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ELECTRICAL CONDUCTIVITY OF CONCRETE CONTAINING SILICA FUME

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ABSTRACT

The influence of silica fume on concrete properties represents an important technical research. In general, silica fume tends to improve both mechanical characteristics and durability of concrete. Thus the electrical properties of concrete containing silica fume can be studied to clarify its physical performance during hydration. The electrical conductivity of neat cement, mortar and concrete pastes was measured during setting and hardening. The ordinary Portland cement was partially replaced by different amounts of silica fume by weight. The changes in the electrical conductivity were reported during setting and hardening after gauging with water. The results of this study showed that the electrical conductivity can be used as an indication for the setting characteristics as well as the structural changes of the hardened pastes made with and without silica fume.

Introduction

Portland cement paste is the most active component of mortar and concrete. Therefore, a special understanding of the nature and early age behaviour of cement paste is of prime importance in making qualified concrete products. This paper investigates the effect of some variables (e.g., water / cement ratios and silica fume admixture content) on the conductivity of the hardened pastes. All tests reported here were made in the state of setting and hardening and measured at relatively low A.C. frequencies (1000 Hz) ; this means that the change in electrical conductivity can be attributed to changes in the number and/or the mobility of charge carrying ions.

Previous investigators (1-3) developed a new method for measuring the electrical resistivity of concrete which eliminates difficulties due to polarization effects. In other studies, the electrical conductivity and resistivity measurements were used to follow the stages of cement hydration (4-8). Further studies showed that the interactions between hydration and setting of tricalcum silicate pastes depend on the lime concentration in the solution (9).

Experimental Work

All tests were carried out using ordinary portland cement. The cement pastes were made with different initial porosities using the water / cement (W/C) ratios by weight of 0.25, 0.4 and 0.6. The mortars were prepared using a sand / cement ratio by weight of 3 :1 and W/C ratios by weight of 0.25, 0.4, and 0.6. The concrete specimens were made using a cement : sand : aggregate ratio by weigt of 1 : 2 : 3 and the W/C ratios described before. The silica fume concrete specimens possess the same ratios of cement, sand and aggregate as concrete but the cement has been partially replaced by silica fume of ratios 5, 10, 15 and 20% by weight and using a water /(cement + silica fume) ratio of 0.4. In conductivity measurements, the test cell was of the co-axial type (10) and included concentric inner and outer electrodes mounted on an insulated base plate; the electrodes were polished before the experiment . The cement pastes, mortars and concretes were placed in the space between the electrodes and the cell was kept in a desiccator at 100 % relative humidity during the test period. The measurement began exactly, three minutes after the first contact with water; this is the zero time of test. Electrodes were hooked to a semi-automatic RLC bridge, B 509; 1000 Hz from TASLA for resistance measurements between the electrodes over the hydration stages of setting and hardening.

Results and Discussion

Results of the electrical conductivity of the various neat cement,mortar and concrete pastes are shown in Figures 1 to 6. The electrical conductivity of neat cement, mortar and concrete specimens increases in the initial stage, reaching a first peak after 1-3 hours and then gradually decreases. After 3 hours, however, a second peak appears. The time of occurence of the second peak increases as the water / cement ratio increases and decreases as the silica fume ratio increases. The increase of electrical conductivity in the initial stage of hydration is due to the increase of ionic concentrations and the mobility of these ions during the initial stages as the water within the pore system becomes saturated with Ca^{++} and OH^- ions and other minor ions leached out from the cement grains, primarily $SO4^{--}$, Na^+ and K^+ (11). These ions are, however, readily absorbed by the formation of a thin layer of hydration products, mainly as ettringite and calcium silicate hydrates, which form an envelope around the unhydrated cement grains. The coating layers consist of electrical double layers of adsorbed calcium ions and counter ions, as well as the formation of cement hydrates; these effects resulted in a decrease in both of the number and mobility of ions leading to a decrease in the conductivity after the first maxima. The second peak in the conductivity-time curves is actually due to two main effects; these are:(i) the osmotic pressure development to split the pieces of the gel covering and the surface of cement grains, which is immediately accessible to water, leading to an increase in the ionic mobility, and (ii) the partial transformation of ettringite ($C_3A.3CaSO_4.32H_2O$) to monosulfate ($C_3A.CaSO_4.18H_2O$). The latter effect results in the release of $2Ca^{++}$ and $2SO4^{--}$ gm ions per one mole of ettringite leading to an increase in the number of ions (12,13). At the later stages of hydration, the formation and later accumulation of cement hydrates resulted in a marked consumption of the number of ions leading to a sharp decrease in the conductivity of the hardened pastes.

