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Research paper

Polarization analysis of green sand and parameter optimization under exciting electric field

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A B S T R A C T

The polarization mechanism of green sand under direct current electric field was further analyzed by means of an equivalent mathematical model, and it was the absorption current that caused the polarization of green sand. However, the absorption current was essentially caused by the ions of the clay. Therefore, the clay was the source of the polarization and its content mainly determined the degree of polarization. Experiments based on the Taguchi method showed that the electrode area had the most important influence on the polarization, followed by the voltage amplitude and the frequency. The interactions of these three parameters did exist, and the interaction between the electrode area and the voltage amplitude had a bigger influence on the polarization than the frequency. The optimal exciting field parameters were that the voltage amplitude was 5 V, the frequency was 1 kHz and the electrode area was 2500 mm^2. The clay content and moisture content can be obtained by an artificial neural net according to AC voltage, DC voltage and DC voltage drop.

1. Introduction

Green sand was a mixture of silica sand, clay, water and other additives, and the green sand casting was one of the most important casting methods due to the simplicity of the process, high productivity and low cost. Therefore, the measurement and control of the composition and performance parameters were a key forefront topic in foundry (Karunakar and Datta, 2007; Sun and Chao, 2009). Among all these parameters, the moisture and the clay were most significant and sensitive parameters affecting the quality of green sand (Paluszkiewicz et al., 2005). So, it had great significances for improving the production efficiency and ensuring the casting quality to accurately and rapidly measure the clay content and the moisture content of green sand.

Currently, there were many kinds of methods for measuring moisture content (Joyce et al., 2005; Loto and Omotoso, 1990; Xiao and Zhang, 2012; Xiao et al., 2009), such as the resistance method, capacitance method and inductive method while few methods for measuring the clay content of green sand. The resistance method was first used to measure the moisture content in foundry. In this traditional method, it was granted that a linear relationship between the resistance and the moisture existed, and the higher the moisture, the lower the resistance. However, besides the moisture content, the resistance of green sand was also affected by many other factors, especially the clay (Uddin, 2008). Accordingly, the accuracy of this method was seriously deteriorated. Therefore, there was a need to further analyze the polarization mechanism of green sand under the electric field, and also to optimize the parameters of the electric field by experiments, which could provide a theoretical foundation for bringing forward the new method of simultaneously measuring both the moisture content and the clay content.

2. Analysis of polarization mechanism of green sand

Fig. 1 was the schematic diagram of the traditional resistance method for measuring the moisture content of green sand (Kundu and Lahiri, 2008; Saikaew and Wiengwiset, 2012). First, a green sand specimen with fixed size and compactness was made, and then it was connected to the circuit. So, the exciting electric field was applied to the green sand specimen, and the corresponding voltage of the sand specimen could be measured. However, experiments showed that the voltage did not always keep a constant when the direct current electric field was employed. Contrarily, the voltage would gradually decease with the time, as shown in Fig. 2 which was typical voltage curve versus the time. This phenomenon was called as the polarization of green sand.

Then what caused the polarization? In order to clear it up, a model of the green sand specimen under the direct current (DC) electric field was established. Here the green sand specimen was regarded as a kind of dispersoid which was composed of many layers of silica sand. Each silica sand surface was surrounded by the membrane made up of the clay and water, and the gap between two layers of sands was filled with the free water where there are many ions from the clay. The silica sands are arranged horizontally to form a thin sand layer, and the sand layer can be considered as a parallel plate capacitor. A lot of sand layers constituted the entire green sand specimen. Therefore, the equivalent model of the sand specimen was simplified to several parallel-plate capacitors which interconnected in series. According to the electrics theory, several

