Cement and Concrete Research 41 (2011) 865–571

Contents lists available at ScienceDirect

Cement and Concrete Research

journal homepage: http://ees.elsevier.com/CEMCON/default.asp

Influence of mineralogy on the hydraulic properties of ladle slag

Daniel Adolfsson [a,*], Ryan Robinson [b], Fredrik Engström [b], Bo Björkman [b]

[a] SSAB Merox SE-61380 Oxelösund, Sweden
[b] Luleå University of Technology Department of Civil, Environmental and Natural Resources Engineering Division of Sustainable Process Engineering, SE-97187 Luleå, Sweden

ARTICLE INFO

Article history:
Received 3 August 2010
Accepted 15 April 2011

Keywords:
Calcium aluminate cement (D)
Calorimetry (A)
Hydration (A)
Ladle furnace slag

ABSTRACT

The present study is aimed at investigating the hydraulic characteristics of ladle furnace slag (LFS), under the pretence of using LFS as a cement substitute in certain applications. Furthermore, LFS has been considered as a possible activator in a blend containing 50% LFS, and 50% ground granulated blast furnace slag (GGBFS). Phases detected in LFS were quantified using Rietveld analysis. Calorimetric studies were performed at 20, 25 and 30 °C in order to calculate the apparent activation energy of hydration and thereby to suggest a kinetic model for the tested compositions within this temperature interval. In addition, compressive strength tests were performed on mortar prisms made with LFS, and LFS/GGBFS which had hydrated for 2, 7 and 28 days. Both compositions reached acceptable early strengths, (e.g. LFS, 33.1 MPa, and LFS/GGBFS, 17.9 MPa, after 2 days), but after 28 days hydration the blend was superior to neat LFS. Related apparent activation energies were determined using an Avrami–Erofeev model and gave $E_a = 58$ kJ/mol for neat LFS and $E_a = 63$ kJ/mol for the blend. The results imply that LFS or a LFS/GGBFS blend can be favourably used as supplement in binder applications such as binder in by-product metallurgical briquettes, which are used as recycle to the blast furnace or basic oxygen furnace depending on the specific briquette composition.

1. Introduction

SSAB EMEA is a producer of high strength steels, and the main types of metallurgical slags that are produced in parallel to the production of steel are blast furnace slag (BFS), basic oxygen furnace slag (BOS) as well as ladle furnace slag (LFS), from the secondary ladle metallurgy. Different combinations of slag formers used in each of the aforementioned operation units are an important reason as to why the mineralogical composition is considerably different in each case. Ground granulated blast furnace slag (GGBFS) produced within SSAB EMEA is very amorphous, i.e. 98% glass content, due to granulation with water. GGBFS is latently hydraulic and requires activation, which is why ordinary Portland cement (OPC) is added. LFS and BOS are crystalline in character since these materials are slowly cooled at ambient temperature in the slag yard. An important difference between LFS and BOS is the high content of calcium aluminates, which are present in the LFS type of slag. Typical minerals found in the BOS are dicalcium silicate, dicalcium ferrite, manganese and magnesia analogues of wuestite as well as free lime. The refining of steel from which the LFS originates includes different process techniques depending on the steel grade. The treatment is generally associated with parameters such as deoxidation, removal of inclusions, addition of alloying elements, desulphurisation, and temperature control of the steel bath, etc. For these reasons, the chemical composition of LFS may vary, but the mineralogical composition can remain relatively stable. The main oxides are CaO, Al_2O_3, SiO_2 and MgO, but the content of MnO can also reach significant levels depending on the steel grade produced. The use of aluminium as a deoxidation agent contributes to the formation of calcium aluminates like mayenite ($C_{12}A_7$), and tricalcium aluminate (C_3A) in the solidified slag. It is generally accepted that calcium aluminates are highly hydraulic, and react very quickly with water, especially mayenite [1]. The hydration of different calcium aluminates in water results in the formation of hydrates such as C_2AH_8, C_4AH_{13}, CAH_{10}, and C_3AH_6, [2], which give strength to the material. Among these hydrates, only C_3AH_6 is thermodynamically stable [3]. Consequently, all the other hydrates eventually convert to C_3AH_6 as a final product and the conversion process can adversely affect the final strength of the material.

Although some studies on the hydraulic potential of LFS have been completed, they are comparatively limited. Recently, Setién et al. [4] characterised ladle slag for use as a construction material. Mineralogical analysis detected crystalline phases such as $C_{12}A_7$, C_3A, and polymorphs of C_2S, among others. It was further suggested that LFS can be recycled in construction and civil engineering applications. It was also concluded, however, that presence of free periclase and carbonation enables volumetric changes which should be considered carefully before the material is used in any application. LFS has also been assessed as raw material for the production of sulphoaluminate belite cement (SAB) [5]. Different mixtures of slag as well as neat LFS were fired at 1200 °C, after which the quenched SAB clinker was characterised, and the hydraulic properties evaluated. It was concluded that steelmaking slags as well as

* Corresponding author. Tel.: +46 155 25 59 62; fax: +46 155 25 58 44.
E-mail address: daniel.adolfsson@ssab.com (D. Adolfsson).

0008-8846/$ – see front matter
doi:10.1016/j.cemconres.2011.04.003