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Hydration characteristics of Portland cement – Electric arc furnace slag blends

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Abstract Utilization of electric arc furnace slag (EAF slag) as blending material for Portland cement has been examined. This was done via the investigation of the hydration characteristic of EAF slag – Portland cement blended mixtures. Various ratios of EAF slag were used namely; 5, 10 and 20 wt% of solid mix. The hydration properties investigated for the various mixtures were; compressive strength, chemically combined water and free lime contents as a function of hydration times. The hydration ages were; 1, 3, 7, 28 and 90 days. In addition, phase composition of the formed hydrates was examined using XRD technique as well as differential thermal analysis (DTA) for some selected samples. The results showed that as the ratio of EAF slag increases the values of compressive strength decrease at all the hydration ages. Hydration kinetics of the investigated mixes was followed by determining the variation of free lime and chemically combined water contents with time of hydration. It was observed that hydration proceeds in four different stages. The values of chemically combined water of the cement pastes blended with EAF slag were less than those of the neat Portland cement paste at all hydration ages. The mode of variation of free lime content with time was nearly similar to that of combined water content. The results of chemically combined water, free lime, XRD analysis as well as thermal analysis were correlated well with those of compressive strength. All these results indicate that the used EAF slag has no significant pozzolanic reactivity.

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Introduction

Slag in general is a byproduct of various metals extraction and refining processes. In the specific case of making steels, the slag is generated at 3 different stages of processing and accordingly classified as: blast furnace slag, electric arc furnace slag and ladle slag [1]. It is well known that technical, economical and

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many environmental benefits are obtained from using alternative construction materials [1–2]. Since the Kyoto Protocol entered into force on February 2005, 35 countries have the obligation of reducing their gaseous emissions between 2008 and 2012 in order to achieve a target of greenhouse effect gas emissions of 8% reduction (CO_2, methane, nitrous oxide, etc.), including CO_2 which represents 80% of the total harmful gases.

Construction is one of the most affected industrial sectors because of its relationship with cement and concrete industries. The environmental regulations, that increase their severity day by day, have made these industries to put in a great effort to reduce their pollution, that is mainly caused by the process of calcite decarbonation that leads to the formation of about 480 kg of CO_2/ton of clinker.

Looking for a reduction of atmospheric contamination, has been and is the cause of looking for new complementary and alternative building materials to substitute traditional ones, this being a priority research line [3,4]. The building sector by their characteristics has enough capacity to recycle large volumes of by-products and wastes generated in different industrial activities, like silica fume, fly ash or blast furnace slag and electric arc furnace slags [5,6].

Several studies have been made to examine the characteristics of EAF oxidizing slag with respect to its application in the construction industry, in particular of its attributes as a material [7,8], its potential expansiveness [9] and its chemical reactivity [10]. The possibility of EAF slag being used satisfactorily in concrete has been demonstrated [11,12]. The principal problems in this field remain the durability of this type of concrete [13,14] and its environmental tolerance [15]. Correctly manufactured EAF slag concrete has good mechanical properties, and its high density is an advantageous property where weight is a key factor, in such constructions as breakwater blocks, foundations, shoring walls, noise barriers, and radiation insulators, among others.

A detailed study has been reported to define and analyze the properties of EAF oxidizing slag, its performance as an aggregate, and the attributes of the concrete in which it is a component [16]. The manufacturing process and results related to the physical and mechanical properties of this type of concrete have also been presented [17].

In the present paper, a further aspect is examined to evaluate the addition of EAF slag to Ordinary Portland cement for producing cement containing an industrial waste with the same specification and more environmental friendly products.

Materials and experimental

Materials

EAF slag

The EAF Slag used in this study was supplied from Ezz Flat Steel Company, Egypt, its chemical composition is shown in Table 1.

Ordinary Portland cement (OPC)

OPC was supplied from Suez Cement Company, Egypt, with a Blaine surface area of 2945 $cm^2\ g^{-1}$; its chemical oxide composition is given in Table 2.

Table 1 EAF slag chemical oxide composition, wt%.

Oxides	CaO	SiO_2	AL_2O_3	Fe_2O_3	MgO	SO_3
	33	13.1	5.51	36.8	5.03	0.14
Oxides	K_2O	P_2O_3	Cr_2o_3	Mn_2O_3	TiO_2	LOI
	–	0.7	0.8	4.18	0.6	–

Table 2 OPC chemical oxide composition, wt%.

Oxides	CaO	SiO_2	AL_2O_3	Fe_2O_3	MgO	SO_3
	61.28	20.46	5.14	3.53	2.80	2.82
Oxides	K_2O	P_2O_3	$Cr_2\ O_3$	Mn2O3	TiO_2	LOI
	0.11	0.20	0.060	0.11	0.33	3.15

Experimental

Different pozzolanic cement pastes were prepared from different OPC–EAF Slag dry mixes. Table 3 shows the mix composition of the different mixes and their designations. Each dry cement blend was mechanically mixed in a porcelain ball mill for 1 h to ascertain complete homogeneity of the mix. Each paste was prepared by mixing the dry mix with the required amount of water, using the same water/solid (W/S) ratio of 0.50, for about 3 min continuously. After complete mixing, the resultant fresh paste was molded into cubic specimens by using one inch cubic molds. The molds, containing the pastes, were cured at about 100% relative humidity for 24 h to attain the final setting, and then, the cubic specimens were demolded and cured under water at room temperature for different time intervals of 3, 7, 28, and 90 days.

Compressive strength

At each time interval, compressive strength tests were performed on the hardened pozzolanic cement pastes using three cubic specimens at each hydration time, and the average value was recorded as $kg\ cm^{-2}$, This was performed using a Ton-industric machine (West Germany) for maximum load of 60 tons.

Stopping of hydration

The resulting crushed specimens of the hardened cement pastes, after measuring compressive strength were ground, and the hydration reaction was stopped using the method described in an earlier publication [18]. The samples were then dried at 90 °C for 3 h. In CO^2-free atmosphere and maintained

Table 3 Mix composition of EAF slag – OPC mixes, wt%.

Mix No.	EAF slag%	OPC%
Mix.0	0	100
Mix.1	5	95
Mix.2	10	90
Mix.3	20	80