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Communication

Effect of temperature on electrical conductivity of blended cement pastes[1]

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Abstract

Previous studies proved that addition of slag and silica fume to ordinary Portland cement increases the chemical resistance to aggressive ion attack and results in lowering of the heat of hydration. In this investigation, the effect of curing temperature on the hydration characteristics of blended cement was studied. The blended cement used in this investigation consists of ordinary Portland cement, slag, and silica fume. The change in phase composition of cement pastes was investigated by differential scanning calorimetry. The electrical conductivity of cement pastes was monitored during setting and hardening at different temperatures. It is demonstrated that the electrical conductivity of cement paste can be used as an effective means of studying the progress of cement hydration and for monitoring structural changes occurring within the paste. The setting time of blended cement changed according to curing temperature.

Keywords: Temperature; Electrical properties; Blended cement

Portland cement paste is the most definitive component of mortar and concrete. Therefore, the early-age behavior of cement paste is of greatest importance in making quality concrete products, as well as in conducting efficient construction work. The main factors that affect the rate of cement hydration are cement composition, cement fineness, water-to-cement ratio, curing time, and curing temperature. Accordingly, for a given cement paste the curing temperature is the major factor affecting the rate of hydration and thus the strength development of concrete. When ordinary Portland cement (OPC) is mixed with water, a series of chemical reactions begins to take place. The reactions of cement with water proceed at different rates for the various mineral phases and involve both hydrolysis and hydration processes [1]. Hydration is a chemical process that, from the anhydrous material through several chemical reactions, leads to the formation of hydrates. This complex process has thermodynamic, kinetic, and structural features, which depend on both chemical and physical parameters [2]. Setting is a definite time event that corresponds to the transition of the paste from soft to hard. The changes in the physical state of water and ionic concentrations within the gauging water were reflected by the change of cement paste electrical conductivity. Alite (C_3S) and belite (C_2S) phases in the clinker are primarily responsible for the strength of the cement paste; C_3S is responsible for strength development during the initial stages of setting and hardening. The addition of microsilica to concrete has been found to be favorable in many ways, such as producing concrete with high strength and low permeability [3–8]. The effect of microsilica on the setting of cement mixes usually shows a longer setting time than that of OPC [9]. The higher the microsilica content, the higher the delay in concrete setting compared to OPC concrete of equal strength [10].

1. Experimental details

The starting materials used in this study were OPC of Blaine surface area 3000 cm^2/g, silica fume of surface area 22 m^2/g, and ground granulated blast-furnace slag of Blaine surface area 3600 cm^2/g. The chemical oxide composition of OPC was found to be CaO 63.80, SiO_2 21.75, Al_2O_3 6.86, Fe_2O_3 1.78, MgO 2.74, SO_3 1.46, Na_2O 0.48, K_2O 0.09, Cl^- 0.007, and ignition loss 1.8%. The chemical composition of silica fume was found to be SiO_2 96.10, Al_2O_3 0.52, Fe_2O_3 0.70, CaO 0.21, MgO 0.48, SO_3 0.10, Na_2O 0.31, K_2O 0.49, and ignition loss 1.14%. The chemical composition of granulated blast-furnace slag was CaO 33.76, SiO_2 38.60, Al_2O_3 13.20, MgO 5.36, Fe_2O_3 3.53, SO_3 0.55, Na_2O 1.33, K_2O 0.66, and Cl^- 0.07%. Different blended cements were prepared as shown in Table 1. The blended cement pastes were prepared using the standard water of consistence. In electrical conductivity measurements, the test cell was of the co-

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Table 1
Mix composition of the investigated cement blends

Mix no.	OPC (%)	Silica fume (%)	Slag (%)
I	100	0	0
II	97.5	2.5	0
III	95	5	0
IV	90	10	0
V	65	0	35
VI	60	0	40
VII	55	0	45

axial type [11] and included concentric inner and outer electrodes mounted on an insulated base plate; the electrodes were polished before the experiment. The cement pastes were placed in the space between the electrodes, and the cell was kept in a humidity chamber at 30° ± 2°C and 40° ± 2°C as well as 100% relative humidity during the test period (24 h). The measurement began exactly 3 minutes after the first contact with water; this is the zero time of test. The electrodes were hooked to RLC meters, model SR 720; 1000 Hz for resistance measurements between the electrodes across the hydration stages of setting and hardening. The hydration of cement pastes were stopped after 24 h of hydration by grinding in acetone-methanol mixture as described elsewhere [12]. The phase composition was performed by using the differential scanning meter (DSC-50).

