the solidified body after MPC and OPC was first dissolved and then diffused (Li et al., 2016). Chen and others made experiments on the stability of cement contaminated soil with diesel oil. The experiment showed that the stable polluted samples had a more compact aggregation structure and higher aggregate content compared with the original samples (Chen et al., 2016). Heidarzadeh and other studied the effect of cement on the treatment of glycerol contaminated clay. It indicated that adding cement to the contaminated soil increased the strength, and the increase of strength depended on the percentage of cement, the curing time and the degree of pollution. Based on the scanning electron microscope analysis, it was found that the presence of glycerol prevented the interaction between soil and cement (Heidarzadeh et al., 2016). Ma and so on studied the effect of cement activated persulfate on PAH contaminated soil. After 12 times freezing and thawing cycles, the soil samples had an anti-disintegration effect during the freezing and thawing cycle (Ma et al., 2017). Gu and so on studied the effects of fly ash on heavy metal absorption in paddy soils polluted by polymetallic contaminated soils (Gu et al., 2013).

To sum up, in the above research work, the solidification of soil pollution by separate cement or fly ash is mainly studied, focusing on the maximum effect of fly ash and cement on the treatment of pollution suddenly and how many doses are added to soil pollution. But few studies have made a detailed study on the curing mechanism of cement and fly ash and there is no systematic explanation of its mechanism. Therefore, based on the above research status, the curing mechanism of contaminated soil by cement and fly ash is mainly studied. Taking the soil as the research object, the solidifying agent of fly ash and water mud mixture is used. The microstructural changes of soil before and after solidification were observed by electron microscope, to analyze the curing mechanism of fly ash and cement on contaminated soil.

3. The method

3.1 Experimental material

According to the characteristic of typical urban pollution components, the contaminated soil is generally mixed with several major types of waste materials such as kitchen waste, waste paper, rubber, plastic, fiber, vegetation, glass, metal, ceramics and clay. Due to the complexity and unevenness of the components, the test result will be very discrete with contaminated soil in landfill used in the experiment, which makes it difficult to analyze the influence of relevant factors. Therefore, this experiment uses man-made contaminated soil for the experiment. The components contained in the soil--kitchen waste, waste paper, fiber and vegetation were simulated by dried cabbage leaves, dry newspaper cut in pieces, old cloth debris and sawdust while the clay, plastic and glass was taken from the waste materials.

Table 1: INDICATORS OF CURING AGENTS

cement	The physical and chemical indexes of fly ash			
325#, Portland cement	Water requirement than (≤%)	The water content (≤%)	fineness (≤%)	Ignition loss (≤%)
	106	0.5	2.9	4.5
	stability	Sulphur trioxide (≤%)	Free lime	Intensity activity index (≥%)
	qualified	0.84	0.08	86

3.2 The experimental method

When preparing the sample, the copper nitrate solution should be firstly prepared following the designed moisture content. Then, the soil and cement should be added into the mixer and fully stirred. Next, after putting copper nitrate solution into the mixer, the mixture should be stirred for 15 minutes. After this, cubic samples with a side length of 70.7 mm were created, covered with a plastic film cover. It would strip from the module after 24 hours and then was sealed into plastic bags. After that, the samples should be stored in standard curing box of constant temperature and humidity (temperature > 220C, relative humidity> 70%) until it reached its curing age. Its UCS test method is the same as that of the conventional cement soil. In addition, the instrument used in the experiment is a conventional vertical loading device, and the control axial strain rate is 1mm / min.

Table 2: Experimental curing agents and admixture

Dosage levels	External admixture and curing agent			
	lime (%)	gypsum (%)	cement (%)	The fly ash (%)
0ne	0.0	0.0	15.0	0.0
two	3.0	3.0	20.0	3.0
three		5.0	25.0	5.0
four			27.0	10.0

