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Influence of Compaction Delay Time on Properties of Stabilized Expansive Soil using Cementitious Material From Calcium Carbide Residue and Rice Husk Ash

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***Abstract*—In order to find compaction delay time effects on the properties of expansive soil stabilized with cementitious material using calcium carbide residue and rice husk ash, based on the findings of experimental investigation, free swelling ratio, Atterberg limit and unconfined compressive strength in different blending content have been analyzed comparatively. In the case of no compaction delay, blending content significantly contributed to variations in free swelling ratio, liquid limit, plasticity index and unconfined compression strength values but not to plastic limit. If compacted delay, free swelling ratio decreases sharply with blending content, and decreases slowly with delay time. For different blending content, liquid limit and plasticity index show different trend with delay time, but plastic limit continuously increases with delay time, and most of the samples reach relatively low plasticity index when blending content is between 15% and 25%. For uncured samples, unconfined compression strength increase with increasing amount of cementitious material regardless how much of delay time. However, after cured 28 days, most of samples strength are maximized when blending content reaches 20%. Based on unconfined compression strength of curing 28 days, the optimum delay time of stabilized expansive soil is between 12-36 hours, and the more blending content, the shorter optimal delay time.**

Keywords*—*Delay time; expansive soil;calcium carbide residue;rice husk ash

I. INTRODUCTION

Expansive soil is characterized with expansion, shrinkage and superconsolidability and is well known as “disaster soil” in geotechnical engineering[1].Due to the great destruction and wide distribution of expansive soil, it generally needs to be stabilized before it is used as engineering filler or foundation. Traditionally, the stabilization binders for expansive soil are hydrated lime and portland cement[2]. However, traditional stabilizers are under discussion not only for their negative environmental effects but also for their costs. For these reasons, various types of solid wastes have tended to use as stabilizers for expansive soil[3,4],such as fly ash[5,6],cement kiln dust[7,8],blast furnace slag[9,10],alkali residue[11,12], and so on.

In China, there are two types of solid waste that are abundant. One is calcium carbide residue(CCR), which is a by-product of acetylene production. Another is rice husk ash (RHA), resulting from burnt rice husk in generating electricity and boiling water. Based on good cementitious properties of mixture combined with CCR and RHA[13],Liu has recently made use of this cementitious material to stabilize expansive soil[14].Comprehensively considering compressive and flexural strength of mortar, the optimum mixing ratio of CCR and RHA was adopted as 35:65. Swelling property, cracking characteristic, unconfined compression strength(UCS) and shear strength of stabilized expansive soil were analyzed and the influences of blending content, curing time and initial water content were investigated. The results have proved feasibility and effectiveness of CCR-RHA in stabilizing expansive soil.

For stabilized soil, it is well known that during geotechnical test the mixture needs to be stored for a period of time after mixed so that the water is evenly distributed and then compacted. The time from mixing to compaction is called compaction delay time. As early as 1961, Michelle has discovered the significant effect of delay time on density, expansion and strength of lime-stabilized expansive soil[15].Moreover, if samples are prepared as specified constant density, the properties of stabilized soil after curing are about the same whether compaction delay time is 40 min or 24h. Since then, several scholars have studied the influence of delay time. For expansive soils stabilized with lime and lime-fly ash, the influences of different compaction delay time (1d, 3d, 7d) on the improvement effect of expansive soil have been discussed from the perspectives of Atterberg limit, free swelling ratio, California bearing ratio (CBR), UCS and compressive modulus by Wang [16]. He found that in the 90-days curing period, the delay time has no obvious effect on its physical properties, but it has an adverse effect on the mechanical properties. Soumya found that plasticity index and maximum dry density(MDD) of lime-stabilized expansive soil were decrease with delay time(ranging from 0 to 48 hours)