2. Results and discussion

The electrical conductivity-time curves obtained for the various blended cement pastes show common characteristics with an initial increase, after mixing with water, followed by a gradual decrease during the initial stage of hydration leading to first peak. Later, the electrical conductivity increases, reaching a second peak, followed by a sharp decrease. The increase of electrical conductivity in the initial stage of hydration is due to the increase of ionic concentration and mobility of ions (Ca^{2+}, OH^-, $SO4^{2-}$, Na^+, and K^+), but the increase of electrical conductivity in the second peak is due to the ettringite transformation into the monosulfate hydrate as well as the osmotic pressure development around cement grains [5]. The gradual decrease in electrical conductivity after the first peak may be due to the formation of a thin layer from cement gel around the cement grains. These thin layers consist of an electrical double layer of adsorbed calcium ions and counter ions, as well as the formation of cement hydrates. The sharp decrease in electrical conductivity at the later stage of hydration is due to the formation and later accumulation of cement hydrates, resulting in a marked consumption of the number of ions. The paste at this stage suffers from an intense crystal formation accompanied by crystal bonding formation with a strong crystalline network. The ions in free water find a more tortuous way to drift through the capillary pores in the paste.

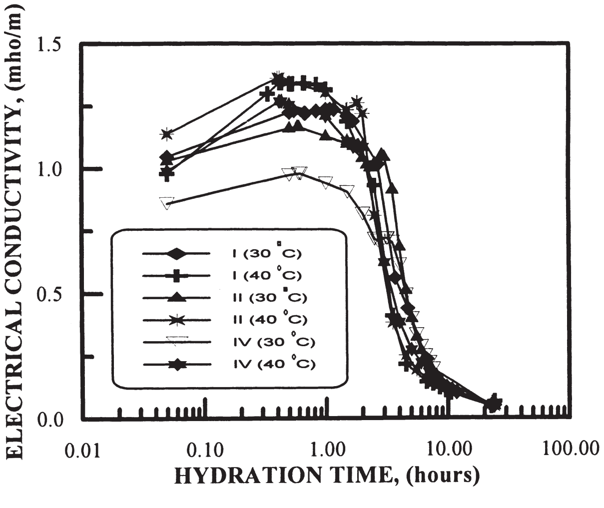

Fig. 1. Electrical conductivity of cement pastes containing silica fume.

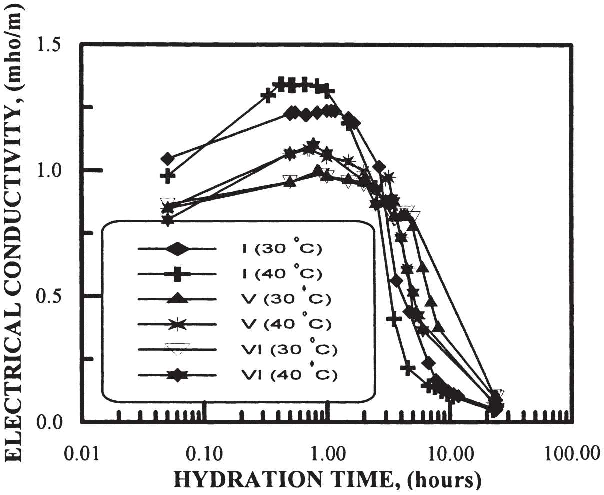

Fig. 2. Electrical conductivity of cement pastes containing slag.

Figs. 1 and 2 illustrate the effect of temperature on electrical conductivity of OPC pastes containing silica fume and slag, respectively. It is clear that the electrical conductivity increases with an increase of hydration temperature as well as decreases with increases of silica fume and slag contents.

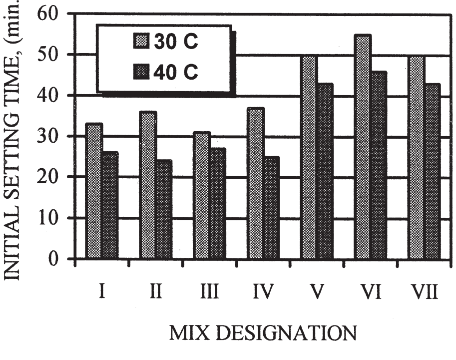

Fig. 3. Effect of curing temperature on initial setting times of blended cement pastes.

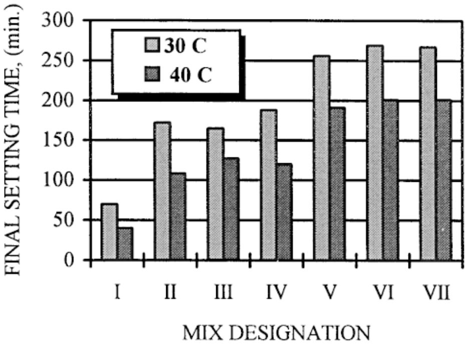

Fig. 4. Effect of curing temperature on final setting times of blended cement pastes.

This may be due to the increase in the mobility and concentration of ions (hydrolysis) corresponding with the increase of curing temperature. Obviously, the higher replacements of OPC by silica fume and slag reduce the hydration processes due to the decrease of cement content (C_3S), which is responsible for early stiffening.

