A comparative study on the role of electro-conductive plastics electrode in direct current electroosmosis

Wei Bai^{1,*}, Tao Jian^{1,2}, Rongbing Lin², Xiaoqian Luo^{1,2} and Lingwei Kong¹

¹State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, China

²University of Chinese Academy of Sciences, Beijing 100049, China

Abstract. The electrode material is one of the critical factors affecting the electroosmosis efficiency. The electroosmotic test was conducted to compare the current, volume moisture content, and energy consumption of Electro-Conductive Plastics Electrode (ECPE) and metal electrode in the dispose of sludge. The results show that: the current decreases of ECPE is smaller than the metal electrode before 20h, and the difference value of moisture content between cathode and anode of ECPE is smaller when electroosmosis is stable. The energy consumption of ECPE is lower in the range of soil moisture content of 35% - 60%. The ECPE has a particular advantage in energy consumption and uniformity of soil moisture content, but has a disadvantage in residual moisture content as compared with the metal electrode.

1 Introduction

In 1809, Russian scientist Reuss found that under the action of the direct current electric field, water moves from a positive pole (anode) to a negative pole (cathode), which is called electroosmosis. Due to the influence of direct current, the particle cations on the surface move to the cathode, which would drag a large amount of water in pores of the soil. During the stage of particles moving, momentum transfers to the surrounding fluid molecules, resulting in electroosmosis from anode to cathode. Therefore, electroosmosis is an effective technology for the dehydration of low permeability materials [1-4]. Casagrande [5] first proved the efficiency of electroosmotic dehydration in low hydraulic conductivity consolidated clay. Since then, this technology has been successfully extended to geoenvironmental engineering and geotechnical engineering applications, including soft soil consolidation [6-7], sludge dewatering [8-9], and remediation of contaminated soil [10-11].

A large number of experimental studies have proved the effectiveness of the electroosmotic method in the consolidation of foundation drainage and treatment of contaminated soil, and various factors affecting the efficiency of electroosmosis (such as the types of soil, the physical and chemical properties of soil particles and pore fluid, voltage, salt content, electrode material, electrode arrangement, electrode spacing) are analyzed. Electrode material has always been investigated due to the significant influence on electroosmosis efficiency. Metal materials are commonly used as electroosmosis electrodes; Several researchers [12-13] have studied the electroosmosis efficiency of different metal electrodes. Kalumba [14] summarized the disadvantages of the metal electrode, mainly including anode corrosion,

difficult exhaust, poor contact between electrode and soil, and high production cost of the electrode. Besides, Fe^{3+} 、 Al^{3+} 、 Cu^{2+} generated by electrode reaction will pollute the surrounding groundwater. The defects of traditional electrode materials make geotechnical scientists develop new materials to improve the durability and efficiency of electrodes.

This paper will report the effects of electrode materials on the electroosmotic process through a test study. We designed an electroosmosis testing cell for the purpose. The results of the investigations are presented and analyzed.

2 Materials and methods

2.1 Materials

The sludge used in this study was obtained from the Ezhou City, China, which has the characteristics of high moisture content, high compressibility, poor water permeability and extremely low strength, the initial bearing capacity is almost zero, and it is still in the flow plastic state after a month of standing. The characteristics of the sludge are shown in Tables 1, 2, and 3. The average moisture content of the specimens of soil is 162.4%, as the main advantage of electroosmosis is to treat soft soil with medium moisture content, so the vacuum preloading was carried out on the soil samples firstly, and the soft soil samples with the average moisture content of 84.5% were obtained, and then the

electroosmotic test was carried out.

