Experimental Study on Erosive Effects of Sodium Hydroxide Solution on Compacted Clay

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Abstract. Direct shear tests were performed on red clay soaked in different concentrations of sodium hydroxide solution and different soaking time. The microstructure of red clay samples was observed by scanning electron microscopy (SEM). The results show that the shear strength of red clay soaked in sodium hydroxide solution decreases as the soaking time and the sodium hydroxide solution concentration increases. The sodium hydroxide solution eroded the cement in the red clay, resulting in the increase of pores between clay particles. The fractal dimension of the red clay particles increased with the increase of the corrosion. The average particle size and average particle area of the red clay particles decrease with the increase of the sodium hydroxide corrosion, and the shape of the soil particles becomes irregular.

1 Introduction

Urban domestic wastewater containing detergents, chemical wastewater from phosphate fertilizer plants or paper mills, ore-washing wastewater generated from ore dressing plants and landfill leachate are alkaline. The complex physical and chemical reactions of lye and soil particles will lead to the destruction of the original structure of the soil. When the soil is soaked in a high concentration of sodium hydroxide solution, its shear strength, cohesion and internal friction angle increase, and there is a maximum value. When the red clay is soaked in a low concentration of sodium hydroxide solution, its shear strength decreases (Chen 2017). When the silt clay is consolidated in alkaline environment, its compressibility and rebound modulus increase with the increase of alkalinity (Chunpeng 2008). The plasticity index of clay decreases in alkaline environment and the plastic limit increases (Qian and Cuihua 2001). After the foundation soil has been eroded by lye, it turns black and soft, and even changes from hard plastic to cast plastic (Gu 1988).

In summary, some scholars have studied the effect of alkaline solution on the mechanical properties of red clay, but no scholar has analyzed the microstructure of red clay soaked in alkali solution. In this experiment, a direct shear test was performed on red clay soaked in sodium hydroxide solution to study the mechanical properties of red clay in different concentrations of sodium hydroxide solution and different soaking

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time. The microstructure of red clay soaked in sodium hydroxide solution was observed by scanning electron microscopy to study the change of the microstructure of the clay in the lye.

2 Experimental Materials, Devices and Methods

2.1 Experimental Materials

The red clay used in this experiment was taken from Yanshan, Guilin. The mineral composition of the red clay was measured by X-ray diffractometer as listed in Table 1. The natural dry density of red clay is 1.65 g/cm^3, and its physical and mechanical parameters are listed in Table 2.

Table 1. Mineral composition of red clay

SiO_2	Fe_2O_3	CaO	K_2O	Na_2O
68.7%	0.86%	0.69%	23.32%	6.43%

The alkaline solution used in the experiment was a sodium hydroxide solution with concentrations of 0%, 3%, 6%, and 12%. The sodium hydroxide used to formulate the solution is a solid particle, neglecting the effect of the volume of sodium hydroxide solid particles on the volume of the solution because of its small volume ratio to the formulation solution.

2.2 Preparation of the Soil Specimens

The air-dried red clay passing through the sieve with a diameter of 2 mm was taken and used to prepare soil specimens with a moisture content of 24.5% (optimal moisture content). The wet red clay was made into specimens with a height of 20 mm and a diameter of 61.8 mm. The specimens were placed in an calorstat (20 °C) for 10 days and then soaked in a sodium hydroxide solution (keeping the temperature at 25 °C and a humidity of 95%).

2.3 Experimental Device

The experiment used a ZJ strain-controlled direct shear apparatus with a shear rate of 0.8 mm/min. Hitachi's S-3400N scanning electron microscope was used to observe the microstructure of the specimens.

Table 2. Physical and mechanical properties of red clay

Physical quantity	Value
Maximum dry density (g/cm^3)	1.87
Optimum moisture content (%)	24.5
Liquid limit water content (%)	58.5
Plastic limit moisture content (%)	36
Plasticity index (%)	22.5
Particle size distribution (> 0.05 mm) (%)	22
Particle size distribution (0.05 ~ 0.005 mm) (%)	38
Particle size distribution (0.005 ~ 0.002 mm) (%)	33
Particle size distribution (< 0.002 mm) (%)	7

3 Results Analysis and Discussion

3.1 Shear Strength of Soil Specimens

The direct shear tests were carried out with four pressures (100 kPa, 200 kPa, 300 kPa and 400 kPa).

From Figs. 1 and 2 can be drawn as follows:

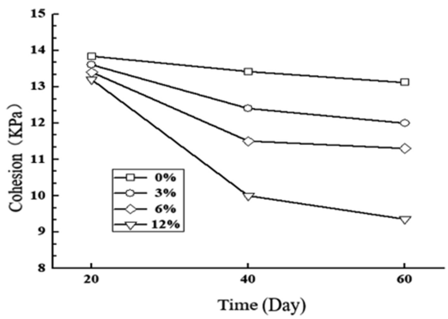


Fig. 1. Cohesion of red clay as a function of time and sodium hydroxide concentration

With the prolongation of soaking time, the cohesion and internal friction angle of red clay soaked in pure water decrease, but their changes are not significant. The cohesion decreases from 13.84 kPa to 13.14 kPa, and the internal friction angle decreases from 10.18° to 10.01°.