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[17].Di Sante has investigated the influence of compaction delay(48 hour) on the compressibility and hydraulic performance of lime stabilized soil[18].The compression index of samples compacted with delay is doubled relative to that of the immediately compacted ones and the hydraulic conductivity is not significantly modified by a delayed compaction. Xiao carried out a test on the improvement of expansive soil by CCR with compaction delay 0, 1, 2, 3 and 5 days and found that when delay time is more than 1 day, the free expansion rate of soil decreased significantly, reaching the standard of roadbed filler[19].Besides, for lateritic soil stabilized with lime, Osinubi has found that the compaction and strength properties of the lime-treated soil decreased with increases in compaction delay time[20].Furthermore, Osinubi used two-way analysis of variance and multiple regression to study the effects of delay time[21]. In no compaction delay, lime content and compactive effort significantly contributed to variations in MDD and CBR values but not to optimum moisture content(OMC). When delay time is between 1 to 3 hours, reductions in MDD,OMC,UCS and CBR values associated with compaction delay were statistically significant, regardless of the compactive effort.

In a word, compaction delay time is an important effect factor for properties of expansive soil with lime or lime-fly ash. Since the stabilizing mechanism of CCR-RHA and lime is similar, the delay time may also significantly affect the performance of stabilized expansive soil with CCR-RHA. This issue has important research implications but has not yet been studied. As a result, the objective of this study is to estimate the influence of delay time on the physical and mechanical properties of expansive soil stabilized with CCR-RHA, and provide scientific guidance for the construction process of stabilizing expansive soil.

II. MATERIALS AND METHODS

A. Materials

1) Expansive soil

The expansive soil used in the experimental programmer was brought from construction site in China. After air-dried in the laboratory, expansive soil is crushed into particles and sieved with sieve size of 2 mm. The particle size of expansive soil is shown in Figure 1. According to the statistics, the composition of various particles in expansive soil is as follows: sand size-6.9%, silt size-52.3% and clay size-40.8%. At the same time, specific gravity, Atterberg limit, free swelling ratio, compaction characteristic were tested and listed in Table 1. Based on these characteristics, the tested soil is classified into CH clay with high liquid limit and categorized as expansive soil with very high swelling potential[22].

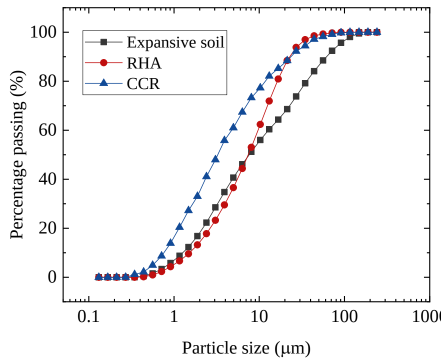

Figure 1. Particle size of test materials

Table 1. The physical properties of expansive soil

Specific gravity	Liquid limit /%	Plastic limit /%	Plasticity index	Free swelling ratio /%	Maximum dry density /g · cm^{-3}	Optimum moisture content /%
2.63	85.6	29.2	56.4	138.5	1.54	21.8

2) RHA

RHA used in the experimental programme was obtained from biomass power plants in Huai'an, China. Most of RHA still retains its original shape like rice husk, it needs to be ground to stimulate its pozzolanic activity. Thence, the grinding of RHA was performed in a vertical planetary ball mill and grinding time is 5 minutes based on past experience[23].

The particle size distribution of RHA were analyzed using a laser particle size analyser and particle size is shown in Figure 1. About 99.8% RHA particles are fine particles(<0.075mm). The chemical composition of RHA was tested by XRF. Its main components is SiO_2 ,which exceeds 72%.

3) CCR

The CCR was collected from an acetylene gas plant located in Huai'an, China. Because the nature CCR is wet, it was dried for 24 hours at 105℃, then ground in a universal grinding machine. The particle size of ground CCR is shown in Figure 1 and its particles are very fine and uniform. The main chemical composition of CCR is CaO and its proportion is more than 70%.

B. Testing methods

(1) Samples preparation

According to previous research by author, the optimum mixing ratio of 35:65 (CCR/RHA) can obtain the best strength[14]. Therefore, in this study, the ratio of CCR/RHA adopts 35:65. At first, CCR and RHA are mixed with optimum mixing ratio.Then, CCR-RHA are blended with expansive soil and the blending content is 0%,5%,10%,15%, 20%,25%,30% respectively. After a while, the mixture are stirred with water and storied in sealed bags for 0,12,24,36,48,60,72 and 144 hours. Until the certain delay time, samples are manufactured according to requirements of free swelling ratio, Atterberg limit and unconfined compression strength test. In addition, part of samples will be cured at 20°C and 95% humidity until 28 days for unconfined compression strength testing.