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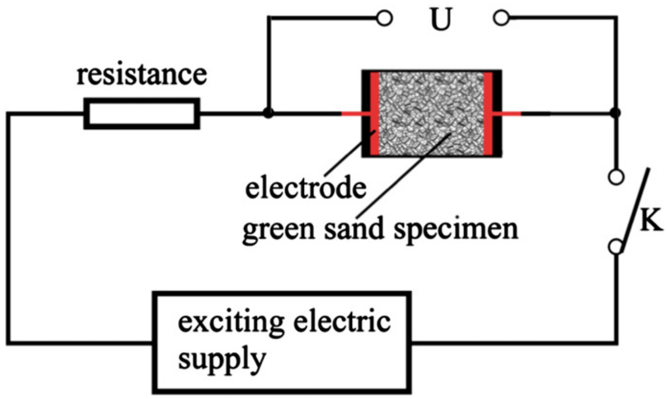

Fig. 1. Electrical schematic diagram of the resistance method measuring the moisture content of green sand.

serial-connection capacitors can be equivalent to a capacitor. Therefore, to simplify the analysis process, the n serial-connection capacitors can be regarded that the equivalent capacitor C1 of the n-1 capacitors was serially connected to another capacitor C2, and the model was shown in Fig. 3(a).

Assumed that the DC voltage applied to the sand specimen was U, and the dielectric constant, conductivity and thickness of the capacitors C1 and C2 were ε_1, κ_1, δ_1, ε_2, κ_2 and δ_2 respectively, and the thickness δ_1 and δ_2 were independent of the voltage U and the time t. According to the continuity of the electric induction intensity, the following relationship existed.

$$\varepsilon_1 E_1 = \varepsilon_2 E_2 \tag{1}$$

where, E_1 and E_2 were the mean electric field intensities of the capacitors C1 and C2.

Therefore, the voltages U_1 and U_2 of the capacitors C1 and C2 could be written as:

$$\begin{cases} U_1 = E_1\delta_1 \\ U_2 = E_2\delta_2 \\ U_1 + U_2 = U \end{cases} \tag{2}$$

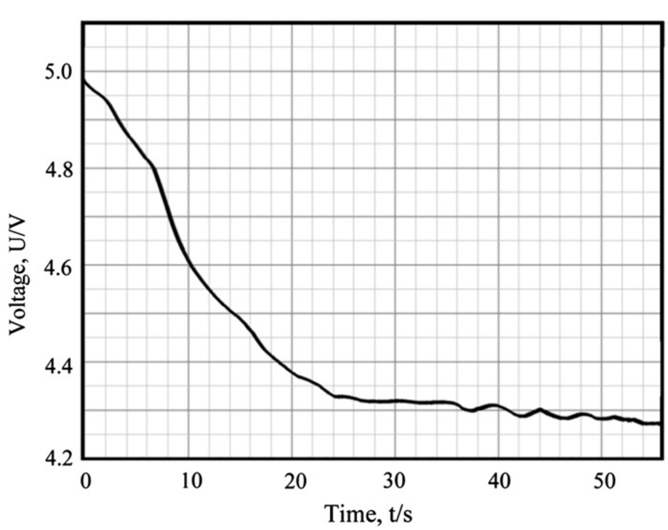

Fig. 2. Voltage drop curve of green sand specimen versus the time.

According to Eq. (2), the electric field intensities E_{10} and E_{20} of the capacitors C1 and C2 can be expressed as Eq. (3) when the DC voltage is applied ($t = 0$).

$$\begin{cases} E_{10} = \dfrac{\varepsilon_2 U}{\varepsilon_1\delta_2 + \varepsilon_2\delta_1} \\ E_{20} = \dfrac{\varepsilon_1 U}{\varepsilon_1\delta_2 + \varepsilon_2\delta_1} \end{cases} \tag{3}$$

With the time t extending, the electric field distribution will be changed by the free charge gathered on the interface until the conduction current densities j_1 and j_2 of the two capacitors reached equivalent, namely $\kappa_1 E_1' = \kappa_2 E_2'$. At that time, the electric field intensities E_1' and E_2' of the two capacitors can be described as:

$$\begin{cases} E_1' = \dfrac{\kappa_2 U}{\kappa_1\delta_2 + \kappa_2\delta_1} \\ E_2' = \dfrac{\kappa_1 U}{\kappa_1\delta_2 + \kappa_2\delta_1} \end{cases} \tag{4}$$

