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Overlay current in a conductive concrete snow melting system

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Abstract

A snow melting system with a base layer of electrically conductive concrete (ECC) and an overlay of normal concrete is described. A quantitative methodology is developed to evaluate the current flow through the overlay concrete when electricity is passed through the conductive concrete. Experimental results are presented to validate the methodology.

Keywords: Concrete; Composite; Electrical properties; Snow melting

1. Introduction

Electrically conductive concrete (ECC) is a patented technology developed at the National Research Council of Canada [1,2]. ECC is almost a pure resistor with electrical resistivities less than 10 Ω cm. When a voltage is applied to ECC, thermal energy is radiated from the ECC in the same fashion as a metallic wire conductor. Therefore, ECC can be used for indoor radiant heating and outdoor snow melting. Snow melting using ECC has been demonstrated in the laboratory and in the field [3,4]. For the reported trials, ECC was covered with a Portland cement concrete (PCC) overlay. The PCC overlay provides a physical barrier to the current flow in the ECC in the same manner as the plastic sheath on a metallic wire conductor. However, there are no perfect electrical insulators, whether PCC or plastic, and some current flows in the insulation. Only a very small current flow (<1 mA) through the insulation is permitted for safety reasons. Traditional Megger-type insulation testing of the PCC overlay is not possible. Therefore, it is the purpose of this paper to summarize a method to test the insulation effectiveness and the current flow through the PCC overlay.

2. Background

In the traditional wire-based snow melting systems, the energy in the wire resistor is radiated to the adjacent concrete by passive thermal conduction; current is limited to the metallic wire conductor by the plastic insulation. Fig. 1 illustrates a typical snow melting arrangement with ECC. The entire ECC layer behaves as a large flat resistor and radiates energy to the PCC overlay by thermal conduction. Primary current flows, via electronic conduction, from the hot to the neutral electrode through the ECC. A small current flows, via ionic conduction, from the hot electrode to the neutral electrode through the PCC overlay. The current in the overlay is difficult to measure because it is problematic to connect an ammeter in series with the overlay. However, the physical properties of the overlay and applied voltages can be measured.

Consider the PCC overlay thickness in Fig. 1 varies from $t=0$ to $t=t_{oc}$. The current through the overlay, $\partial I_{oc}(t)$, can be expressed as

$$I_{oc} = \int_{t=0}^{t=t_{oc}} \partial I_{oc}(t) \quad (1)$$

From Ohm's law,

$$\partial I_{oc}(t) = \frac{V_b(t)}{R(t)} \quad (2)$$

where $V_b(t)$ is the potential difference across the overlay and $R(t)$ is the overlay resistance. $R(t)$ is related to the

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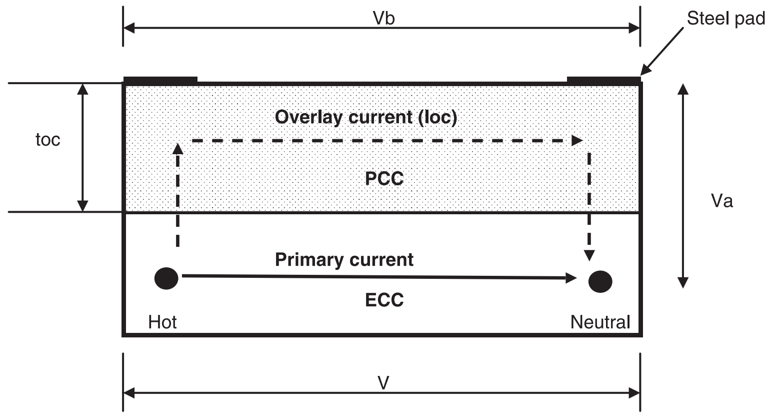

Fig. 1. Composite slab design for snow melting using ECC and a PCC overlay.

physical properties of the PCC overlay through the expression

$$R(t) = \frac{d}{L\partial t}\rho_{oc} \tag{3}$$

where $d(m)$ is the distance between electrodes, $L(m)$ is the electrode length and ρ_{oc} (Ω m) is the overlay resistivity.

When a voltage, V, is applied across the hot and neutral electrodes, a potential develops across the surface of the PCC overlay, V_b, and potentials develop from the electrodes to the PCC overlay surface, V_a. Both V_a and V_b depend on the overlay thickness. Hence, the relationship between the voltages is

$$V = 2V_a(t) + V_b(t) \tag{4}$$

when $t=0$, then $V_b(t)=V$, and when $t=t_{oc}$, $V_b(t)=V-2V_a$. Therefore, the general expression for $V_b(t)$ is

$$V_b(t) = V - 2V_a(t) = V - 2\frac{V_a}{t_{oc}}t \tag{5}$$

Substituting Eqs. (3) and (5) into Eq. (2), and subsequently integrating between the limits of Eq. (1), yields an expression for the current through the overlay.

$$I_{oc} = \frac{V - V_a}{\frac{d}{Lt_{oc}}\rho_{oc}} \tag{6}$$

However, the total overlay resistance, R_{oc} (Ω), for thickness t_{oc} is

$$R_{oc} = \frac{d}{Lt_{oc}}\rho_{oc} \tag{7}$$

Combining Eqs. (6) and (7) gives

$$I_{oc} = \frac{V - V_a}{R_{oc}} \tag{8}$$

Eq. (8) can be further simplified. Assume that V_a and V_b are proportional to V. Accordingly,

$$V_a = \alpha V \tag{9a}$$

$$V_b = \beta V \tag{9b}$$

α and β are bulk material properties related to thickness and resistivity. The relationship between α and β is deduced by combining Eqs. (4) and (9a) and (9b).

$$\beta = 1 - 2\alpha \quad (0 \leq \alpha,\ \beta \leq 1) \tag{10}$$

Substituting Eq. (9a) into Eq. (8) gives an expression for the current in the PCC overlay relating readily determined values: the applied voltage (V), overlay resistance (R_{oc}) and overlay bulk material parameter (α).

$$I_{oc} = \frac{V(1-\alpha)}{R_{oc}} \tag{11}$$

3. Experiment

ECC was prepared as described in the patent [1]. The PCC overlay was cast onto the ECC. The overlay had a w/c ratio of 0.325 and a mass design of cement/fine aggregate/coarse aggregate of 1:2:2. Steel pads were cast on the overlay surface. The steel pads were located above the electrodes. The dimensions of the experimental slab were $L=0.24$ m, $d=0.31$ m and $t_{oc}=0.05$ m.