At the same soaking time, the cohesion of red clay decreases with the concentration of sodium hydroxide solution. The cohesion of red clay rapidly decreases when it is soaked in sodium hydroxide solution for 20 days to 40 days, and the cohesion decreases slowly when it is soaked for more than 40 days.Take a specimen soaked in 12% sodium hydroxide solution for example. When the red clay specimens were soaked in sodium hydroxide solution for 20 days to 40 days, the cohesion decreases from 13.2 kPa to 11.3 kPa. When the red clay specimens are soaked for 40 days to 60 days, the cohesion decreases from 11.3 kPa to 10.2 kPa, and the changes are not significant.

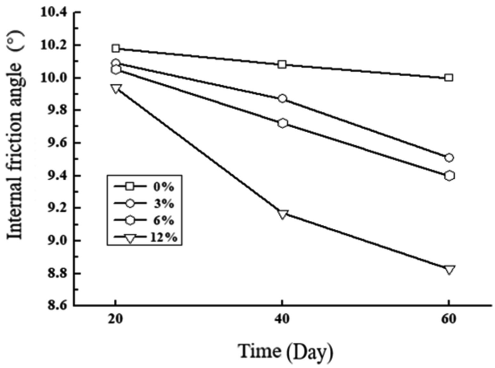


Fig. 2. Internal friction angle of red clay as a function of time and sodium hydroxide concentration

The internal friction angle of red clay decreases with the increase of the concentration of sodium hydroxide solution and the soaking time, but the changes are not significant. When soaked in 12% sodium hydroxide solution for 60 days, the internal friction angle of red clay decreases from 9.9 to 8.9.

3.2 Analysis of Moisture Content of Soil Specimens

From Fig. 3, it can be seen that:

The red clay specimen soaked in a concentration of 0% sodium hydroxide solution showed a slow increase in water content, which is maintained between 35.0% and 35.6% with a growth rate of only 1.71%.

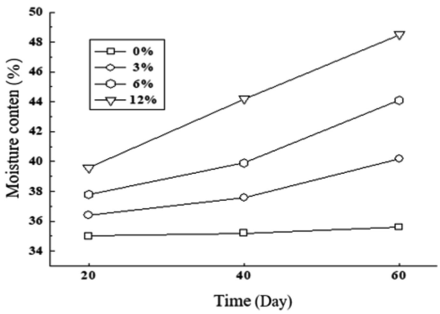


Fig. 3. Graph of water content of red clay as a function of time and solution concentration

In red clay soaked in the same concentration of sodium hydroxide solution, the moisture content increases with the soaking time. Taking a specimen soaked in a 6% sodium hydroxide solution as an example, the water content of the soil specimen after soaking for 20 days is 36.4%, and the water content after soaking for 60 days is 40.2%.

The growth rate of water content of red clay soaked in 6% sodium hydroxide solution is 10.44%, which is far more great than that of red clay soaked in 0% sodium hydroxide solution. This shows that the moisture content of red clay soaked in sodium hydroxide solution is higher than that of red clay soaked in pure water.

The moisture content of red clay at the same soaking time increases with the concentration of sodium hydroxide solution. Taking red clay soaked for 40 days as an example, the moisture content of red clay is 44.2% when soaked in 12% sodium hydroxide solution, which is significantly greater than the 39.9% moisture content of red clay soaked in 3% sodium hydroxide.

3.3 Microstructure Characteristics of Red Clay Specimens

It can be seen from Fig. 4 that the clay surface was not eroded by the sodium hydroxide solution has few pores and is arranged in a laminated manner. With the increase of corrosion, the pores on the surface of red clay increase, forming a structural system composed of granular and massive particles, and the soil structure becomes loose. As the concentration of the sodium hydroxide solution increases, the cement in the red clay is corroded, resulting in a decrease in the volume of the cement and an increase in the pore volume between the clay particles.

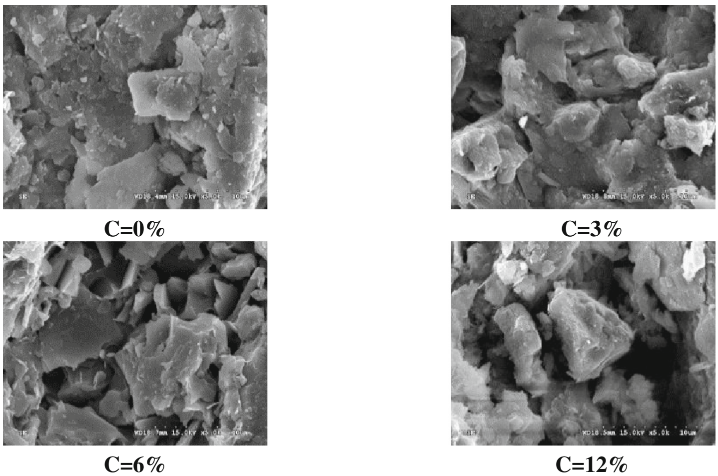


Fig. 4. Microstructure of soil specimens soaked for 60 days in different concentrations of sodium hydroxide

