World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:10, No:7, 2016

Assessing the Effect of Freezing and Thawing of Coverzone of Ground Granulated Blast-Furnace Slag Concrete

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Open Science Index, Civil and Environmental Engineering Vol:10, No:7, 2016 publications.waset.org/10004790.pdf

Abstract**—**Freezing and thawing are considered to be one of the major causes of concrete deterioration in the cold regions. This study aimed at assessing the freezing and thawing of concrete within the cover zone by monitoring the formation of ice and melting at different temperatures using electrical measurement technique. A multi-electrode array system was used to obtain the resistivity of ice formation and melting at discrete depths within the cover zone of the concrete. A total number of four concrete specimens (250 mm x 250 mm x 150 mm) made of ordinary Portland cement concrete and ordinary Portland cement replaced by 65% ground granulated blast furnace slag (GGBS) is investigated. Water/binder ratios of 0.35 and 0.65 were produced and ponded with water to ensure full saturation and then subjected to freezing and thawing process in a refrigerator within a temperature range of -30 ^{0}C and 20 ^{0}C over a period of time 24 hours. The data were collected and analysed. The obtained results show that the addition of GGBS changed the pore structure of the concrete which resulted in the decrease in conductance. It was recommended among others that, the surface of the concrete structure should be protected as this will help to prevent the instantaneous propagation of ice trough the rebar and to avoid corrosion and subsequent damage.

Keywords**—**Concrete, conductance, deterioration, freezing and thawing, ordinary Portland cement.

I. INTRODUCTION

As more concrete structures are built in harsher environments, coupled with the ever increasing demand for lower cost, shorter construction periods, more ambitious and complex structures and designs, the demand for durable concrete has increased and becomes significant [3]. Durability is an essential parameter when talking about the building material because it has indirect consequence on economy, serviceability, and maintenance [1]. In the past, there is the perception that concrete does not require maintenance due to its nature which contradicts the concept of durability. Concrete needs repair and maintenance because the best workmanship may not always be achieved [5]. It is impossible to prevent deterioration completely due to the wide range of exposure conditions of concrete. Nevertheless, if the mechanics of deterioration is understood, the rate of deterioration can be retarded and consequently attain the desired life of concrete. In Europe, for example, for infrastructure only, about 40-60% of funds set aside for construction are allocated to take care of the inspection, maintenance and repair of existing concrete structures. In the UK, a considerable amount of money (about £550 million) is allocated to the maintenance and repair of concrete structures. Therefore, it is obvious that durability is a major issue which puts structures at risk and increasing budgets on maintenance and repairs [2].

Concrete, as a building material, is subjected to a variety of environments, which affects its durability in a variety of ways. A key cause for concrete degradation is as a result of corrosion of steel reinforcement. The cover zone of the reinforced concrete which provides protection to steel is exposed to physical actions such as freeze thaw attack and weathering and chemical actions such as chloride ingress. Equally, when exposed, concrete is affected by the transport properties such as absorption, permeability and diffusion and when that happens through the cover zone of the concrete, the steel reinforcement will corrode. Subsequently, the concrete cracks as a result of the increased stresses which occur on the surface of the reinforcement.

Electrical resistivity is a good non-destructive test for evaluating the concrete durability. The electrical properties behave similarly in movement through the concrete with the transport properties such as absorption, permeability and diffusion move through the concrete. The durability of concrete can be predicted if the electrical resistivity is known because it indicates the ease of flow of the different transportation properties.

Cyclic freezing and thawing is regarded as one of the major reasons of concrete degradation in cold regions. The degradation originates due to freezing and thawing of the pore water in the concrete as temperature changes. Hence, the change in phase results in change in dimension and internal stress within the concrete and therefore can lead to failure [4].

The freezing and thawing durability of concrete is of paramount significance in the countries having below zero temperature conditions. For example, about one third of all concrete made in Nordic countries should have acceptable freezing and thawing resistance. However, the stresses and strains in concrete caused by freezing and thawing loads are nearly unknown, and the building regulations for the production of freezing durable concrete are based on standardized test procedures and indirect production rules [4].

