METHOD FOR IDENTIFYING CONCRETE MATURITY DURING CONSTRUCTION

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Abstract. The paper analyzes the method of identifying the maturity of concrete based on the results of measuring the temperature of concrete during its maturation using a temperature sensor built into the concrete. This method controls the maturity of concrete indirectly. The authors propose a method of controlling the maturity of concrete based on the results of direct measurement of its electrical parameters using a three-electrode capacitive sensor built into the concrete. The obtained measurement results are compared with the corresponding parameters of the electrical standard sample of concrete formed under laboratory conditions of its maturation. A feature of the work is that due to the design parameters of the sensor, only concrete without filler is monitored. This ensures the invariance of the results of measuring electrical parameters to the heterogeneity of concrete caused by different ratios of components in the control zone. The use of a three-electrode sensor also eliminates the disadvantages of a two-electrode sensor built into concrete due to the influence of edge effects on the measurement result. The controlled volume of concrete is formed by the specified dimensions of the opening of the third electrode, which is located between two working electrodes. An algorithm for the practical implementation of such a method in real conditions of concrete maturation is presented. At the same time, the equivalent capacitance and active conductivity of the admittance of concrete are measured. Based on the obtained results, the dielectric constant and specific conductivity of concrete are found at constant dimensions of the three-electrode capacitive sensor.

Keywords: Admittance, frequency, quality, concrete maturity, identification, testing, standard sample, resistivity, dielectric constant

1. Introduction

Many construction subcontractors neglect recommendations and regulatory documents, and also perform poor-quality work related to the maintenance of concrete maturity. This leads to the appearance of cracks, the causes of which the subcontractor tries to attribute to the quality of the concrete. Such accusations entail long-term disputes, additional losses for the purchase of repair mixtures, and even the loss of a client. As is known, one of the main parameters of concrete is its strength, which is achieved by its maturity. Mature concrete must meet the strength requirements of industry regulatory documents. This is especially true for concrete during construction, in particular the manufacture of concrete floors in multi-storey buildings. Timely identification of concrete maturity reduces construction time, reduces costs for renting formwork and ensures the reliability of the floor. That is why the task of improving methods for identifying the maturity of concrete floors is relevant.

2. Analysis of publications

A modern temperature monitoring system "Maturix" has been launched in Ukraine, which monitors the temperature of concrete during its solidification in real time. The global operator began operating in January 2021. The network is most widely used in the housing and communal services sector for digital accounting of municipal resources, in the construction industry to control the maturation of concrete, in logistics to track rolling stock, in agriculture to improve yields. Currently, the network provides 25% coverage of the population of Ukraine, and operates in Kyiv, Kharkiv, Dnipropetrovsk, Odessa, Poltava, Cherkasy regions. The system implements a method for identifying the maturity of concrete in real time during construction [1]. Therefore, the "Maturix" system makes it possible to control the process at all stages of concrete maturation. As a result, we get a high-quality construction and satisfied consumers. The method is based on the results of measuring the temperature change of concrete elements using temperature sensors embedded in concrete. The change in concrete temperature during the curing process is monitored in real time. The test procedure has been standardized in ASTM C1074 – 19. The maturity index is used to compare the results of maturity tests with the compressive strength of concrete obtained from cylinder specimens matured in laboratory conditions. The resulting ratios can be used to monitor the strength development of fresh and early-age concrete. This helps to avoid thermal cracking, which reduces the service life of the structure and leads to additional repair costs. Such a system allows developers to monitor the maturation of concrete in real time, reduce the cost of repairing cracks caused by non-compliance with the temperature regime, reduce heating costs and improve the quality of the structure and its service life. The disadvantage of this method is that the identification of concrete maturity during construction based on the results of temperature measurements is carried out indirectly on the basis of theoretical calculations, which may not coincide with the real results. The accuracy of the implementation of such a method largely depends on the inaccuracy of the initial measurement data, inconsistency of data collection, etc. At the same time, such a control method assumes the same conditions throughout the entire period of concrete maturation. However, changes in the environment or parameters of the maturation process may affect the results, and with significant changes, the results may be incorrect. This requires careful recalibration and ensuring high-quality data collection.

