Monitoring the early-age properties of cement-based concrete by electrical conductance in combination with isothermal calorimetry

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ABSTRACT
A novel method based on electrical conductance in combination with isothermal calorimetry was used for monitoring the early-age properties of cement-based concrete. Two different mortars, one with OPC and another with 50% GGBS replacement, were tested. Preliminary results show that the proposed method can clearly monitor the hydration process and the structural development in the samples.

Key words: Testing, setting time, hydration, conductivity, resistivity, isothermal conductive calorimetry.

1. INTRODUCTION

Almost 100 years ago, close to 100 years after Joseph Aspdin's patent for Portland cement (filed on October 21, 1824), Shimizu in 1928 proposed an electrical method for determining the setting time of Portland cement [1]. This method was proposed instead of the Vicat test method [2] which was originally developed by Louis-Joseph Vicat in 1828 [3]. Shimizu [1] discovered and showed that the electrical conductivity measured during the setting and hardening suddenly changed at the moment corresponding to the final set. Since then, many researchers have investigated electrical methods for studying development of properties of cement-based materials. At Chalmers University of Technology, Huang [4] & Huang et al. [5] used conductivity measurements to monitor the electrical properties of pastes to map the hydration induced microstructural changes in cement-based materials and found good correlation between setting time (determined with needle penetration) and critical time of microstructural changes by conductance testing. Moreover, Huang et al. [6] used the formation factor to describe the setting and hardening process of concrete and found that this performed better than ultrasonic pulse velocity on indicating the setting process and a good correlation could be established between formation factor and compressive strength. Nowadays, heat of hydration, hydration kinetics and reactivity of cement and supplementary cementitious materials are often studied by isothermal conductive calorimetry (ICC), [7] & [8], and the ion dissolution process is either monitored with methods determining elemental concentrations or by conductance measurements.

Based on this, we therefore propose, as one step towards understanding the interaction between initial ion dissolution and the development of hydrates and pore structure of cementitious material, to combine ICC with the electrical method (conductance) to study hydration kinetics and ion dissolution in hydrating cement in the same sample. In this paper we present some initial results from tests done when developing a conductance monitoring system.

2. EXPERIMENTS

To assess the measurement system, two different mortars were mixed according to SS-EN 196-1 using 225 g water, 1350 g of CEN Standard Sand and 450 g of cement (CEM I 52.5 R) or with 225 g cement and 225 g GGBS (ground, granulated blast furnace slag Merit from Swecem).

The heat development of mortars was measured with a I-Cal 4000 HPC isothermal calorimeter from Calmetrix and a mortar sample of 50 g were placed into the calorimeter. For each mortar mix four samples were measured and in two of these the conductivity was measured in the calorimeter simultaneously with the heat flow. The conductance was measured with a four-point electrode set-up (Wenner) to minimize polarization effects.

3. RESULTS AND DISCUSSION

The conductance and heat flow values are presented in Fig. 1 and Fig. 2. As can be seen, the conductance initially increased gradually due to ion dissolution until it reached a peak value after about 2 to 3 hours and after this the conductance starts to decrease. From the ICC it can be seen that the initial high heat flow, due to the initial ion dissolution, coincides with the increase in conductance and the induction period (low heat flow) with the peak conductance. The acceleration period when the heat flow increase due to hydration also coincides with the decrease of conductance and this is associated with the setting-time and initial hardening as hydrates are formed and more ions dissolve. Moreover, in the second peak in the ICC heat flow curve associated with aluminate dissolution and sulfate depletion is also noticeable in the conductance curve and especially for the mix with GGBS which also indicates an increased release of hydroxide ions and an increase of conductance can be seen.

The conductance continuous to decrease with time as shown in Fig. 3 and Fig. 4 by the relative conductance (in relation to the conductance at peak value). For the mortar with 50 % GGBS there is a notable decrease in conductance over time and most markedly after about a week (168 hours) with the GGBS reaction while the CEM I mortar show much less decreases of conductance over time. The conductivity measurement can also be used to predict the porosity- and strength-development, as shown e.g. by [4], with the formation factor, *F*, which is the inverse of the relative conductance. The formation factor was presented by Archie [9] to relate the electrical conductivity of sandstone to its permeability or porosity.

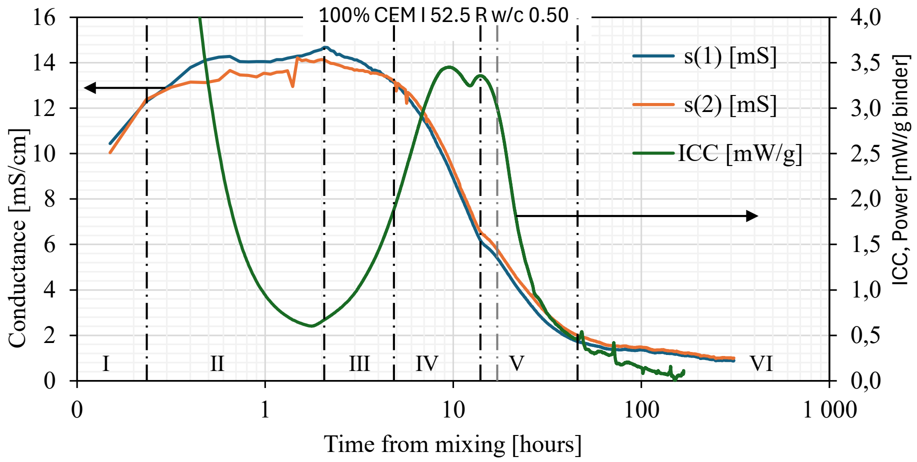

Figure 1 – Development of conductance and thermal power (ICC) for CEM I 52.5 R.