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(2) Samples testing

In order to understand the effect of delay time on stabilized expansive soil, free swelling test,liquid-plastic limit combined test,unconfined compression test were carried out according to "Test Method of Soils for Highway Engineering" (JTG E40-2007, Chinese standard) [24].

III. RESULTS AND DISCUSSION

A. Free swelling ratio

(1) The variation of free swelling ratio of stabilized expansive soil with CCR-RHA content are presented in Figure 2. Obviously, no matter how long the delay time, as blending content increase, free swelling ratio of stabilized soil go on decreasing gradually. For example, when delay time is 0h and blending content increases from 0.0 to 30.0%, free swelling ratio decreases from 138.5% to 67.5%. According to "Technical code for buildings in expansive soil regions "(GB 50112-2013), the swelling potential of expansive soil changes from extremely strong to medium. When delay time is 24h and blending content is 30.0%, free swelling ratio become to 59.5%, at this moment the swelling potential of expansive soil is weak. As a result, the addition of CCR-RHA has greatly overcome the expansion of expansive soil. Firstly, replacement may be the important reason for this phenomenon. Since CCR and RHA are non-expanding granule, the proportion of swellable particles in the stabilized soil gradually decreases as the amount of the blending content increases, then its expansion is bound to decrease. However, it is worth noting that the reduction rate of free swelling ratio decreases as the blending content increases. Especially when the blending content is greater than 20%, this trend is more obvious. This law shows that there are not only replacement, but also other reactions. Since the main component of CCR is $Ca(OH)_2$, When CCR is in contact with water, it will be dissociated into Ca^{2+} and OH^- ions. It is well known that Na^+ and K^+ are existed in clay minerals of expansive soil, such as montmorillonite and illite. Under alkaline conditions, Na^+ and K^+ can be replaced by Ca^{2+} with ion exchange. As a result, the composition of montmorillonite and illite in the expansive soil has changed. That is to say, some minerals with expansion potential have changed these nature. Meanwhile, the thickness of water film between clay particles become thinner, it will inhibit the expansion of the soil.

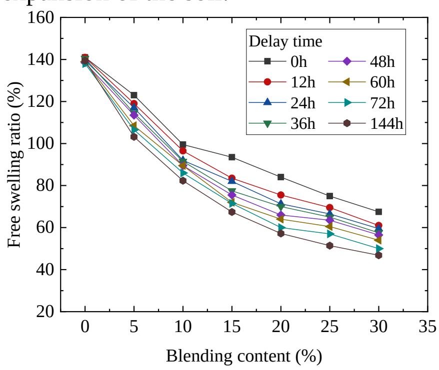


Figure 2 Free swelling ratio varied with blending content

(2) Figure 3 shows that the association between swelling potential of stabilized expansive soil samples and delay time. It is clearly visible that the delay time does not have much effect on the expansion of untreated soil, but the effect is obvious for stabilized soil. As delay time increases, free swelling ratio of stabilized soil decreases accordingly. Giving an example with blending content 20%,when delay time increases from 0h to 72h and 144h, free swelling ratio decreases from 84.0% to 60.1% and 57.2%. This is because as the delay time increases, the ion exchange between Na^+,K^+ and Ca^{2+} become more and more sufficient. According to the previous analysis, the expansion potential decreases with increasing amount of ion exchange. Furthermore, a trend can be obtained that in early stage of compaction delay expansion reduction is very fast, and slow relatively in later stage. For example, the reduction rate of free swelling ratio is 0.33% in range of 0-72h, but only 0.04% in range of 72-144h when blending content is 20%. The reason is that the water film between clay particles becomes thicker and thicker with the ion exchange progressing, and many ions enclosed in the clay cannot participate in the reaction.

