Construction and Building Materials 95 (2015) 197–206

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Design of masonry mortars fabricated concurrently with different steel slag aggregates

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HIGHLIGHTS

- The simultaneous application of different slag in mortar as fines is presented.
- The mixtures reached are suitable to produce masonry materials with a standard strength.
- Properties of the mortar change in accordance with the degree of substitution of sand by steel fines.
- Microstructural characterisation show good distribution between all of its components.

ARTICLE INFO

Article history:
Received 1 June 2015
Received in revised form 13 July 2015
Accepted 15 July 2015
Available online 20 July 2015

Keywords:
Slag
Masonry mortar
Physical properties
Mechanical strength

ABSTRACT

The simultaneous application of electric arc furnace slag and ladle furnace white slag, in substitution of natural fine aggregate in masonry mortars, is presented with the principal objective of achieving mixes that show a similar performance to conventional mortars. Materials dosed with steel slag fines at different levels of substitution (25%, 50%, 75% and 100%) were designed, employing commercial admixtures in the samples. A comparative study of the most significant mortar properties is conducted, such as workability, adhesiveness, water retentivity and mechanical strength, between the mortars prepared with natural fine aggregate and those manufactured with additions of slag. The results indicate that technically viable mortars may be obtained for their use in construction and building, which thereby achieve the reuse and valorization of waste products that would otherwise be disposed of in landfill sites.

1. Introduction

The obtaining of pig iron and steel industry generates significant amounts of waste in the form of different slags, the use of which can be advantageous in construction, because of their physical–chemical characteristics [1–2].

Global brute production of steel in 2013 was 1606 millions of MT of which 72% was produced in Blast Furnaces (BF) and 28% in Electric Arc Furnaces Slag (EAFS). In 2014, 60% of all steel produced in Europe was in BF and 40% was in EAF [3].

However, the steel industry in Spain is practically based on the reuse of scrap obtained from the process of recycling waste materials, as well as from waste generated in the processes of transformation, in such a way that 75% of steel production is extracted from Electric Arc Furnaces (EAF). This study therefore centres on finding alternative ways of using the waste generated in these types of processes, as at present, around 23% of all slag are disposed of in landfill sites [4].

These slags, because of their properties, imply a potential opportunity to generate resources for their use as recycled material, especially in construction and civil works where the consumption of raw materials is important. It may be used as a coarse aggregate to be used as gravel in the manufacture of concretes [5], with good behaviour against durability tests [6] and in surfacing layers [7].

The characteristics of white LFS slags and their chemical compositions differ from those of black EAFS depending on the conditions and steel production techniques, as well as the scrap employed as a raw material [8].

These wastes may be employed in substitution of cement in commercial mortars, due to the latent hydraulic properties present in white slags performing well in accelerated ageing [9–10]. Equally, the slags can be used in the manufacture of self-compacting concretes reinforced with steel fibres [11], in solid stabilization [12] as a corrector of agricultural soils and in the construction of embankments [13].

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http://dx.doi.org/10.1016/j.conbuildmat.2015.07.164
0950-0618/

Table 1
Chemical composition of raw materials (%). Analysis by X-ray fluorescence spectrometry and X-ray diffraction.

	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	TiO_2	Na_2O	K_2O	MnO	P_2O_5
Cement*	4.0	21.3	60.4	6.1	1.5	–	0.4	1.5	–	1.5
Sand	0.06	98.4	0.03	0.9	–	0.02	–	0.57	0.02	–
EAFS	26.35	23.9	27.7	13.1	3.2	0.68	–	0.01	4.6	0.46
LFS	3.21	19.25	58.75	8.53	9.81	0.34	0.07	–		0.04

EAFS Phase	EAFS Estimated concentration	LFS Phase	LFS Estimated concentration
$Ca_2Al(AlSiO_7)$	High	Ca_2SiO_4	Medium
Fe_3O_4 – Magnetite	Low-medium	$(CaO)_5\ (Al_2O_3)_3$	Residual
FeO – Westite	Low	$CaCO_3$ – Calcite	High
		$Ca(OH)_2$ – Portlandite	High
		MgO – Periclasa	Low

* To add a 2% of loss on ignition at the final percentage is required.

This work develops another way of jointly valuing these types of wastes (EAFS and LFS), as steel fine aggregate in the manufacture of masonry mortars, with the aim of achieving mixtures with equivalent performances to those of conventional mortars.

2. Experimental

2.1. Raw materials

2.1.1. Cement

A Portland cement with a density of 3150 kg/m^3 type CEM I 42.5 R was used, as per standard EN 197-1 [14], free from additions, that develops its initial strength at an early age. The chosen cement is acceptable for the preparation of masonry mortar as it attains a high strength at 28 days, without excessive hydration heat, reducing the risk of possible cracking due to plastic shrinkage of the test mortars. Its chemical composition is shown in Table 1.