Figure 1 shows the effect of W/C ratio on the electrical conductivity of the neat cement pastes. It is clear that the time of the first conductivity peak remains practically unchanged, but its intensity

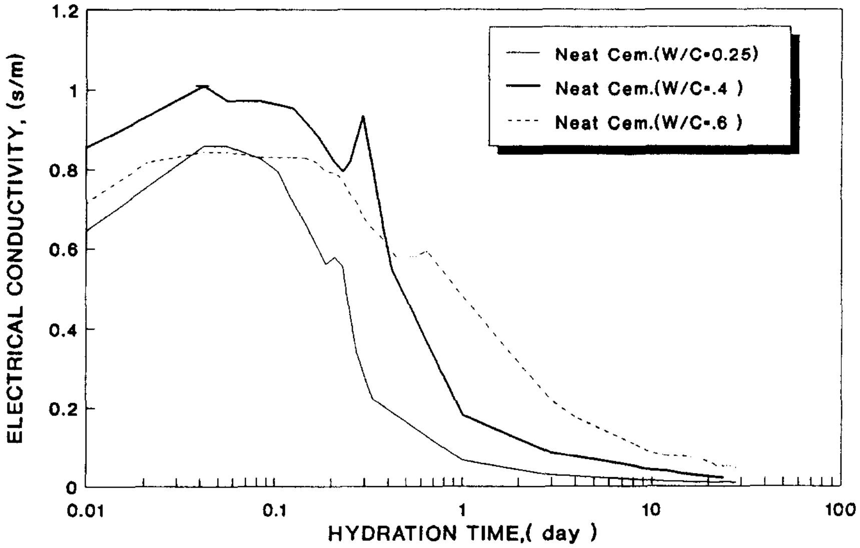

FIG.(1)
Electrical conductivity of cement pastes (W/C=0.25,0.4 and 0.6) during hydration.

decreases as the W/C ratio decreases. The second peak occurs at 5:20, 6:55 and 15:00 hr. for the pastes made with the W/C ratios of 0.25, 0.4 and 0.6, respectively. Therefore, the increase in the initial W/C ratio of the paste results in an increase in the time at which the second conductivity peak appears. This result is mainly attributed to the increased degree of stability of ettringite formed in higher porosity pastes (made with higher W/C ratios) as compared with the pastes made with a lower porosity (W/C=0.25).

Figure 2 illustrates the effect of W/C ratio on the electrical conductivity of the mortar pastes. It shows that the height of the first conductivity maximum increases as the W/C ratio increases. This result is mainly due to the increased degree of hydrolysis of the cement constituents with increasing W/C ratios of the mortar pastes. The second maximum on the conductogram, however, appears at the hydration times 6:10, 7:25 and 8:50 hr. for the mortar pastes made with the W/C ratios of 0.25, 0.4, and 0.6 respectively. Therefore the results of increasing time of second conductivity peak with increasing W/C ratio of the hardened mortars are similar to those of the neat cement pastes.