Three voltages were measured for each experiment: the applied voltage, V, between the electrodes, the voltage

Table 1
Measured V_a, V_b and I_{oc} values versus V

V (V)	5.60	10.6	15.5	20.2	25.0	30.4	35.6	40.2	45.4
V_a (V)	1.34	2.48	3.63	4.81	5.84	7.08	8.35	9.30	10.34
V_b (V)	2.90	5.48	8.05	10.54	13.1	16.0	18.8	21.4	24.4
I_{oc} (mA)	0.007	0.012	0.018	0.024	0.029	0.036	0.042	0.048	0.054

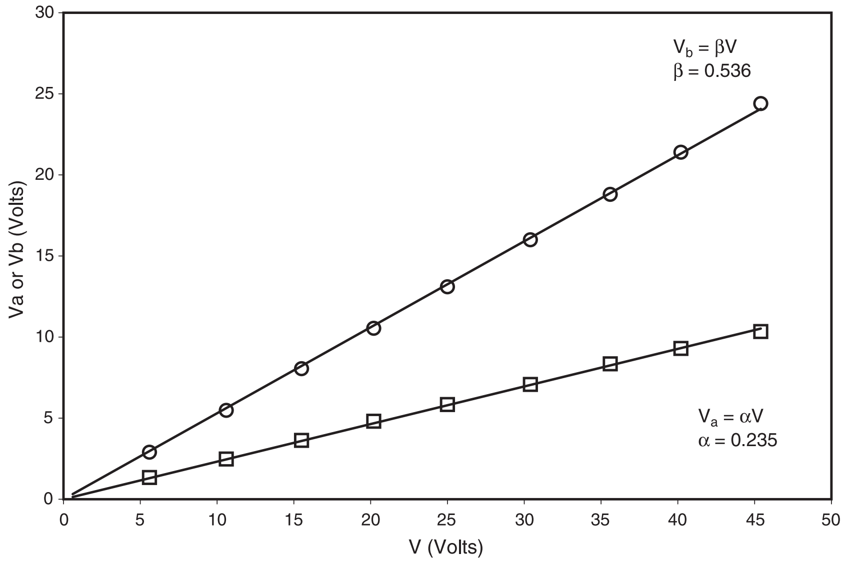

Fig. 2. Relationship between V_a, V_b and V.

across the overlay surface, V_b, and the voltage between the overlay surface and the electrodes, V_a. A Keithley Model 175 digital multimeter measured the voltages and resistances.

4. Results and discussion

Values for V_a ,V_b and V have been summarized in Table 1. V_a and V_b are plotted against V in Fig. 2. It can be seen that Eqs. (9a) and (9b) are valid and the values for α and β from the slopes are 0.235 and 0.536, respectively. R_{oc} was 650 kΩ.

I_{oc} was calculated using Eq. (11). The results are included in Table 1. For applied voltages up to $\sim$45 V, the current through the overlay is very small (i.e., less than 1/20 of a milliampere). For typical applications, applied voltages are always less than 15 V and the primary current through the ECC layer is less than 30 A [2]. In this case, the current through the overlay is extremely small (0.012 mA) and well below the 1 mA guideline.

At the design stage, reference to Eq. (11) is critical. To further decrease current through the overlay, the nature of the overlay can be adjusted to produce higher resistances either by incorporating supplementary cementitious materials (i.e., silica fume or ground granulated blast furnace slag), by careful curing control or by the incorporation of electrical insulation barrier materials. Alternately, the thickness of the overlay can be increased; however, the energy efficiency for snow melting will be compromised with a very thick overlay.

The very small current flow in the PCC overlay suggests that the durability of the PCC and on any reinforcing steel in the overlay should not be compromised. However, it remains a topic for further study.

5. Conclusions

1. When a composite concrete slab (consisting of a base layer of ECC and a PCC overlay) is used to electrically melt snow, the current in the overlay can be determined at the design stage by measuring the properties of the overlay and the applied voltage and subsequently using Eq. (11).
2. It is the thickness and the resistivity of the PCC overlay that most significantly impacts the ability of the overlay to decay electrical potential and the magnitude of the current in the overlay.
3. Experimental results indicate that current in the PCC overlay is small over a wide power range.

References

[1] P. Xie, P. Gu, Y. Fu, J. Beaudoin, Cement based conductive compositions, U.S. Patent Number 5,447,564 (September 5, 1995).

[2] G. Pye, R. Myers, M. Arnott, J. Beaudoin, P.J. Tumidajski, Conductive concrete compositions, U.S. Patent Number 6,503,318 B2 (January 7, 2003).

[3] P. Xie, J. Beaudoin, Electrically conductive concrete and its application in deicing, Advances in Concrete Technology, Proceeding of 2nd CANMET/ACI International Symposium, Las Vegas, NV, USA, SP 154-21, American Concrete Institute (ACI), Detroit, Michigan, 1995, pp. 399–417.

[4] P.J. Tumidajski, High powered concrete, St. Lawrence Cem. World 6 (1) (2002 July) 5.