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II. MATERIAL, SAMPLE AND CURING

The sample comprised of OPC clinker combined with GGBS as Supplementary Cementitious Materials (SCM) used in blending was combined in accordance with BS EN 197-1:2000. A water binder ratio of 0.35 and 0.65 were used. The sand used was concreting sand with a maximum particle size of 4mm along with two grades of crushed granite (10 mm and 20 mm) of low porosity (~0.7%-0.9%). Plasticizer polycarboxylate SikaPlast, conforming to BS EN 934-2 was used. Specimens were 250×250×150 mm (thick) slabs, the upper surface of each slab had a 20 mm high ponding area which held water, hence, allowing water to be ponded on the surface of the slab.

III. EXPERIMENTAL AND TEST PROCEDURE

A. *Two-Point Multi-Electrode Array Set-up*

This experiment used a two point embedded multi-electrode array system. The set-up of the inverted T shaped PVC which holds the electrode in place is illustrated in Fig. 1. Each electrode was made up of stainless steel pins of 1.6 mm diameter. A stainless steel of 10 mm diameter was exposed on the end of each electrode. The electrodes were spaced horizontally at 10mm interval, and then vertically spaced at depths of 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, and 75 mm respectively from the surface of the specimen. In order to ensure better distribution around the probes when pouring, the electrodes were overlapped against each other in a vertical plane. The tip of each probe exposed was placed at a distance of 45mm from the face of the T shaped PVC so as to reduce the aggregate-wall-effect. In order to take temperature readings during the experiment, thermistors were integrated into the face of the PVC former at varying depths of 10 mm, 30 mm, 50 mm and 75 mm. The collected data were then corrected to temperature. The thermistor resistances were then converted to temperature readings in (^{0}C) and(K) by using the Stein-Hart equation:

$$T = [A + B\ln R + C(\ln R)^3]^{-1} - 273.15 \quad (1)$$

$$T = [A + B\ln R + C(\ln R)^3]^{-1} \quad (2)$$

where, R = the measured resistance of the thermistor (Ω), T = temperature (ºC and K), A, B, C = coefficients which depend on the type of thermistor, were calculated from manufacturer data, respectively, to be: 1.287600011×10^{-3} K-^{1}; 2.357183092×10^{-4} K^{-1} and 9.509464377×10^{-8} K^{-1}.

B. *Freezing and Thawing Procedure*

The samples were ponded by using pure tap water which has been allowed to cool at room temperature to ensure that the specimens are fully saturated before subjecting them to the freezing and thawing process. The ponding process lasted for seven days. Before subjecting the specimens into the freezing and thawing chamber, the surface of the specimens was de-ponded by the use of clean dry sponges and also covered with a thick plastic lid to prevent any further moisture loss. The sponges used were the yellow ones and care was taken to ensure that the sponges were not mistaken with the other ones used for other solutions. After attaining full saturation, each of the four specimens X1(65% GGBS and 0.35 w/b ratio), X3(65% GGBS and 0.65 w/b ratio), C1 (100% OPC and 0.35 w/b ratio), and C3 (100% OPC and 0.65 w/b ratio) was separately put in a freezing and thawing chamber for 24 hours for the freezing cycle. The freezer temperature was dropped to -30 ^{0}C from the room temperature of 20 ^{0}C. The logger was set at five-minute interval and the readings were automatically stored in the logger. After 24 hours, the freezing and thawing chamber was then switched off and the specimen was allowed to melt for 24 hours at room temperature for the thawing cycle to take place. The same procedure was repeated for specimen C3, X1, and X3 and after which the logger was removed, and then the data were downloaded for analysis on a computer. The set up can be seen in Fig. 2.

