Experimental Study on Weathering Mechanism of Shale from Zhang Cheng Expressway and its Utilization

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ABSTRACT: To explore the feasibility of weathered shale as expressway subgrade, the study on the mechanism of shale weathering and its filling strength (CBR test) were carried out. The SEM images of shale samples from Zhang Cheng expressway under different immersion time were obtained and the mineral components and micro-structure were observed and analyzed. The chemical and mineral compositions as well as clay mineral of shale samples were also tested by X-ray diffraction method. Time scope for disintegration, weathering mechanism and micro-structure change of shale samples were discussed. Based on these experiments, California bearing ratio (CBR) tests under different compaction degree were carried out under the optimum water content of shale samples within the range of ±0.8%. The test results show that the most disintegration of shale occurred within 12 hours and the complete disintegration was within 24 hours and micro-structure, mineral and chemical compositions changed dramatically; The CBR value of shale sample after disintegration can satisfy the requirements of subgrade filling on expressway construction.

INTRODUCTION

Zhangjiakou-Chengde expressway (Short Zhang Cheng expressway), widely distributed shale along this road line, is a typical expressway across mountain area. Shale has relatively high strength in natural state and low capacity to resist weathering. It will be easy to disintegrate into the massive or granular soil and lose its strength when it exposed to the air (Xia et al. 2011 & Zheng et al. 2012). The large subgrade settlement would cause distress when untreated shales are used as subgrade filling directly. On the other side, abandoned shales will occupy a large amount of land and the cost will be huge (Luo et al. 2012). Therefore, it’s critical to study on the feasibility of weathered shale as expressway subgrade filling. Many researches on mechanism and micro-mechanism of special soft rocks were conducted by scanning electron microscope, energy spectrum analysis, X-ray diffraction, physic mechanical experiments, as well as chemical analysis of water sample (Liu et al. 2000 & Zhou et al. 2005). On the other hand, many CBR tests of strong weathering rock were done to judge its potential strength as the subgrade filling (Cui et al. 2014 & Chen et al. 2012 & Guo et al. 2014). In this paper, shale samples were taken from a typical section of K72+488 to K72+681.89 of Zhang Cheng expressway, the phenomena on immersion of shale were observed and micro-structure changes of shale samples during the process of disintegration were studied by means of scanning electron microscope.
(SEM) and X-ray diffraction. California bearing ratio (CBR) tests were carried out with shales material of complete disintegration. The results showed that shale can be potentially used as subgrade filling material on expressway construction.

1 TEST SCHEME

The samples were collected from Zhang Cheng expressway at the section of K72+488 to K72+681.89. The color of shale sample is gray with little brown and the sample is full of pelitic texture with horizontal bedding and low hardness and thin sandstone is occasionally located inside.

1.1 Immersion test

The undisturbed cubic shale sample, which has a geometry of 3cm in length, 1cm in width and 2cm in height, was immersed in water with 1cm depth at room temperature. The process of disintegration within 48 hours was observed and recorded changes and differences.

1.2 SEM test

Four samples, which has a geometry of 1cm in length, 1cm in width and 1cm in height, were immersed in water with 0.5cm depth, lasted 0h, 12h, 24h and 48h separately. After immersion, shale samples were prepared by several procedures including air drying, impregnating with epoxy resin, hardening, sawing, polishing and coating. The purpose of utilization of epoxy resin is to prevent the disturbance in shale structure (Wang et al. 2010). The micro-morphology with two sides of the widest crack of shale samples were observed under the scanning electron microscope with the method of point scanning and energy spectrum analysis (FIG.1(a) and (b)).

1.3 X-Ray diffraction analysis

Four samples, which has a geometry of 5cm in length, 3cm in width and 2cm in height, were prepared for X-ray diffraction analysis at room temperature. Half of height of these samples were immersed in water, lasted 0h, 12h, 24h and 48h separately. The whole rock analysis was experimented with four samples after grinding to a powder (200 mesh) and the clay mineral analysis was conducted with sample immersed for 24 hours (according to the immersion test results).

![Figure 1. Scanning electron microscopy images.](image-url)
2 ANALYSIS AND RESULTS OF TESTS

2.1 Analysis and results of immersion test

Under the conditions of immersed into water with 1cm depth, the changes of sample disintegration were observed (FIG.2). After 15 minutes (FIG.2(b)), a 3mm long micro-crack appeared vertically along the bedding plane. After 30 minutes (FIG.2(c)), the depth of that micro-crack extended 2mm in the vertical direction and another 4mm long micro-crack appeared on the surface of shale. Some micro-cracks occurred in the vertical direction. After 80 minutes (FIG.2(d)), the micro-crack on the surface of shale extended to 5mm in the vertical direction and netted with cracks along the bedding plane. In addition, the number of cracks increased in the direction. After 140 minutes (FIG.2(e)), the width of vertical crack from 3mm to 5mm extended up to 0.5mm and several micro-cracks appeared around the crack. After 12 hours (FIG.2(f)), that crack was completely cracked along the bedding plane, with debris falling down. After 24 hours (FIG.2(g)), a new crack of 3mm appeared on the surface of shale and these debris continued to falling. After 48 hours (FIG.2(h)), there is no more obvious change in shale.

The observation results showed that cracks mainly appeared along the bedding plane after 12-hour immersion. These cracks were gradually extended and the number of cracks increased with immersion time increasing.

(a) 0 minutes      (b) 15 minutes      (c) 30 minutes      (d) 80 minutes

(e) 120 minutes   (f) 12 hours       (g) 24 hours       (h) 48 hours

Figure 2. Disintegration process of undisturbed shale under the condition of immersion in water.