Methods for measuring the electrical parameters of concrete (electrical resistance of concrete) in order to control its strength are also known from literary sources. Such methods are implemented by applying the electrodes of a two-electrode capacitive sensor to a sample of mature concrete directly [2-8] or by embedding a two-electrode capacitive sensor with a circular cross-section of the electrodes in fresh concrete [9]. The disadvantage of such measurements is the influence of edge effects of a two-electrode capacitive sensor [10] on the determination of the resistivity or conductivity of concrete.

3. Purpose of the Work

The objective of the work is to create a method for operational control of concrete maturity during construction in real conditions based on the results of measuring informative electrical parameters of concrete admittance, which reflect its specific conductivity and dielectric permittivity.

4. Method of monitoring concrete maturity by electrical parameters and its implementation

4.1 Method of measuring electrical parameters of concrete

The essence of the proposed method is that during the maturation of concrete, direct measurements of the active and reactive components of its admittance are carried out. They reflect, as is known [11], the conductivity and dielectric constant of the controlled concrete, which change during the maturation process. At the same time, since concrete contains an aqueous solution with sand and cement, as well as a filler in the form of gravel, each component in particular and their ratio directly affect the electrical parameters of concrete. Due to the limited dimensions of the capacitive sensor, the ratio of the liquid mass of concrete and gravel can be different and, accordingly, we obtain different measurement results. It should be noted that the brand of concrete, and accordingly, its strength, is determined mainly by the brand of cement and its ratio to sand. Taking this into account, the authors propose to measure the electrical parameters of just such a part of concrete. To ensure such a measurement, it is necessary to separate the gravel from the cement mass of the concrete. For this purpose, it is proposed to use a capacitive sensor of such dimensions that the gravel will not fall into the interelectrode space of the sensor. That is, the interelectrode distance of the sensor should be smaller than the size of the gravel. This also ensures higher sensitivity of the sensor, since the distance between the electrodes is reduced. In addition, to ensure the invariance of the result from the edge effects, which is inherent in capacitive sensors of a two-electrode design, it is proposed to additionally use a third electrode placed between two working electrodes with a fixed interelectrode distance. In the case of using a third electrode with a hole, it is possible to form an active area of the working electrodes of the capacitive sensor. This area will be determined by the fixed dimensions of the hole of the third electrode. All three electrodes during installation in concrete must provide contact on the surface of the overlap for connecting the measuring device. This makes it possible to control the above-mentioned electrical parameters of concrete of a given volume during its maturation. Based on the obtained results of measuring the active and reactive components of the admittance of concrete, it is possible to calculate the specific conductivity of concrete and its dielectric permittivity.

The obtained measurement results are compared with the corresponding parameters of a standard sample of the same concrete. The level of its maturity is estimated based on the results of the comparison. In this case, the relative quality indicators Q_1, Q_2 are written as the relations:

$$Q_1 = \frac{Im(Y_x)}{Im(Y_0)} = \frac{C_x}{C_0} = \frac{A_x \varepsilon_x}{A_0 \varepsilon_0} = \frac{\varepsilon_x}{\varepsilon_o}, \qquad (1)$$

$$Q_2 = \frac{Re(Y_x)}{Re(Y_0)} = \frac{G_x}{G_0} = \frac{A_x \sigma_x}{A_0 \sigma_0} = \frac{\sigma_x}{\sigma_o}, \qquad (2)$$

where $Y_x = \omega C_x$ та $Y_0 = \omega C_0$ - admittances of the controlled object and the electrical standard sample, respectively, at the test signal frequency; C_x and C_0 and C_x and C_0 - equivalent capacitances and conductivities of the admittances of the controlled object and the electrical standard sample, respectively, at the frequency ω of the test signal; ε_x , ε_0 and σ_x , σ_0 - dielectric constants and specific conductivities of the controlled concrete and the electrical concrete sample, respectively. A_1 and A_2 - of capacitive sensors embedded in controlled concrete and standard concrete sample.

Under the condition $Q_1 \leq 1$ and $Q_2 \leq 1$ the controlled concrete corresponds to the specified level of maturity. Under other conditions, it is necessary to extend the concrete maturation time with subsequent measurement of the specified electrical parameters.