2.1.2. Natural aggregates

– *Siliceous sand* from a sedimentary bed referred to as "Rounded siliceous sand 0/2 mm" with a real density of 2600 kg/m^3.

– *Limestone filler* composed of calcium carbonate ($CaCO_3$), with a density of 2700 kg/m^3. This aggregate has over 70% of particle diameter with less than 0.063 mm.

2.1.3. Steel slag fines

Prior to its assessment as a steel slag fine, it is necessary to ensure volumetric stability by means of crushing, milling and subsequent homogenisation of the material, extending it over the ground for thorough weathering [15]. The metallic particles were removed from both slags with an electromagnetic sorter.

– *Electric-arc furnace oxidising slag (EAFS)* extracted from an EAF. Prior to its use, the slag was triturated and sieved and then washed to eliminate waste powder adhering to the grains, sieving the fraction used by means of an automatic siever. The slag appearance is a whitish–greyish, pulverulent, dusty mineral aggregate. The real density of the particles was 3645 kg/m^3. After washed treatment, the chemical composition of black EAFS is shown in Table 1 and mainly contains iron, calcium, silica and aluminium oxides, and other minority components such as MgO and MnO. Scanning electron microscopy (SEM) images of the black slag are shown in Fig. 1. They are formed by particles of between 2 and 20 µm. They contain discontinuous crystalline aggregates formed by hydration during weathering of the calcium oxides and magnesium oxides present in the slag. Their appearance is disaggregated and they present significant surface porosity.

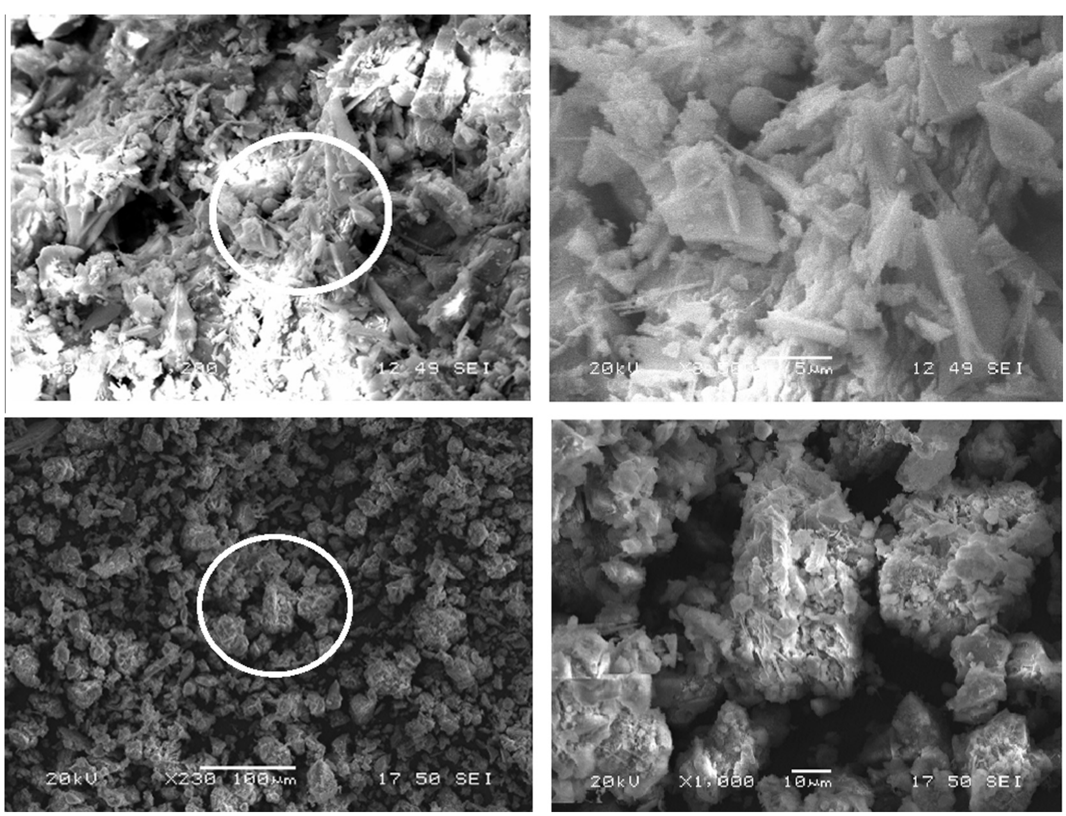

Fig. 1. SEM of furnace slag by secondary electron mode. Top: Electric-arc furnace oxidising slag (EAFS). Bottom: Ladle furnace slag (LFS).