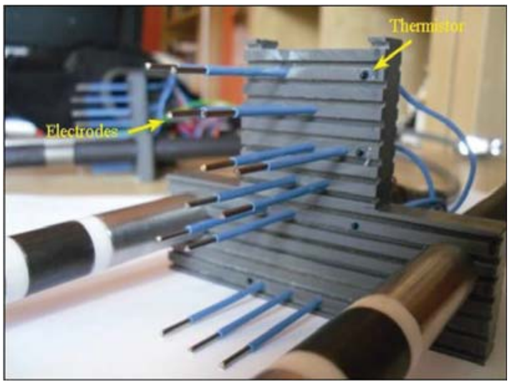

Fig. 1 Multi Electrode sensor array

Fig. 2 Freezing and thawing chamber setup

C. *Electrical Measurement System*

An automated measurement system was used to gather two-point resistance data from the electrode embedded array system in the concrete slabs. The system consists of a concrete resistance logger linked to a multiplexing unit, which allows up to 72 two-point channels to be monitored via six 37-way D-type connector and cable assemblies. Measurements are obtained by using a 1000 mV peak to peak ac voltage signal (350 mV RMS) at 1000 Hz. The logger stores measured resistance data in an operator pre-programmed format to a non-volatile memory. As-measured data is uploaded in 39

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Microsoft Excel csv format for subsequent processing to a personal computer (PC) via an RS232 port connector. The logger was set to record a cycle reading at every five-minute interval for a period of 24 hours.

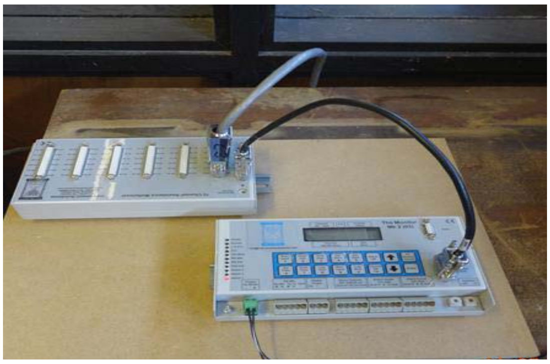

Fig. 3 Measurement system

IV. Result and Discussion

A. Electrical Conductance during Freezing and Thawing Cycle

The sample conductance was calculated from the electrical resistivity of each specimen which was measured at various temperature range.

During freezing, the electrical conductance is higher at depth 10 mm (approximately -12.3 s/m) and decreases slightly at depth 30 mm, 50 mm, and 75 mm. However, during thawing, the electrical conductance at depth 10 mm exhibits higher value (approximately -8.9 s/m) and decreases with depths 30 mm, 50 mm and 75 mm (approximately -10.1 s/m). The electrical conductance as observed at all depths decreases with depth through the specimen.