4.2. Implementation of the proposed method for monitoring concrete maturity

To implement the method for monitoring maturity, a three-electrode capacitive sensor with metal electrodes of specified geometric dimensions is embedded in fresh concrete during concreting of the floor. That is, the controlled concrete is located in the interelectrode space, which forms an impedance (admittance) of a capacitive nature with active and reactive components. For this purpose, a sensor with plane-parallel electrodes is used. The geometric dimensions of such a capacitive sensor (area and interelectrode distance) form the constant of the capacitive sensor. To measure the specified electrical parameters of concrete, it is necessary to use an appropriate measuring device that will ensure the appropriate connection of the three-electrode sensor built into the concrete. To obtain relative quality indicators (1) and (2), the device must provide a mode for measuring capacitance and conductivity, as reactive and active components of the admittance of concrete. These requirements are met, in particular, by the portable immittance parameter meter E7-13. It allows direct measurement of equivalent capacitance, as a reactive component, and conductivity, as an active component of admittance at a frequency of 1 kHz of a test sinusoidal signal of a given amplitude level. As noted above, the obtained results of measuring the admittance components of concrete are compared with the corresponding values of the components of an electrical standard sample. Such a sample is a concrete sample of the same brand and manufactured using the same manufacturing technology with a built-in capacitive sensor of a similar design. In this case, the normalized maturity of concrete is achieved in laboratory conditions and the specified parameters are measured similarly. Thus, we obtain an electrical standard sample of concrete with normalized values 1kHz of the corresponding electrical parameters under the specified temperature conditions. In order to take into account the effect of temperature on the electrical parameters of the controlled concrete, it is possible to additionally embed a temperature sensor with a built-in three-electrode sensor or place a standard sample in the conditions of concrete maturation. To implement the proposed method of monitoring concrete maturity, as noted above, Fig. 1 shows a simplified design of a three-electrode sensor of plane-parallel design embedded in concrete.

A feature of such a sensor is that it uses a third electrode 3 (Fig. 1a) (it is mostly called a protective electrode). It is placed between the working electrodes 1, 2 (Fig. 1b) and has a rectangular (Fig. 1c) or round (Fig. 1d) hole. This is precisely why the active area of the working electrodes is formed at a constant distance between them. In this way, the disadvantage of two-electrode sensors, caused by the influence of edge effects, is eliminated. This makes it possible to form a given volume of concrete, which is the object of control of its electrophysical parameters. Equivalent electrical circuits of such a three-electrode sensor embedded in concrete are shown in Fig. 2.

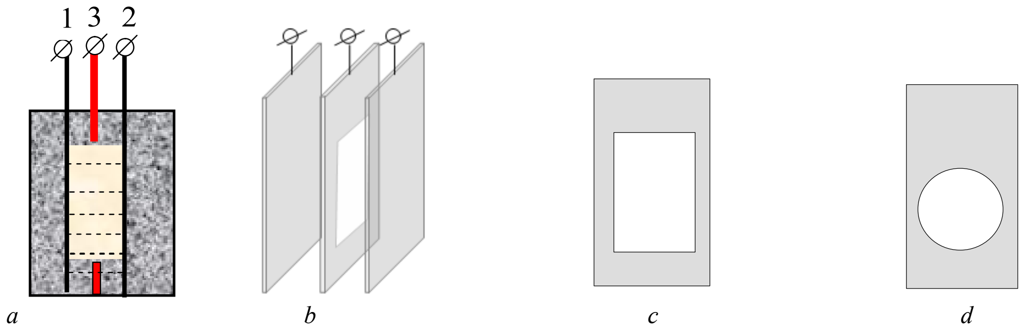

Fig. 1. Design of a three-electrode capacitive (a) sensor and shape of the protective electrode (b, c, d)