2.2 Analysis and results of the SEM test

2.2.1 Point scanning analysis

According to the results of point energy spectrum, the particles around the widest crack for 0h and 12h sample were mainly discriminated (Zhang et al. 2011). Quartz,
albite, potash feldspar, calcite and chlorite were determined. Quartz and albite had no noticeable change after 48-hour immersion. The new emerged minerals were calcite and chlorite. The emergence of new minerals indicated that some components had been changed.

2.2.2 Map scanning analysis

The percentage of each element on the edge of cracks for four samples were collected and summarized in FIG. 3.

![Figure 3. The percentage of each element.](image)

FIG.3 shows that the element content of Al rapidly increases by 15%, and the element content of Fe is decreased by 10% within 12 hours. The element content of K and Ba/Ti change only within 5%. The element of Na, Mg and Ca have little change within 48 hours. The changes of elements mean that the elements of Fe, K and Al are more influential on the shale weathering.

The grain size distribution was determined according to IPP analysis, FIG.4 and 5 show that the content of particle size between 6 and 7 μm is the largest portion in shale samples within 12 hours and the content of particle size between 10 and 13 μm has just a few changes within 48 hours. The results showed that shale rapidly disintegrated within 12 hours and its particle size was concentrated on 6μm to 7μm.

![Figure 4. The change of average particle size in 0~24 hours.](image)  ![Figure 5. The content of particle size between 6 and 7μm within 48 hours.](image)
2.3 Analysis and results of X-ray diffraction test

2.3.1 Analysis and results of the whole rock analysis

According to the results of the whole rock analysis, FIG.6 shows that the content percentage of quartz is from 67.7% to 87.1%, the content percentage of calcium aluminum silicate is from 10.5% to 12.1%, the content percentage of albite is about 10% and the content of orthoclase is about 8.6%.

![Figure 6. Peak values diagram of the whole rock analysis within 48 hours.](image)

![Figure 7. Peak values diagram of the clay minerals analysis of 24 hours' sample.](image)

In order to accurately determine the clay mineral components, three experiments are carried out with the sample immersed for 24 hours. Natural oriented slices (Short N slices) is conducted as reference test, ethylene glycol treatment oriented slices (Short EG slices) is used to distinguish between expansive and no expansive mineral and heat treatment oriented slices (Short T slices) is used to distinguish among chlorite, kaolinite and the other minerals of 14Å.

Different mineral interplanar spacing and relative intensity of diffraction were obtained with tests of the N, EG and T oriented treatment. According to the comparative analysis of standard minerals with test data, the clay minerals in shale samples are distinguished (Zhang et al. 2003 & Pu, 2011 & GB/T. 2013). The results are shown in FIG.7.

(1) When crystal plane spacing are 3.22Å and 3.34Å, there are no changes of the spectral line after ethylene glycol treatment and heat treatment, which is the characteristic of the mixture of montmorillonite and illite.

(2) When the crystal plane spacing is 4.99Å, the spectral line is disappeared after ethylene glycol treatment, which is the characteristic of illite.

(3) There are spectral lines of muscovite when the crystal plane spacing is 9.92Å.

The results showed that the mineral components which have been changed in shale may be montmorillonite and illite during the process of weathering.

Results of the three tests, SEM, X-ray diffraction and immersion, coincide with each other. These results showed that the disintegration of shale was more severe.
within 12 hours and the particle size became smaller. Mineral components changed obviously in 24 hours, especially montmorillonite and illite.

3 STUDY ON APPLICATION OF SHALE AFTER DISINTEGRATION

The California Bearing Ratio (CBR) denotes the potential strength of subgrade material and is an important index to evaluate its performance in expressway. This test is to simulate the most unfavorable environment of subgrade filling on the expressway and to reflect the actual situation of strength decrease in subgrade filling when pores are filled with water (Chen et al. 2001). In this article, the California Bearing Ratio (CBR) test is used to judge the potential possibility of the complete disintegration shale. The maximum dry density of the complete disintegrate shale is 1.77g/cm³ with optimum water content of 14.20%. The CBR test were carried out according to Chinese Standard (JTG E40-2007). The shale samples with dry density of 1.73g/cm³, 1.65g/cm³ and 1.59g/cm³ respectively, corresponding to compaction degree of 98%, 93% and 90%, were prepared. Nine groups of specimens were prepared under the optimum water content within the range of ±0.8%. The results are shown in Table 1.

Table 1. The Results of CBR Test.

<table>
<thead>
<tr>
<th>Content of Water/%</th>
<th>Compaction degree/K</th>
<th>Dry Density /g/cm³</th>
<th>CBR₂.₅</th>
<th>CBR₅.₀</th>
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<tr>
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The results show that the CBR\textsubscript{5.0} value of the complete disintegration shale would be used to evaluate potential strength of subgrade filling material in Zhang Cheng expressway. When the particle size of shale is about 40mm and dry density is greater than 1.59g/cm\textsuperscript{3} (or the compaction degree is greater than 90%) and the value of CBR test is greater than 3%, its strength can be satisfied with Chinese Standard (JTG D30-2015). The CBR\textsubscript{5.0} values shown in Table 1 are greater than 3%, the strength of shale after complete disintegration can meet the requirement of the subgrade filling.

4 CONCLUSIONS

(1) The main failure mode of shale was the development of netting between the horizontal cracks and vertical cracks. The majority of disintegration occurred within 12 hours and the complete disintegration was within 24 hours.

(2) Particle size of shale after the complete disintegration became smaller, which was mainly 6um to 7um at the micro level. The elements of Fe, K and Al had main effects on the shale weathering when it exposed in the air and water. The mineral composition which have been changed in shale weathering mainly may be montmorillonite and illite.
(3) Shale that was complete disintegration can be used as subgrade filling after disintegration, the value of CBR test could satisfy the requirements of Chinese Standard JTG D30-2015).

REFERENCES