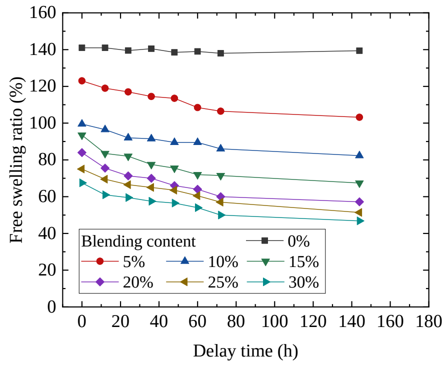


Figure 3. Free swelling ratio varied with delay time

B. Atterberg limit

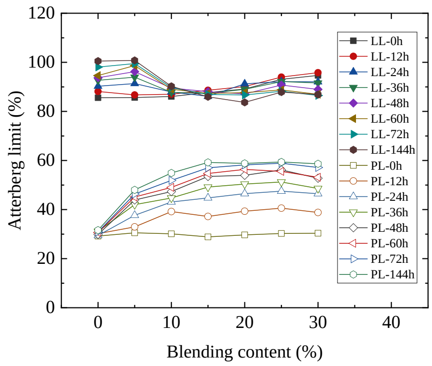
The effects of CCR-RHA content and delay time on Atterberg limits of stabilized expansive soil are investigated.

(1) Figure 4 shows the variations of liquid limit(LL), plastic limit(PL) and plasticity index(PI) with blending content on different delay time. When the delay time is relatively short (less than 24h) LL increases with the increase of blending content, conversely when the delay time is relatively long (more than 60 hours) LL decreases. However, between 24h and 60h, The change of LL with blending content is not obvious. For the case of delay and no delay, the change in PL presents two different laws. If there is no delay(immediate compaction), the PL remains basically unchanged even if blending content increases. However, if compaction is delayed, the PL increases first and then decreases with the increase of blending content. The maximum plastic limit point is about 15-25% .The trend of LL and PL leads to the following rule of plasticity index: for undelayed samples, the PI increases with blending content, probably because the particle fineness of RHA and CCR is smaller than that of expansive soil; for the samples with compaction delay, with the increase of blending content, the PI decreases first and then increases slowly. Most of the samples reach a minimum plasticity index when the blending content is between 15% and 25%.

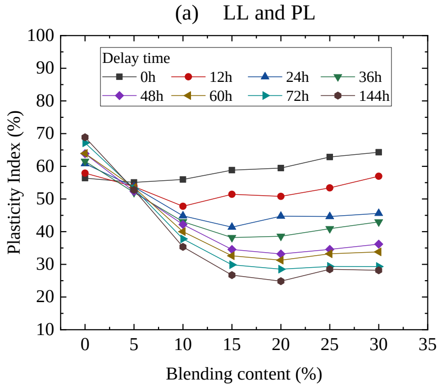
(2) Figure 5 shows the influence of delay time on LL, PL and PI with different CCR-RHA content. When the blending content is relatively low (less than 10%) LL increases with the

increase of delay time, conversely, when the blending content is relatively high (more than 20%) LL decreases. If the blending content is between 10% and 20%, LL has no obvious changes. Meanwhile, for untreated expansive soil, PL is basically unchanged with the increase of delay time. But after adding CCR-RHA, PL increases with delay time. The increase rate decreases as the delay time increases. At the beginning, the increase is fast, and then gradually stabilizes. As a result, for different blending content, PI shows different trend with delay time. For pure expansive soil sample, PI increases with delay time. When blending content is 5%, PI has very weak change. But blending content exceed 5%, PI decreases obviously with delay time.

The above phenomenon mainly comes from two aspects. On the one hand, with increase in CCR-RHA content, due to depletion in double layer, the soil particle come close to each other and gets flocculated. These flocculated structure entrapped some amount of water in the void which cause increase in plasticity characteristics. On the other hand, with delay time increasing more number of calcium ions reacts with the oxygen peaks of soil and reduce the affinity of water absorption in soil, thus the diffuse double layer thickness reduced. As a result, by increasing the delay time, the PL value is found to increase initially and PI follows a decreasing trend. Of course, this property is only apparent when the amount of CCR-RHA is up to a certain amount.