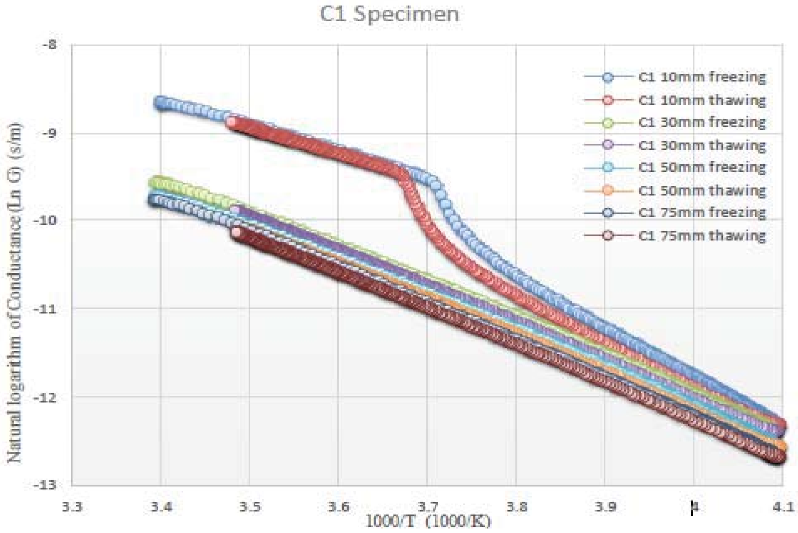

Fig. 4 Natural logarithm of conductance vs 1000/T for specimen C1

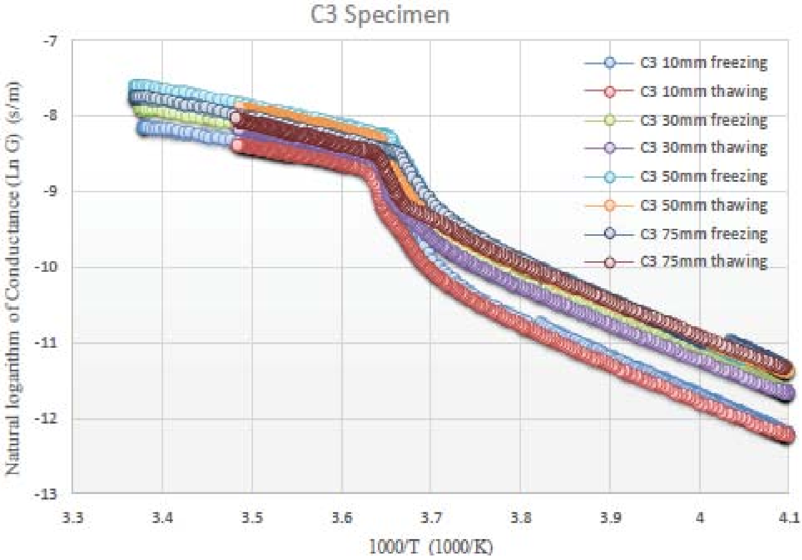

Fig. 5 Natural logarithm of conductance vs 1000/T for specimen C3

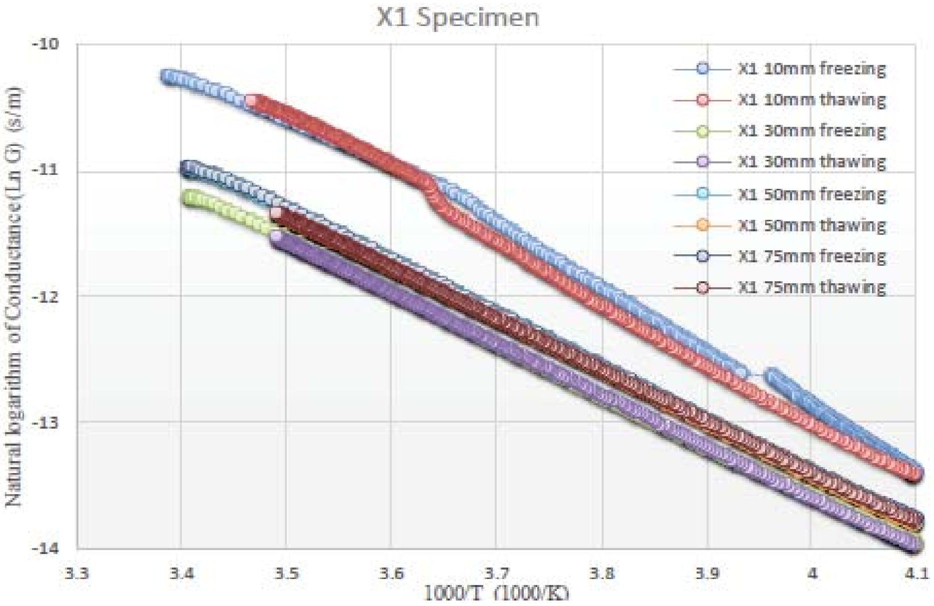

Fig. 6 Natural logarithm of conductance vs 1000/T for specimen X1

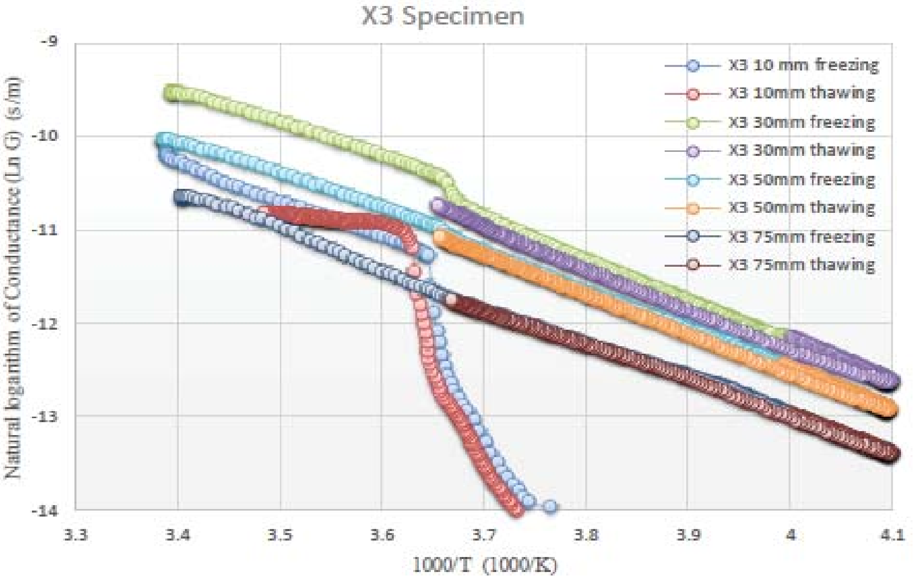

Fig. 7 Natural logarithm of conductance vs 1000/T for specimen X3

It can be observed that during freezing, the electrical conductance is lower at depth 10 mm (approximately -12.2 s/m) and slightly increases with depth 30 mm, 50 mm and 75 mm (approximately -11.3 s/m) through the specimen. However, during thawing, the electrical conductance at depth 10 mm exhibits lower value (about -8.4 s/m) and increases with depths 30 mm, 50 mm and the highest value at depth 75 mm (approximately -8.0 s/m). The electrical conductance increases slightly with depth.

It can be seen that as temperature decreases during freezing, the electrical conductance also decreases, and during thawing when there is a rise in temperature, the electrical conductance increases. The electrical conductance during freezing at depth of 10 mm is higher than at other depths (approximately -13.4 s/m), followed by depths 50 mm, 75 mm and lower at depth 30 mm (-14 s/m). However, during thawing, the electrical conductance is much higher. At depth 10 mm, the conductance is -10.4 s/m followed by depths 50 mm, 75 mm and lower at depth 30 mm (-11.5 s/m). It can be observed that the electrical conductance during freezing at depth 30 mm is higher than that at other depths (-12.7 s/m), followed by 50 mm, 75 mm, and then lower at depth 10mm (approximately -14 s/m). Equally, during thawing, the electrical conductance at depth 30 mm (approximately -10.8 s/m) is higher than that at the other depths in the order of 10 mm, 50 mm, and 75 mm. However, at depth 75 mm, the specimen exhibits lowest electrical conductance during freezing and thawing at approximately -13.4 s/m and -11.8 s/m respectively.

Specimen C1 was subjected to three freezing and thawing cycles in order to assess the cyclic effect of freezing and thawing. Figs. 8 and 9 show the relationship between the three cycles at depth 10 mm because it is the surface of the specimen and 75 mm because it is the depth close to the rebars. It can be observed that the electrical conductance during freezing and thawing at both depths is more or less the same and did not change and the electrical conductance at depth 10 mm is higher than at depth 75 mm. However, it can be said that the number of cycles that the specimen was subjected to has no effect on its behaviour.

