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Electrical conductivity and phase composition of calcium aluminate cement containing air-cooled and water-cooled slag at 20, 40 and 60 °C

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Abstract

Calcium aluminate cement (CAC) pastes containing Egyptian air-cooled slag (AS) or water-cooled slag (WS) were prepared using different amounts of slag, namely, 5, 10, 15, 20 and 25 mass%. The pastes were prepared with deionized water using the required water of standard consistency to produce normal workability. The variations of electrical conductivity with the hydration time were measured at 20, 40 and 60 °C. The results demonstrate that electrical conductivity is a useful technique to study the change in the phase composition at different temperatures during the setting and hardening of calcium aluminate cement as well as reflecting the role of AS and WS, preventing the conversion occurring during the CAC hydration.

Keywords: Calcium aluminate cement; Air-cooled slag; Water-cooled slag; Temperature; Electrical properties and microstructure

1. Introduction

Calcium aluminate cement (CAC) is very resistant to chemical attack and high temperatures. The temperature at which hydrates are formed is important in the hydration of CAC. Different hydration products are created, i.e., CAH_{10}, C_2AH_8 and C_3AH_6, depending on the temperature at which the process takes place. The conversion of hexagonal phases (CAH_{10} or C_2AH_8) to C_3AH_6 and AH_3 in the hydration of CAC under certain temperature conditions has been a major problem, limiting its use as a structural material. This conversion reduces the strength development of CAC.

Pure gehlenite does not seem to react with water, but the phase present in CAC contains other oxides in solid solution, and there is evidence that it is more reactive [1]. The presence of gehlenite hydrate (C_2ASH_8), also called stratlingite, in CAC pastes has been studied [2,3]. Stratlingite is an Afm phase closely related to C_2AH_8; it is stable relative to hydrogarnet at ambient temperature. The formation of stratlingite prevents the conversion of the hydration products of CAC [4]. It has also been shown that stratlingite forms as a stable phase in the temperature range of 20–70 °C [5]. It was reported that, in CAC-blends containing 30–50 mass% silica fume, stratlingite is the dominant hydration product after 1 week at 40 °C or below, but at higher temperatures, C_3AH_6 is already formed after 1 day. Microsilica and granulated blast-furnace slag can react with CAC in the presence of water, resulting in the formation of stratlingite [6,7]. Fentiman et al. [8] found that stratlingite was formed as the dominant hydrate when hydration occurs at 40 °C or above in mixtures containing around 50 mass% slag. At early ages, the strengths of 50:50 CAC/slag mixtures are lower than that of CAC alone. However, the blends show continuous increase in strength up to 2 years without a minimum in strength associated as a result of the conversion process.

Electrical conductivity and pH measurements conducted on dilute cement suspensions as a function of time indicated that the hydration of CAC is a dissolution and precipitation process [9–11]. Classical techniques such as XRD, DTA and SEM and advanced techniques (ultrasonic velocity, acoustic emission monitoring) were used to give informa-

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Table 1
Chemical analysis of the starting materials, (mass%)

Oxides	CAC	AS	WS
SiO_2	4.59	32.69	37.21
Al_2O_3	53.68	8.17	10.45
Fe_2O_3	1.24	1.89	1.27
CaO	35.52	33.57	35.70
MgO	n.d.	1.35	2.05
SO_3	n.d.	0.01	0.15
L.O.I	n.d.	–	–
K_2O	n.d.	0.43	0.71
Na_2O	n.d.	1.47	1.60
TiO_2	2.92	0.46	0.35
MnO	Nill	4.48	3.50
BaO	–	6.63	3.11
S^-	Nill	0.01	3.62
Blaine surface area, cm^2/g	3500	3500	3200

tion about the morphology and phase composition of the formed hydrates [12,13].