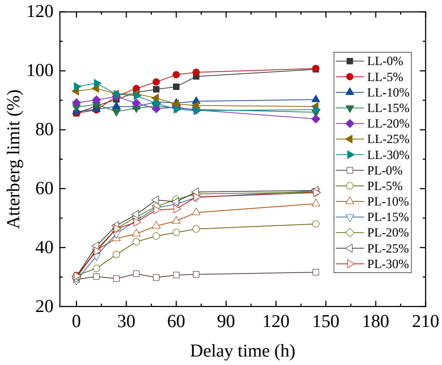


(a) LL and PL

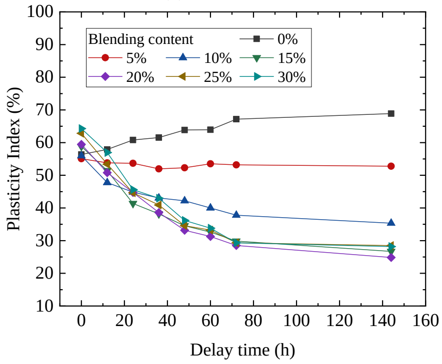


(b) PI

Figure 4. Atterberg limit varied with blending content



(a) LL and PL

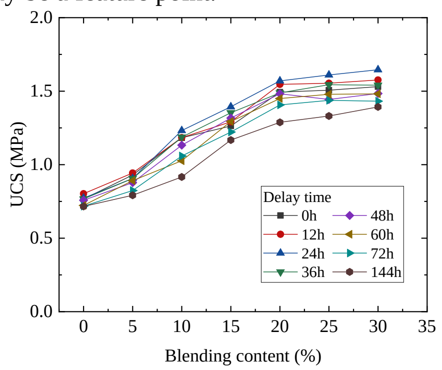


(b) PI

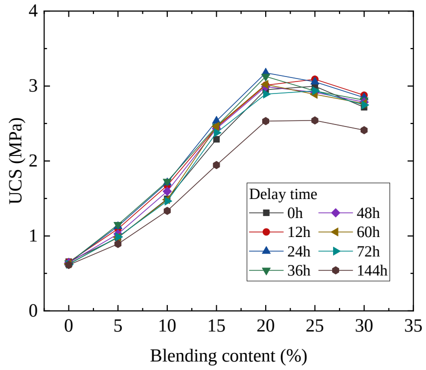
Figure 5.Atterberg limit varied with delay time

C. Unconfined compression strength

(1)The unconfined compressive strength(UCS) versus blending content of CCR-RHA cementitious material are described in Figure 6 for curing 0 and 28 days. For uncured expansive soil, no matter how long the delay time, UCS usually increase with increasing amount of CCR-RHA. For example, in Figure 6(a), when delay time is 24h, UCS increases from 0.77 MPa to 1.65MPa as CCR-RHA content increases from 0 to 30%. The admixture of CCR-RHA play a good filling role because of their fine particles. The additive changes the structure of soil particles, reduces plasticity and improve the compactness of samples. In addition, the more blending content, the higher the amount of ion exchange, and the stronger the agglomeration of the soil. Therefore, the uncured expansive soil has an increased strength as the CCR-RHA content increases. It is worth noting that when the CCR-RHA content exceeds 20%, the increase rate of UCS lower significantly. This phenomenon shows that 20% of blending content may be a feature point.