3.3 The preparation and curing of contaminated soil

The preparation of contaminated soil samples can be divided into two stages: (1) The various crushed component material of the soil should be weighed according to the ratio plan in Table 1 and fully stirred to make 3 types of contaminated soil specimens. (2) When the contaminated soil is prepared, the contaminated soil, curing agent and external admixture should be weighed according to the experiment plan in Table 2, and the proper amount of water (the moisture content is 60%) should be added to thoroughly mix and stir with those materials. The NJ-160A cement mortar mixer produced by XX City Building Materials Instrument Machinery Factory was used. The prepared mixture will be placed in a three-jaw mold with a diameter of 39.1 mm and a height of 80 mm and samples are made according to the provisions of "Geotechnical Test Procedures" (SL237-1999). The prepared sample have to be put in the standard curing room with the temperature of (20 ± 5) ℃ and the humidity above 95% until it reached the specified curing age of which this experiment was 28 d. When the specimen is cured to the specified age, it will be stripped from the module and subjected to strength and deformation tests. The strength test employed YSH-II limestone unconfined pressure gauge from Nanjing Soil Instrument Factory Co., Ltd, and is processed in accordance with "Geotechnical Test Procedures " (SL237-1999). In the experiment, when the axial strain is less than 3%, the reading should be recorded every 0.5% strain (or 0.4 mm). When it is greater than or equal to 3%, the reading should be recorded every 1% strain (or 0.8mm). The test of each sample should be completed in 8 to 10 minutes.

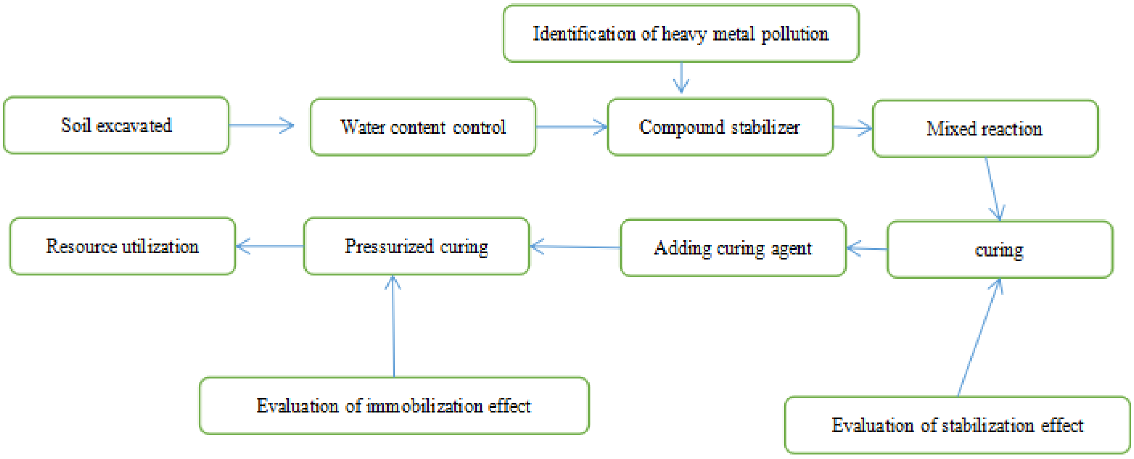

Figure 2: Process for curing contaminated soil

4. The result and analysis

4.1 The impact of fly ash content

Fly ash, an active solid waste produced by coal combustion, can improve the strength and mechanical properties of the soil, if it is added in the solidified soil. To illustrate the effect of fly ash content on the strength, the UCS of three types of soils (soil I (fresh), soil II (strong degradation period) or soil III (stable degradation period)) with 3%, 5% and 10% fly ash content was tested. With the same cement content, the strength of the three types of soils all increased with more fly ash content. Compared with the case without fly ash, the strength of the solidified soil with 3% fly ash content respectively increased by about 19.4%, 13.4% and 4.1%, those with 5% content increased by 22.6%, 26.8% and 15.6%, and those with 10% increased by around 45.7%, 33.6% and 25.5%. This is because fly ash is an active material containing a large amount of substances such as SiO_2, Al_2O_3, FeO, Fe_2O_3, CaO, TiO_2, MgO, K_2O, Na_2O, SO_3 and MnO_2. Those substances would react with the hydration products of cement to generate volcanic ash and produce products such as hydrated calcium silicate and hydrated calcium aluminate and further promoted the hydration of cement. At the same time, the fine particles in the fly ash can be filled into the pores of the contaminated soil to further enhance the strength of the soil.