Figs. 3 and 4 show the effect of hydration temperatures on the initial and final setting times of cement pastes containing silica fume and slag, respectively. The general trend in the results indicates that both the initial and final setting times increase as the silica fume and slag contents increase at all curing temperatures. This is expected, because microsilica replaces part of the OPC, thus increasing the early stiffening potential and mixing water. The retardation of setting is attributed primarily to the decrease in the cement content (C_3S), which is responsible for early stiffening. Evidently, the initial and final setting times decrease as the curing temperatures increase. This may be due to the increased rate of hydration with temperature, particularly at early ages. The degree of hydration is controlled by the density and thickness of the calcium silicate hydrate layer around the cement grains. This layer retards hydration and, when it attains a certain thickness, it prevents further hydration during the later ages.

Fig. 5 illustrates the DSC thermograms of blended cement pastes containing slag, cured for 24 h at 40°C. Evidently, there were almost five endothermic peaks in all thermograms. The first peak located at about 110°C is mainly due to the decomposition of calcium silicate hydrates, mainly as CSH-(I). The second endothermic peak observed at about 160°C represents the decomposition of the calcium silicate hydrates, mainly as CSH-(II). The third endothermic peak located at about 470°C represents the decomposition of calcium hydroxide (CH).

The last endotherms peaks appearing at about 670°C and 720°C represent the decomposition of amorphous and crystalline calcium carbonate ($CaCO_3$), respectively. The mean features of the thermograms are characterized by a decrease of the enthalpy of $Ca(OH)_2$ phase from 440 to 300 mJ and the increase of enthalpy of CSH-(I) from 160 to 260 mJ as the slag content increases from 0 to 40%. This result is mainly attributed to the further hydration reaction between slag and the calcium hydroxide. The enthalpy of calcium carbonate phase decreases from 58 to 45 mJ as the slag increases from 0 to 45%. Therefore, slag replacement of OPC results in an increase of the resistance of the hardened cement pastes to carbon dioxide attack.

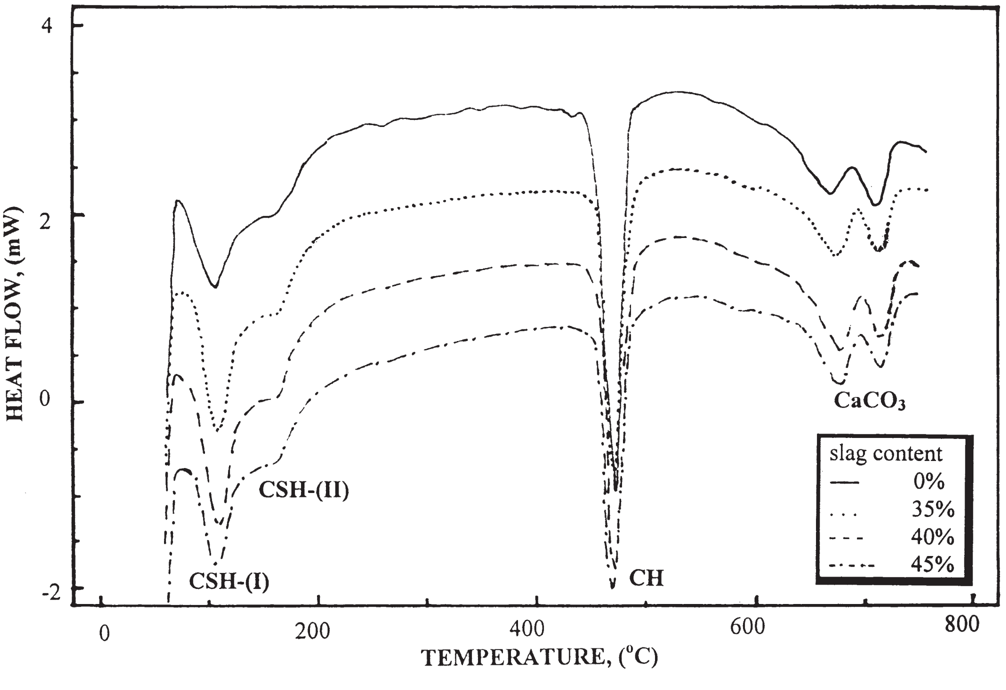

Fig. 5. DSC thermograms of cement pastes containing slag after 24 h of hydration at 40°C.

3. Conclusions

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

1. Electrical conductivity is an accurate and reproducible method that yields important information on some physicochemical changes taking place during cement hydration, especially during the early stages of hydration.
2. High curing temperature accelerates the setting of cement pastes for all mixes.
3. The use of silica fume and slag as a partial replacement decelerates, in general, the setting of the pastes; the higher the replacement level, the greater the effect.

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