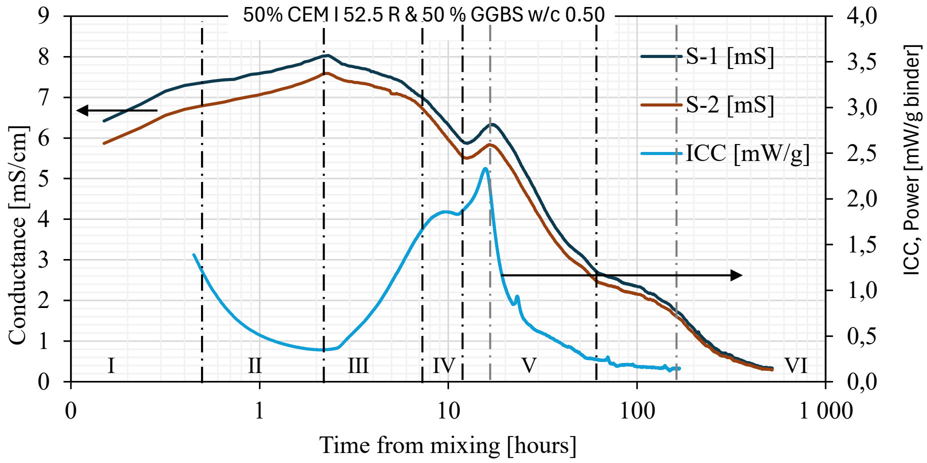

Figure 2 – Development of conductance and thermal power (ICC) for CEM I 52.5 R mixed with 50 % GGBS.

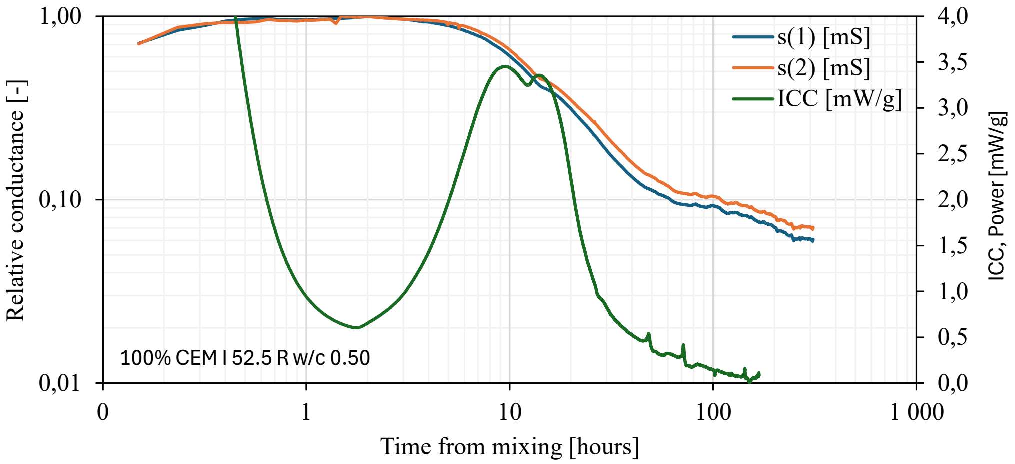

Figure 3 – Development of the relative conductance and thermal power (ICC) for CEM I 52.5 R.

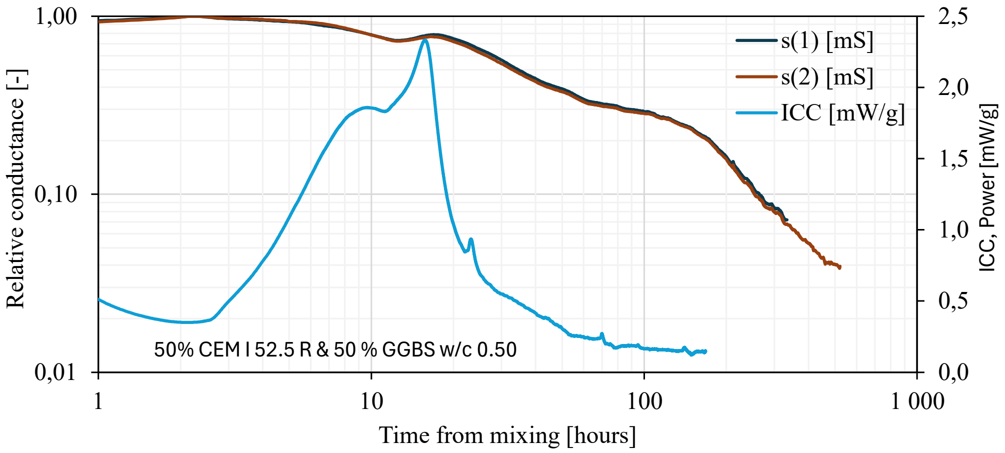

Figure 2 – Development relative conductance and thermal power (ICC) for CEM I 52.5 R mixed with 50 % GGBS.

4. Conclusions

Close to 100 years have gone since Shimizu used conductivity measurements for measuring the setting time of Portland cement and blast furnace slag cements. Using conductivity measurements to study the initial ion dissolution, hydration and pore structure development in cement-based materials is now attracting more attention [4] and has been shown to be a useful tool for investigating cement hydration in combination with isothermal conductive calorimetry. Based on our preliminary study the following conclusions can be drawn:

- As shown by Shimizu, 100 years ago, conductivity measurement is a useful method to study hydration and to assess setting time as well as pore structure development and is able to determine the time when hydrates start to formed in the ion saturated pore solution.
- When combined with isothermal conductive calorimetry it is possible to draw clearer conclusions about ion dissolution and hydrate formation in the early-age.
- The conductivity measurement can also be used to predict the porosity- and strength-development, as shown e.g. by [4], by the formation factor or the inverse of relative conductance presented in this paper.

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