Table 1. Physical properties of sludge

Parameter	Value
Specific gravity	2.68
Liquid limit (%)	69.1
Plasticity limit (%)	38.5
USCS ^a classification	MH
Wet density (g/cm ³)	1.42
Dry density (g/cm ³)	0.77
Grain composition	
>0.075	2.1%
0.005-0.075	51.4%
<0.005	46.5%

^aUnified Soil Classification System

Table 2. Mineral composition of sludge

Parameter	Value
Quartz	66.88
Illite	29.13
Kaolinite	3.99

Table 3. Chemical composition of sludge

Parameter	Value	Parameter	Value
SiO ₂	58.16	CaO	0.78
Al ₂ O ₃	18.21	Na ₂ O	0.66
TF ₂ O ₃	7.57	K ₂ O	2.49
MgO	1.36	TiO ₂	0.97
P ₂ O ₅	0.13	H ₂ O	1.56
MnO	0.074	Loss on ignition	9.56

2.2 Testing facility

The testing facility used for the electroosmotic is shown in Fig.1. A rectangular box 20×10×10 cm (L×W×H) with three drain holes (diameter of 6mm) at the bottom of the cathode electrode was constructed with Plexiglas plates. The water is flowed out of three drain holes during the electroosmosis process, and the water discharged is collected and recorded. The electrode plate 10×11 cm with 16 holes (diameter of 5 mm) evenly distributed is slightly larger than the section of the testing box to facilitate voltage application. The holes can not only ensure good contact between the electrode plate and sludge but be used as a drainage channel. There is a non-woven fabric between the electrode and the Plexiglas box to prevent the drain hole from being blocked by soil particles. In order to decrease the water absorption of non-woven fabric that may reduce the water discharged, the non-woven fabric should be saturated (the non-woven fabric is suspended in the air without dripping) before the electroosmosis test.

Fig.1 Schematic of electroosmosis testing box and the electrode plate

2.3 Electrode materials

The electrode materials used in the test were steel, copper, aluminum, and electro-conductive plastics, record as SE, CE, AE, and ECPE, respectively. The resistance of steel, copper, aluminum at 20 °C respectively is $9.78 \times 10^{-8} \Omega \cdot m$ 、 $1.75 \times 10^{-8} \Omega \cdot m$ 、 $2.83 \times 10^{-8} \Omega \cdot m$, which is smaller than of electro-conductive plastics (about $10^{-6} \Omega \cdot m$); however, they are far less than the resistance of the soil (1-20 $\Omega \cdot m$). The tests were conducted with the applied voltage of 24V. The initial moisture content of tests is similar, around 84%±1%. For metal electrode, if the moisture content at anode or cathode is lower than 20%, 35%, or the current intensity is lower than 0.5mA, the test is terminated, while for ECPE, they are 40%, 60%, 0.05A.

3 Results and analysis

3.1 Influence on current

The initial current of SE, CE, and AE is similar, about 0.5mA, while the resistivity of ECPE is higher than that of metal material, so the initial current measured is relatively small, which is 0.12mA. As shown in Fig.2, the current of SE, CE, and AE decreased rapidly within 20 h after starting the test, and the decreased amplitude was about 61.1%, 55.1%, and 69.8%, respectively, and then the decline amplitude was relatively reduced and tended to be stable. At the end of the measurement, the decreased amplitude relative to the initial current was 90.7%, 85.7%, and 97.7%, respectively. However, the decrease range of current in the ECPE test is only 8.3% within 20h, and 66.7% at the end of measurement compared with the initial current.

Fig.2 The current changes with the time of different electrode materials

3.2 Influence on moisture content

As shown in Fig.3, the moisture content at the anode of the metal electrode (SE, CE, and AE) decreases rapidly after electroosmosis within 20h and then tends to be stable. When the electroosmosis is stable, the moisture content at the anode of SE is less than 40%, while the moisture content at the anode of CE and AE is about 45% and 50%. The moisture content at the anode of the metal electrode is stable in 20 hours, while the moisture content at the anode of ECPE begins to decrease. The phenomenon is consistent with the current decrease of the ECPE at the beginning of the test. At the end of the test, the time of ECPE is nearly twice as compared to the metal electrode, whereas the final electroosmosis effect is not as good as that of the metal electrode, the moisture content at the anode is about 50%.