Table 3: Comparison of strength enhancement of polluted and cured soil with different amount of fly Ash

Contaminated soil type	Comparison of the strength of contaminated soil under different fly ash content		
	3% increase (%)	5% increase (%)	10% increase (%)
Contaminated soil I (fresh)	19.4	22.6	45.7
Contaminated soil II (degradation period)	13.4	26.8	33.6
Contaminated soil III (degradation stability)	4.1	15.6	25.5

4.2 The effect of the cement content

With the same copper ions content and curing age, the UCS of copper contaminated soil increased with more cement content. Those with curing age of 14 d and 28 d increased more rapidly than those with 7 d. The strength of the soil with curing age of 7d and 14d didn't change much when the copper ion content reached 0.5%, which indicated that the increasing in cement content failed to improve the strength with a relatively high copper ion content.

4.3 The effect of gypsum content

Gypsum is a monoclinic mineral with a high cleavage composed of calcium sulfate dihydrate and is easy to crack onto flakes. With an aim to explain the effect of gypsum content on the strength of solidified contaminated soil, the changes in UCS of three types of soils with 0%、3% and 5% gypsum content was tested with the addition of cement.

When the 3% and 5% gypsum were added in three types of soils, the strength of those soils with 15% cement content was all improved comparing with those without gypsum content. As to soil I (fresh), it was improved to 41.8 kPa and 47.3 kPa. However, with the growing of the cement content, the improvement of the strength slowed down. When the cement content is 30%, the strength of soil I with gypsum was respectively improved to 14.5kPa and 41.3 kPa. As to soil II (strong degradation period), its strength was improved to 150.9 kPa and 156.1 kPa, and the improving rate almost remain the same with the increasing of cement content. When the cement content is 30%, its strength was improved to 149.0 kPa and 159.2 kPa. The strength of soil III (stable degradation period) was improved to 115.3 kPa and 134.3 kPa with an increase of 9.4% and 10.9%. Then, with the increase in cement content, the improvement of its strength slowed down. When the cement content reached 30%, the strength was improved to 9.0 kPa and 17.2 kPa, respectively an increase of 0.5% and 1.0%, which revealed that the gypsum had no significant impact on the strength of soil in the stable degradation period.

Table 4: 3 % and 5 % gypsum mixing, 15 % and 30 % respectively, compared with the strength of contaminated soil that was not mixed with cement

Contaminated soil type	3% gypsum content		5%gypsum content	
	15% cement content	30% cement content	15% cement content	30% cement content
Contaminated soil I (fresh)	41.8 kPa	14.5kPa	47.3kPa	41.3 kPa
Contaminated soil II (degradation period)	150.9 kPa	149.0 kPa	156.1 kPa	159.2 kPa
Contaminated soil III (degradation stability)	115.3 kPa	124.3 kPa	134.3 kPa	151.5 kPa

4.4 The analysis of UCS

This section illustrates the relationship between UCS and the cuing agent content to explore the relationship between the strength of contaminated soil and the curing agent content with the optimal moisture content. With the same curing age, the UCS was enhanced with the increase of curing agent content. This disclosed that the curing agent evidently ameliorate the performance of the soil thus enhancing its density and strength. With the same curing agent content, the UCS augmented as the curing age went longer. Besides, the strength was improved evidently in the initial period of curing with less amount of the curing agent, however, its improving speed slowed down as the curing age became longer. With more curing agent, the strength was improved slowly in the initial period, and an evident increase happened only when the curing age is longer than 21 days.

5. Conclusion

It is concluded that the UCS of the solidified contaminated soil will be enhanced with the increase of the curing agent content. In addition, with a smaller curing agent content, the soil compressive strength will be more evidently improved as the curing agent content increases. The strength is also improved with the increase of curing age. When the curing agent content is smaller, the improving speed is faster than that in the initial period when the curing age is between 21d-28d. however, when the curing agent content is larger, the strength will be greatly improved with the curing age is between 7d-14d, and its improving speed decreases in the later period. The shear strength index of solidified contaminated soil increases with the growing of curing agent content, and the cohesion is more obviously enhanced. With different mix ratios of fly ash and cement, the contaminated soil with more cement content has a more evident increase in cohesion and internal friction force. As the curing age increases, the shear strength of contaminated soil will be improved. After 14 d when the cohesion and internal friction angle become basically stable, the strength remains almost unchanged. The changes in microstructure of the soil before and after solidification observed by scanning electron microscopy showed that the curing agent turned the weak bond between the original particles into a cementitious bond, thus explaining the internal factors that improve the strength of the contaminated soil.

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