Cement containing water-cooled slag (WS) has long been used in Egypt. However, there are many other unexploited slag by-products such as air-cooled blast furnace slag (BFS) and steel-making slag. The feasibility of utilizing these types of slags with cement has been ignored due to the judgment that air-cooled slag (AS) is hydraulically unreactive. Consequently, little of these materials is used, or their use is limited to low-value applications. A comparative study of the hydraulic reactivity of AS and WS produced from the same blast furnace and the same raw materials has been conducted [14]. Although the reactivity of AS is lower than WS at room temperature, it can still be exploited as a hydraulic material. Even, if these slags cannot fulfill the requirements of the standard specifications for blended cements, their hydraulic activities can be exploited in building materials such as autoclaved products or bricks. The latter may be an economical alternative for developing countries inasmuch as little technology is required.

The aim of this research work is to study the methods by which each type of slag mixed with calcium aluminate cement can be evaluated at 20, 40 and 60 °C curing temperatures. In the present study, electrical conductivity technique was used for monitoring the changes occurring during the initial setting from zero time (3 min) up to 7 days (10080 min) as well as for assessing the hydraulic activity of AS in comparison with WS. This investigation was carried out using pastes to correlate the physicochemical and microstructure characteristics of the hydration products which are formed.

Table 2
Mix compositions and the required water for normal consistency of CAC/slag blends

	CAC	AS	WS	Water of consistency, %
M.0	100	0	–	25.5
M.5	95	5	–	24.9
M.10	90	10	–	24.5
M.15	85	15	–	24.3
M.20	80	20	–	24.0
M.25	75	25	–	23.8
C.5	95	–	5	25.2
C.10	90	–	10	24.9
C.15	85	–	15	24.6
C.20	80	–	20	24.3
C.25	75	–	25	24.0

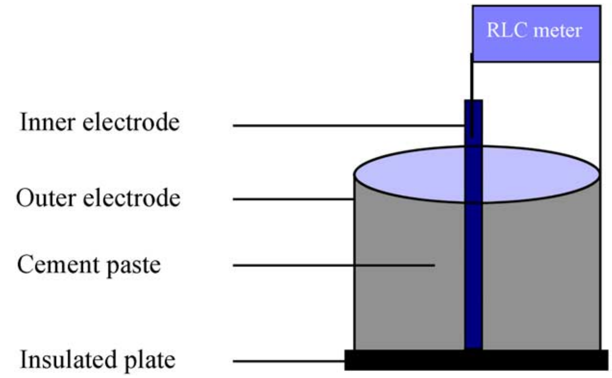

Fig. 1. Electrical conductivity cell.

2. Experimental techniques

The materials used in this investigation were calcium aluminate cement, Egyptian air-cooled and water-cooled slags provided by the Iron and Steel Company, Helwan, Egypt. The chemical composition of these raw materials is given in Table 1. XRD pattern of air-cooled slag reveals the presence of gehlenite (C_2AS) and quartz. The quartz may be contamination during the cooling process of molten slag. The water-cooled slag shows a hump existing between 20°–35°, indicating the presence of amorphous glassy phase. The mix proportions are shown in Table 2. Each blend was mixed in a porcelain ball mill with four balls for 1 h to

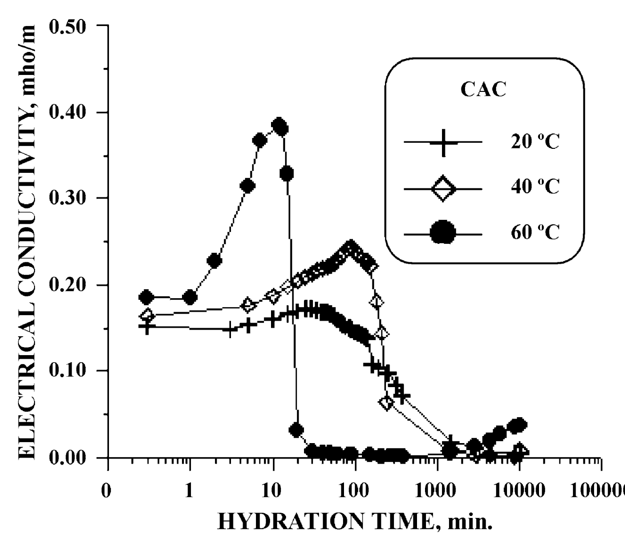

Fig. 2. Electrical conductivity of CAC at different temperatures.