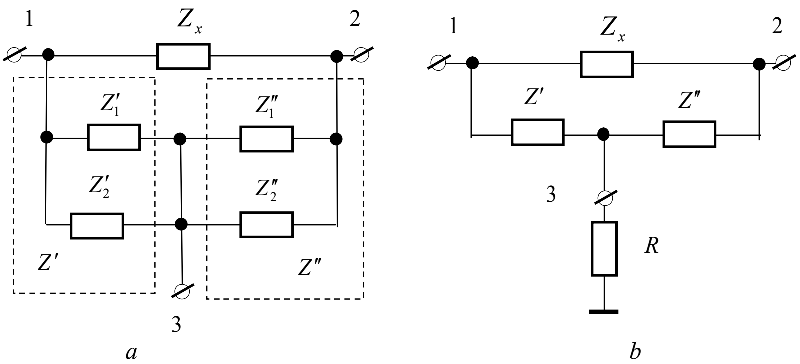

Fig. 2. Equivalent electrical circuits of a three-electrode sensor embedded in concrete: a) general circuit; b) simplified circuit

The diagram (Fig. 2a) displays all types of impedances (informative and non-informative) of such a control object. Non-informative impedance contains the impedance formed by the impedances Z' and Z'' between working electrodes 1, 2, respectively, and protective electrode 3. The specified non-informative impedance is due to the impedance of the insulating materials of the sensor Z_1 (Z_1' and Z_1''), bulk and surface impedance Z_2 (Z_2' and Z_2'' concrete, caused by edge effects of the sensor. In the case of using a two-electrode capacitive, as is known, the specified non-informative impedance shunts the informative impedance of the concrete Z_x . This leads to measurement errors. However, if a three-electrode connection is used, the shunting effect of these uninformative impedances is practically reduced to zero [10]. In this case, the simplified equivalent circuit of such a sensor, taking into account the above, already has the form shown in Fig. 2c (impedance Z', covering impedances Z_1', Z_2' and Z'' with impedances , Z_1'', Z_2'').

In this case, the total non-informative impedance Z_p between the working electrodes (1, 2) is determined by the well-known formula

$$Z_p = Z' + Z'' + \frac{Z' Z''}{R}, \quad (3)$$

and provided $R \to 0$ impedance $Z_p \to \infty$, which ensures invariance to non-informative impedance..

So, the above-mentioned measuring device measures the impedance parameters of concrete, which is placed in the interelectrode space of such a fixed-volume sensor. In this case, the three-electrode sensor eliminates the above-mentioned uninformative impedances, namely:

- impedance of the insulating structures of the sensor for connecting the electrodes;
- the ability to control the maturity of concrete inside the overlap at any distance from the surfaces;
- impedance caused by edge effects and parasitic capacitance of the connecting wires, by which the sensor is connected to the measuring circuit.

In addition, it is possible to:

- - separate the liquid phase of concrete, eliminating the influence of the electrical parameters of gravel;
- - form a given volume of concrete, which is determined by the size of the opening of the protective electrode and the interelectrode distance of the working electrodes.

5. Conclusions

1. The proposed method allows you to directly control the quality of concrete floors based on the results of measuring electrical parameters. These parameters are the reactive and active components of the admittance of the controlled concrete, which reflect its dielectric constant and specific conductivity. The specified parameters are obtained by measuring the equivalent capacitance and conductivity, as parameters of the admittance of concrete.

2. The use of a three-electrode capacitive sensor of a plane-parallel design to implement the proposed method allows you to separate the liquid phase of concrete (without filler) of a given volume. Such separation is achieved due to the selected linear dimensions between the electrodes, which are smaller than the dimensions of the filler. In this case, the volume of the controlled concrete is formed by the interelectrode size of the working electrodes and the size of the opening of the protective electrode placed between them.

3. To measure the electrical parameters of concrete, you can use a meter of the active and reactive components of the admittance at a fixed frequency of the test signal. Such components can be capacitance and conductivity or active and reactive components of admittance. According to the obtained results, if necessary, the dielectric constant and specific conductivity are calculated. The meter must provide for the connection of a three-electrode sensor.

4. The proposed three-electrode sensor for monitoring concrete maturity allows monitoring concrete maturity by the height of the concrete mass. For this, it is necessary to orient the hole of the protective electrode within its overall dimensions and concrete thickness.

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Conflict of Interest.

The authors declare that there are no financial or other potential conflicts of interest regarding this work.

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