Figure 3 demonstrates the effect of W/C ratio on the electrical conductivity of concrete . It shows that the variations of the first conductivity maxima are nearly similar to those of mortars and pastes, but the second conductivity maxima appear at 7:20 and 9:20 hr. for the W/C ratios of 0.4 and 0.6, respectively. Evidently, the second conductivity maximum of the concrete made with a W/C ratio of 0.25 is not defined.

Figure 4 shows the effect of W/C ratio on electrical conductivity of concrete containing silica fume. Obviously, the second conductivity peak decreases as the silica fume content increases. This is due to the ability of silica fume to modify the microstructure of the cement paste - aggregate interface by the consumption of the free lime released as a result of cement hydration.

Figure 5 illustrates the relationship between the electrical conductivity and W/C ratio of the various pastes investigated. It is clear that, the electrical conductivity increases as the W/C ratios increased. The regression equations for neat cement, mortar and concrete are written in the form :

6^{J} (neat cement) = 0.10590 (W/C) - 0.0168 (s/m) (1)

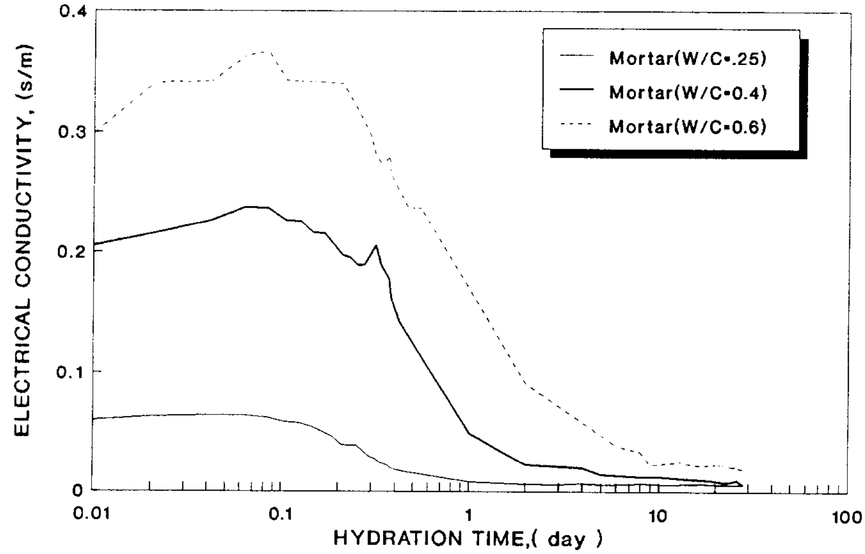

FIG.(2)
Electrical conductivity of mortar pastes (W/C=0.25,0.4 and 0.6)during hydration.

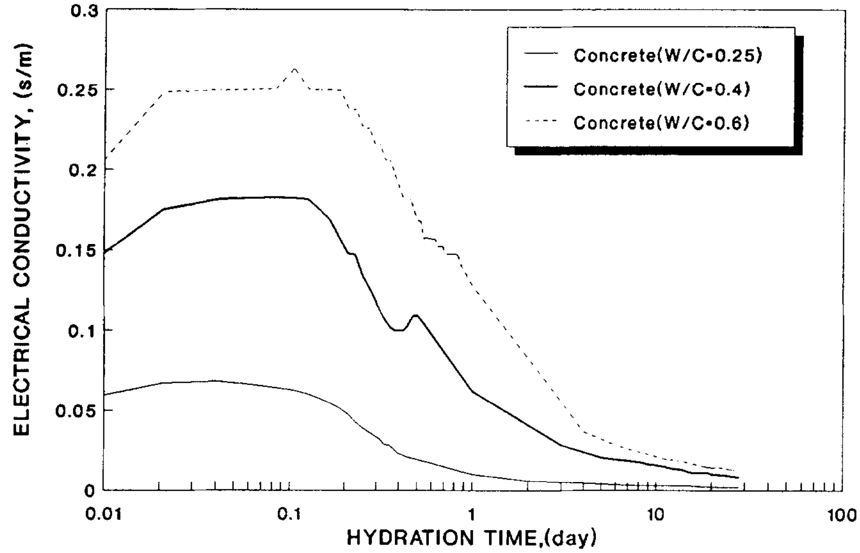

FIG.(3)
Electrical conductivity of concrete pastes (W/C=0.25,0.4 and 0.6)during hydration.