Fig. 3 The moisture content changes at the anode with the time of different electrodes

Different from the change of moisture content at the anode, the difference of moisture at the cathode of the four electrodes is relatively small, and the residual moisture content is stable between 60% - 70%. The stabilization time of SE and CE is short, and the moisture content decreases significantly. Therefore, the electroosmosis is slightly better than that of AE and ECPE, as shown in Figure 4. However, it should be noted that ECPE has little difference value in moisture content at cathode and anode when it is stable, which proves that the soil moisture content is more uniform. Nevertheless, in the stabilization time, the ECPE is about 3.5 times of metal electrode.

Fig. 4 The moisture content changes at the cathode with the time of different electrodes

3.3 Influence on energy consumption of unit drainage

As shown in Fig.5, in the range of 35% to 60% moisture content, the energy consumption unit drainage of CE and ECPE is less than one joule; When the moisture content of anode is reduced to 35%, the drainage capacity of ECPE is minimal, but the current has no noticeable change, which leads to the increase of energy consumption, and the electroosmosis can not achieve the ideal drainage effect. Therefore, the electro-conductive plastics may be unfit for using as the electrode when the soil moisture content is below 35%. Furthermore, in the initial stage of electroosmosis, the energy consumption of unit drainage decreases, which due to taking a period from power on to drainage, while in the initial stage of electroosmosis, the water content is high, the resistance of soil is small, the current is large, and the power is considered under the condition of constant voltage, the power consumption unit drainage is extensive.

Fig.5 Energy consumption of unit drainage of different electrodes

4 Conclusions

The electroosmosis of ECPE and metal electrode was studied by the test. The results show that: in the process of electroosmosis, the current change range of ECPE is smaller than that of the metal electrode; the difference value of moisture content of soil between cathode and anode in ECPE test is smaller when the electroosmosis is stable, that is, the moisture content of the soil is uniform,

but the time is several times of that of the metal electrode; from the perspective of energy consumption of unit drainage, within the range of 35% - 60% moisture content, the ECPE is less than that of the SE and CE. The ECPE has a particular advantage in energy consumption and uniformity of soil moisture content, but has a disadvantage in residual moisture content as compared with the metal electrode.

Acknowledgment

This research work was funded by the National Natural Science Foundation of China (Grant No. 41772339).

Reference

1. J. Virkutyte, M. Sillanpää, P. Latostenenmaa. SCI TOTAL ENVIRON 289, 1 (2002).
2. R.E. Saichek, K.R. Reddy. CRIT REV ENV SCI TEC 35, 2 (2005).
3. A.B. Fourie, D.G. Johns, C.F. Jones. Can.Geotech.J 44, 2 (2007).
4. M.J. Moghadam, H. Moayedi, M.M. Sadeghi, A. Hajiannia. Environ Geochem Health 38, 6(2016).
5. I.L. Casagrande. Acta Geotech 1, 3 (1949).
6. S.R. Kaniraj, H.L. Huong, J.H.S. Yee. Geotech Geol Eng 29, 3 (2011).
7. V. Jeyakanthan, C.T. Gnanendran, S.C.R. Lo. Can. Geotech. J 48, 12 (2011).
8. A. Mahmoud, J. Olivier, J. Vaxelaire, A.F. Hoadley. Water Resour 79, 2 (2011).
9. H. Yoshida, T. Yoshikawa, M. Kawasaki. DRY TECHNOL 31, 7 (2013).
10. S.O. Kim, K.W. Kim. J HAZARD MATER B, 85 (2001).
11. M. Cánovas, J. Valenzuela, L. Romero, P. Conzález. J MATER RES TECHNOL 9, 3 (2020).
12. N.C. Lockhart. COLLOID SURFACE B 6, 3 (1983).
13. E.T. Mohamad, M.Z. Othman, S.S. Adnan. Electro J Geotech Eng 16, 3 (2011).
14. D. Kalumba, S. Glendinning, C.D.F. Rogers. J ENVIRON ENG 135, 11 (2009).