(a)cured 0 day



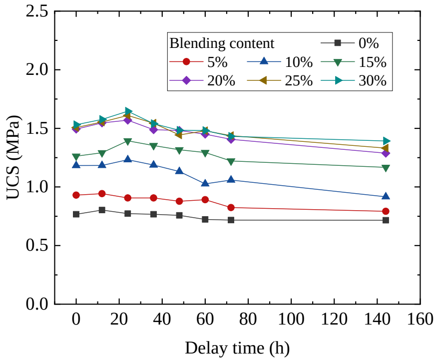
(b) cured 28days

Figure 6. UCS varied with blending content

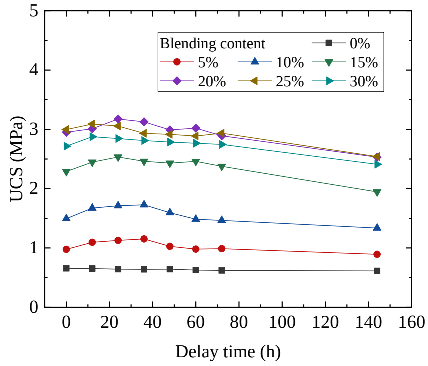
(2)Compared with uncured stabilized soil, the strength and variation of samples after curing have changed significantly, as shown in Figure 6(b). When delay time is 24h, for the sample with 20% blending content, the UCS of samples cured 28 days is about 2.0 times that of uncured samples. This result indicates that during the curing period, the cement material(CCR-RHA) has produced a series of chemical reactions with the expansive soil and formed new solidified substance.

Another interesting phenomenon is that the UCS and blending content are not positively correlated, and the strength of samples is usually maximized when blending content is 20%. A decrease in strength may been caused by unsoundness due to free lime when CCR content exceeded the required amount.

(3) The relationship between UCS of stabilized expansive soil and delay time are described for curing 0 day and 28 days in Figure 7. There are several rules that can be obtained through comprehensive analysis.



(a) cured 0 day



(b) cured 28days

Figure 7. UCS varied with delay time

First, if the sample is not cured and directly subjected to compression test, there is a maximum compressive strength for all groups of blending content, as shown in Figure 7(a). The time corresponding to the maximum compressive strength is defined as the optimal delay time. When the blending content is 0% or 5%, the optimal delay time is 12 hours, and when the blending content exceed 5%, the optimal delay time is 24 hours. Moreover, if the time is greater than optimal delay time, the strength tends to decrease with time. It can be clearly found that when the time delay reaches 144 hours, the UCS of test soil is significantly reduced compared with delay time of 12-24 hours. Giving an example of 20% blending content, when delay time is 24h, UCS is 1.57MPa, but when delay time is 144h, UCS is only 1.29MPa. This is mainly due to the agglomeration of the soil particles during the suffocation and the formation of agglomerates. When the suffocating time is long, the volume of agglomerates is relatively large. As a result, when compacting the sample, the compactness of the sample is obviously weakened due to the poor gradation of soil particles.

Second, if no CCR-RHA cementitious material is added, the delay time has little effect on the 28-day curing strength. This means that although the compaction delay may affect the particle structure of the initial sample, this effect will gradually weaken after a period of curing time. However, after the addition of CCR-RHA, compaction delay time will affect the strength of cured samples. As same with uncured samples, the strength of cured samples for long-term compaction delay (144h) was significantly lower than short-term delay(12-72h). Moreover, the optimum delay time is different for cured samples with different blending content. When the blending content is relatively small, such as less than 10%, the optimum delay time is between 24-36 hours. When the blending content between 10% and 20%, the strength is maximum after 24 hours delay. When the blending content is more than 20%, the optimum delay time is about 12 hours. The general rule is that the more the blending content, the shorter the optimal delay time.

IV. CONCLUSIONS

A study of compaction delay time influence on the properties (free swelling ratio, Atterberg limit and unconfined compressive strength) of expansive soil stabilized with CCR-RHA cementitious material using different blending content has been conducted. Based on the findings of experimental investigation the following conclusions are drawn:(1)In the case of no compaction delay, blending content significantly contributed to variations in free swelling ratio, LL, PI and UCS values but not to PL.(2)If compacted delay, free swelling ratio decreases sharply with the blending content, and decreases slowly with delay time.(3) For different blending content, LL,PI shows different trend with delay time, but PL continuously increases with delay time. When blending content is 5%, PI has no obvious change. But blending content exceed 5%, PI decreases rapidly with delay time. In addition, most of the samples reach a minimum PI when the blending content is between 15% and 25%.(4)For uncured samples, UCS increase with increasing amount of CCR-RHA regardless how much of delay time. However, after cured 28 days, UCS and blending content are not positively correlated, and the most of samples strength are maximized when blending content is 20%. Based on UCS of cured 28 days, the optimum delay time of stabilized expansive soil is between 12-36 hours, and the more blending content, the shorter optimal delay time.

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