σ (mortar) = 0.05622 (W/C) - 0.01276 (s/m) (2)

σ (concrete) = 0.03135 (W/C) - 0.00573 (s/m) (3)

Figure 6 shows the relationship between electrical conductivity or porosity of concrete (water /(cement+silica fume) = 0.4) with the silica fume content. It is shows that, the electrical conductivity

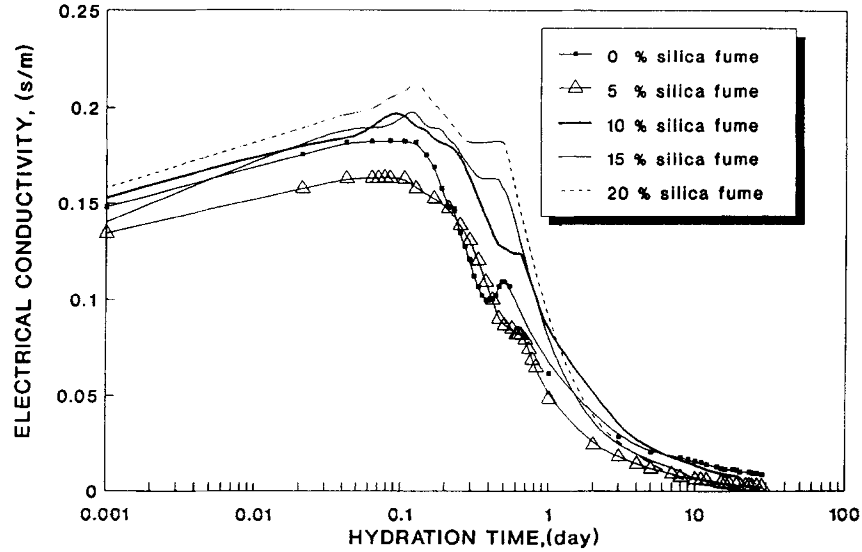

FIG.(4)
Electrical conductivity of concrete contaning silica fume [W/(C+S)=0.4].

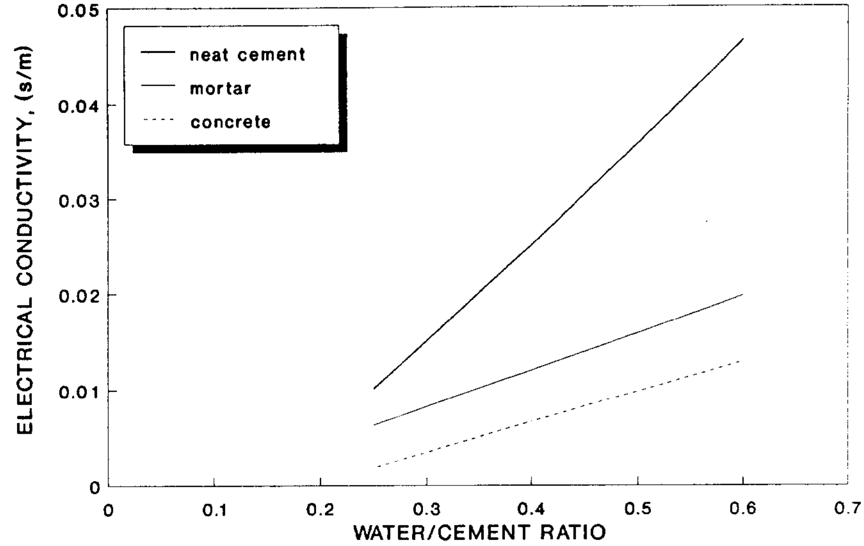

FIG.(5)
Relationship between electrical conductivity and water/cement ratio of neat cement, mortar and concrete(moist cured for 28 days).