In order to analyz the influence of concentration of sodium hydroxide solution on the microstructure parameters of clay, the average particle size and particle area were calculated by the image analysis program. The statistical results are showned in Fig. 5. The average particle size of red clay decreases with increasing concentration of sodium hydroxide solution, and at a concentration of 0% to 3%, the red clay particle size changes little. When the concentration of sodium hydroxide increases from 6% to 12%, the average particle size of red clay decreases rapidly. The decrease of the average particle size reflects the erosion of red clay by the sodium hydroxide solution, resulting in an uneven particle size distribution of the red clay. As the red clay erosion increases, the clay particle area decreases rapidly from 1000000 um^2 in 0% concentration to 25000 um^2 in 12% concentration.

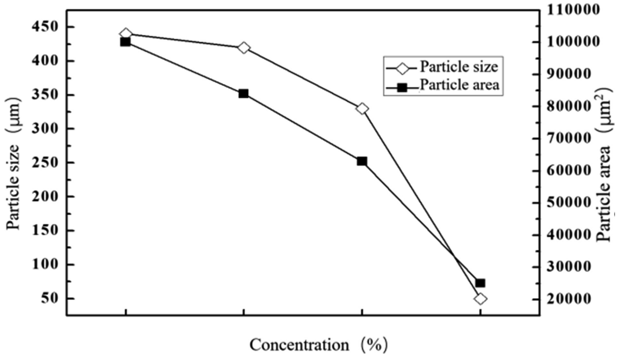


Fig. 5. Variation of mean diameter and area of particle soaked by sodium hydroxide solution

The fractal dimension reflects the complexity of the particle profile curve. The function diagram in Fig. 6 shows that the concentration of sodium hydroxide has a significant effect on the fractal dimension of the red clay particles, from the initial 1.04 to the final 7.6, the growth rate is 630%, which reflects the corrosion of red clay by sodium hydroxide solution.

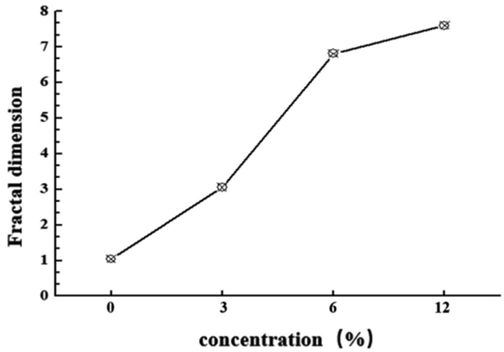
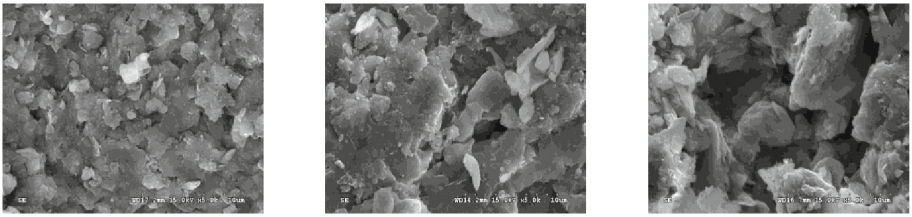


Fig. 6. Fractal dimension change of clay particles

Figure 7 shows the microstructure of red clay soaked in a 12% sodium hydroxide solution for different soaked times. It can be seen that the red clay has a compact structure in the early stage of soaking, and the clay particle size is uniform, indicating that the sodium hydroxide solution is not a severe red earth erosion.



(a) T=20d (b) T=40d (c) T=60

Fig. 7. The microstructure of the soaked clay with 12% sodium hydroxide solution changes with time

As the soaking time increases, the surface of the red clay becomes rough, the soil particles begin to gather, the arrangement is loose and disorderly, and the honeycomb structure appears, and the pore size between the soil particles expands. When soaked for 60 days, the pores of red clay become significantly larger, and the agglomerated soil particles show a flocculent structure.

4 Conclusion

With the increase of sodium hydroxide concentration and soaking time, the cohesion and internal friction angle of clay show a decreasing tendency. At the initial stage of soaking, the cohesive force decreases sharply and tends to be stable in the later period.

From the microstructure of red clay, it can be seen that when the erosion concentration increases, the voids of the red clay increase, the average particle size and area of the particles decrease, and the particle fractal dimension increases, indicating that the sodium hydroxide solution has a significant effect on the red clay erosion.

The main reason for the decrease of the shear strength of red clay is that the sodium hydroxide solution chemically reacts with the cement in red clay, the cement is eroded, the connection between soil particles weakens, and the pores become larger.

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