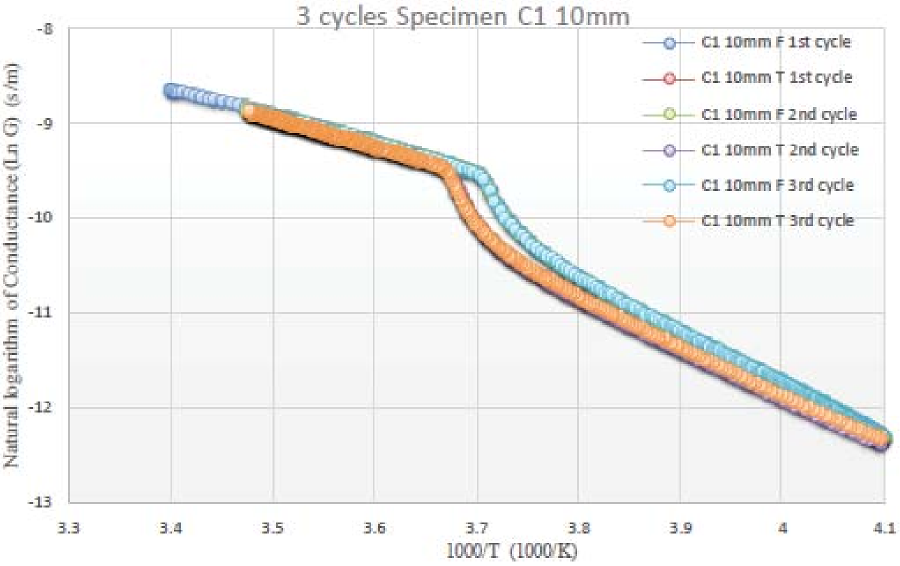

Fig. 8 Natural logarithm of conductance vs 1000/T for specimen C110 mm three cycles subjected to three cycles of freezing and thawing

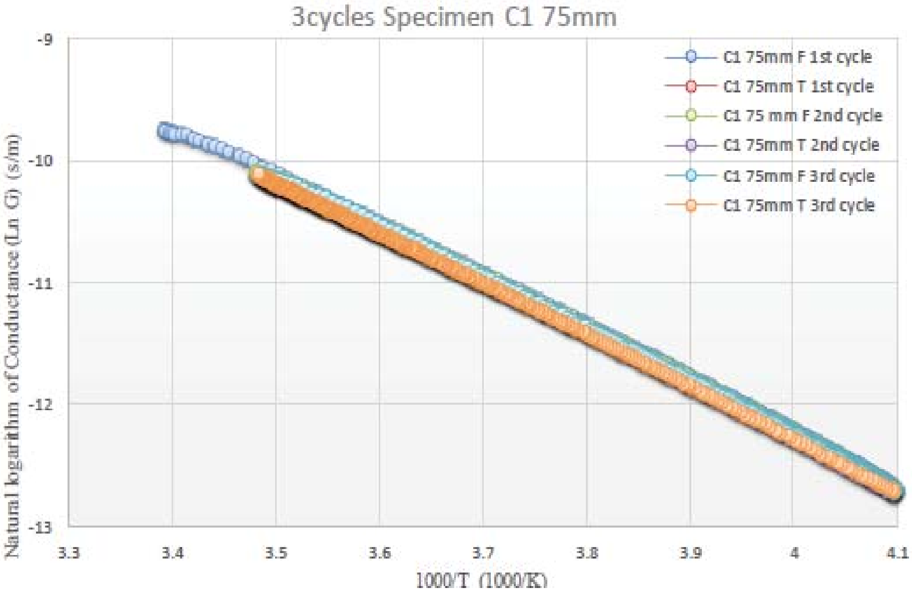

Fig. 9 Natural logarithm of conductance vs 1000/T for specimen C1 75 mm subjected to three cycles of freezing and thawing

V. CONCLUSION

In conclusion, the electrical conductance during thawing is much higher irrespective of water/binder ratio and additive. This is because the temperature during thawing process tends to increase. The electrical conductance of concrete is dependent on temperature and any change in temperature will affect the conductance. The conductance in freezing process is lower than that in the thawing process at any given temperature as observed. This is an indication of hysteresis of ice formation in the freezing process. Also, it can be seen that more ice exists in the thawing process. It is quite interesting to see that the electrical conductance during freezing and thawing for specimen C1 and C3 are much higher than the conductance of X1 and X3. This could be that the addition of GGBS changed the pore structure which results in lower conductance of the specimen with replacement.

Comparison of specimen C1 and C3 shows that the electrical conductance for specimen C3 during freezing, and

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thawing is higher than that of C1 at all depths. This could be that the higher water/binder ratio made the concrete more permeable and hence results in higher conductance.

From the comparison of specimen X1 and X3, it can be concluded that the electrical conductance of specimen X3 is higher than that of X1 except at depth 10 mm which X1 specimen exhibits higher value. This could also be that the higher water/binder ratio made the concrete more permeable and hence results in higher electrical conductance.

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