decreases as the silica fume content increases and correlated by the following equation :

$$\sigma = 0.009 - 0.00286\,X + 0.00039\,X^2 - 2.12E\text{-}5\,X^3 + 3.99E\text{-}7\,X^4 \qquad (s/m) \qquad (4)$$

where:

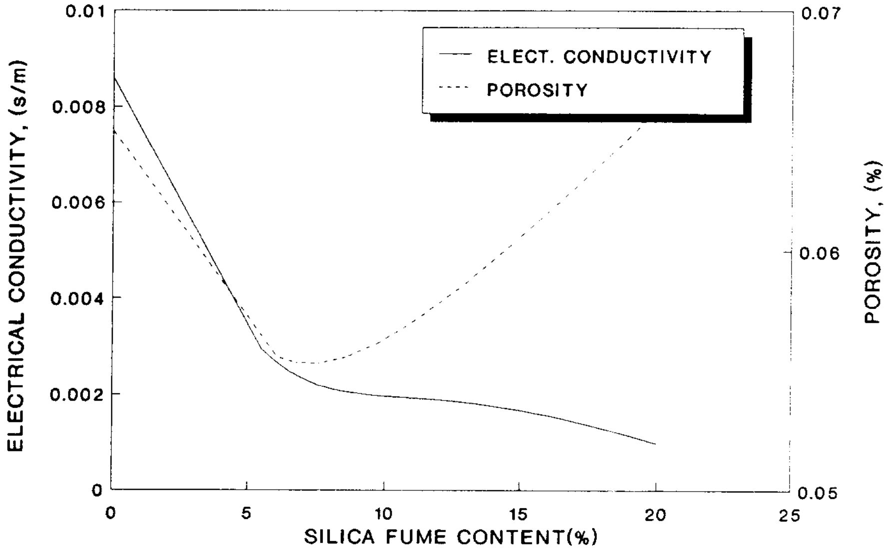

FIG.(6)
Relationship between electrical conductivity or porosity of concrete and silica fume content [W/(C+S)=0.4].

σ is the electrical conductivity in (s/m), and
X is the silica fume content by weight of cement.

Figure (6) shows that the porosity decreases up to 5% silica fume content and then gradually increases as the silica fume content increases, and is correlated by the following equation :

$$P = 0.065 - 0.00385 X + 0.00037X^2 - 8.99 E - 6 X^3 \quad (5)$$

where:

P is the porosity,and.
X is the silica fume content by weight of cement.

The inital decrease in porosity with increasing the silica fume content up to 5% is mainly attributed to the formation of ill-crystallized calcium silicate hydrates as a result of interaction between silica fume and free lime released during cement hydration. These hydrates are first formed around and in between the cement grains leading to a decrease in the porosity. By increasing the silica fume content above 5%, however the stabilization of the formed calcium silicate hydrates, via crystallization, results in a sort of opening of the pore system of the hardened concrete leading to a gradual increase in porosity.

Conclusions

The main conclusions derived from this study may be summarized as follows:

1 - The changes in electrical conductivity reflect the physical and chemical changes in the cement paste and can be used to monitor setting and hardening processes .
2 - Significant changes in electrical conductivity occur when the paste gains its rigidity.
3 - As the water / cement ratio increases, the conductivity increases and the structure growth process is retarded.
4 - The second conductivity maximum of concrete contaning silica fume decreases as the silica fume ratio increases.
5 - The electrical conductivity of concrete containing silica fume, moist cured at 28 days, decreases as the silica fume content increases.
6 - The porosity of silica fume concrete moist cured at 28 days, decreases as the silica fume content increases up to 5% and then increases as the silica fume content increases.

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