Before the conduction current densities reached equivalent, the relationship between the current density j_1 and the time t can be written as Eq. (5) according to the continuity of the current.

$$j_1 = \kappa_1 E_1 + \varepsilon_1 \frac{dE_1}{dt} = \kappa_2 E_2 + \varepsilon_2 \frac{dE_2}{dt} \tag{5}$$

According to Eqs. (5) and (2), the following equation can be got.

$$\frac{dE_1}{dt} + \frac{\kappa_1\delta_2 + \kappa_2\delta_1}{\varepsilon_1\delta_2 + \varepsilon_2\delta_1} E_1 = \frac{\kappa_2 U}{\varepsilon_1\delta_2 + \varepsilon_2\delta_1} \tag{6}$$

Assumed that $\frac{1}{\tau} = \frac{\kappa_1\delta_2 + \kappa_2\delta_1}{\varepsilon_1\delta_2 + \varepsilon_2\delta_1}$, then Eq. (7) can be got by the integral of Eq. (6).

$$E_1 = \frac{\kappa_2}{\delta_1\kappa_2 + \delta_2\kappa_1} U + c \cdot \exp\left(-\frac{t}{\tau}\right) \tag{7}$$

where, c was the integral constant.

When the time $t = 0$, the integral constant c can be calculated according to Eqs. (7) and (3).

$$c = \left(\frac{\varepsilon_2}{\varepsilon_1\delta_2 + \varepsilon_2\delta_1} - \frac{\kappa_2}{\kappa_1\delta_2 + \kappa_2\delta_1}\right) U \tag{8}$$

Therefore, the relationship between the electric field intensity E_1 of the capacitor C1 and the time t can be given.

$$E_1 = \frac{\kappa_2}{\delta_1\kappa_2 + \delta_2\kappa_1} U + \left(\frac{\varepsilon_2}{\varepsilon_1\delta_2 + \varepsilon_2\delta_1} - \frac{\kappa_2}{\kappa_1\delta_2 + \kappa_2\delta_1}\right) U \cdot \exp\left(-\frac{t}{\tau}\right) \tag{9}$$

According to Eqs. (5) and (9), the total current of the sand specimen was written as:

$$\begin{aligned} i = jS &= \frac{\kappa_1\kappa_2 S}{\delta_1\kappa_2 + \delta_2\kappa_1} U + \frac{(\varepsilon_1\kappa_2 - \varepsilon_2\kappa_1)^2 \delta_1\delta_2 S}{(\delta_1\varepsilon_2 + \delta_2\varepsilon_1)^2 (\delta_1\kappa_2 + \delta_2\kappa_1)} U \cdot \exp\left(-\frac{t}{\tau}\right) \\ &= \frac{U}{R'} + \frac{U}{R} \cdot \exp\left(-\frac{t}{RC}\right) \end{aligned} \tag{10}$$

where, i was the total current, S was the polar plate area of the capacitor, $R' = R_1 + R_2 = \frac{\delta_1\kappa_2 + \delta_2\kappa_1}{\kappa_1\kappa_2 S}$ was a part of the equivalent resistance of the green sand specimen, $R = \frac{(\delta_1\varepsilon_2 - \delta_2\varepsilon_1)^2}{(\varepsilon_1\kappa_2 + \varepsilon_2\kappa_1)\delta_1\delta_2 S}$ was another part of the equivalent resistance of the green sand specimen, and $C = \frac{(\varepsilon_1\kappa_2 - \varepsilon_2\kappa_1)^2 \delta_1\delta_2 S}{(\delta_1\varepsilon_2 + \delta_2\varepsilon_1)(\delta_1\kappa_2 + \delta_2\kappa_1)^2}$ was the equivalent capacitance of the green sand specimen.