Case study

Steel scale waste as component in mortars production: An experimental study

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A B S T R A C T

The present research reports on the results of some experiments dealing with the recycling of steel scale waste in the production of mortars. Materials were prepared mixing a commercial CEMII/B-LL cement, a steel scale waste, a commercial natural aggregate, superplasticizer and water. Natural aggregate was replaced with different proportions (5, 10, 20, 30 and 40 wt%) of steel scale waste. Water absorption, apparent density, compression strength and thermal conductivity were measured after 28 d of curing. After curing, all hydrated materials displayed: good compressive strength and low water absorption; increased apparent density with steel scale addition; improvement of thermal conductivity in materials containing up to 10 wt% steel scale addition.

1. Introduction

Industry development, population growth and the rising of consumerism have produced a rapid increase in the production of waste materials. It would be desirable to reduce waste disposal and promote recycling of waste as raw materials for other productions whenever it is possible. A large part of solid waste is produced by iron and steel industries so, if they are not properly disposed, they might damage environment and consequently have influence on human health.

Steel scale waste (SSW), a by-product of steel production, is formed on the surface of steel monoliths during their high temperature thermal treatments after casting; SSW mainly contains iron oxides and a minor fractions of other oxides as function of steel composition. This type of waste, generally known as "calamine", is presently mainly disposed of to landfill or used to prepare counterweights concretes, due to the higher specific gravity of calamine with respect to that of all the other components that are generally used to prepare ordinary mortars or concretes.

The use of many industrial waste in concretes and/or mortars production could by-pass the problem of their landfill disposal and, at the same time, promote the production of sustainable building materials [4]. Alwaeli and Nadziakiewicz [1] proposed scale and steel chips waste as a partial replacement of sand in concrete while Takeda et al. [20] studied the physical properties of iron-oxide scales.

In the present research, mortars were produced using a fixed ratio of cement/aggregate (c/a = 1/3), as it has been often proposed in literature by other authors [17,19], whereas SSW was previously milled and transformed into a powdered product and then added in different proportions to replace part or at least all of the fine fraction of the natural aggregate.

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The aim of this study is to evaluate if the addition of SSW enables to improve some properties of the hydrated mortars without paying an exaggerated cost in terms of mechanical performances or workability of the fresh pastes with respect to a reference blank composition. We also aim to demonstrate that specific gravity and thermal conductivity of the SSW containing mortars are improved with respect to the reference composition.

2. Materials and methods

The starting materials used were: a CEM II/B-LL cement, a natural aggregate with maximum particle dimension of 4.76 mm, Blaine fineness of 3480 cm^2 g^{-1} (EN 933-2), density of 2.46 g cm^{-3} and water absorption 0.37% (the measurement was carried out following the ASTM C127 and C128 norms) [13] which were mixed with different proportions of powdered SSW. The as received SSW was transformed into a powder by milling and then sieved though 1 mm, 500 μm and 200 μm sieves. The three parts of powdered steel scale were collected separately, but re-blended in such proportions as to approximate the equivalent particle size distribution of the replaced natural aggregate. In line with our previous works dealing with the production of cement based materials [13,14], the Glenium 51 (BASF) superplasticizer was also used for mortars preparation. The required amount of water was added to each starting blend. The chemical analysis of cement, natural aggregate and SSW, determined by a Spectro Mass 2000 ICP mass spectrometer is reported, in terms of oxides, in Table 1 which also displays loss on ignition (LOI), obtained after thermal treatment at 1000 °C for 2 h; "undetermined" refers to the cumulative quantity of all oxides determined in quantity lower than 0.1 wt%.

The particle size distribution (PSD) of the fine fraction of the aggregate, that of CEM II/B-LL and the one of the powdered SSW was investigated by a Horiba LA950 laser scattering PSD analyzer. Analyses were made in water after a 3 min sonication and PSD curves are represented with logarithmic abscissa. In order to access the PSD of the aggregate's fine fraction, the total as received product was sieved (1000 μm) and fines were separated from coarse particles.

The crystalline phases of starting components as well as those of the hydrated materials were investigated by X-ray diffraction (XRD). XRD patterns were recorded on a Philips X'Pert Pro Detector X'celerator operating at 40 kV and 40 mA using Ni-filtered Cu-Kα radiation. Spectra were collected using a step size of 0.02° and a counting time of 40 s per angular abscissa in the range of 20–80°. Philips X'Pert High Score software was used for phase identification and semi-quantitative analysis (RIR method) [8]. In order to identify geometric shape and eventual porosity of the SSW particles, powders were examined by an Hitachi Tabletop Microscope TM3030.

The ratio between cement and aggregate quantity (natural aggregate plus SSW) was set at 1/3 in order to produce mortars with good workability and high compression strength, in line with the UNI EN 206-1, as it was previously proposed by other authors [17,19]. Some reference SSW free compositions, hereafter called R, containing cement, natural aggregate, superplasticizer and an optimized amount of water were also prepared as blank samples in order to compare the mechanical behavior, after hydration, of the materials produced, bearing in mind that the focus of the present research regards the production of materials obtained by replacing part of the natural aggregate with an equivalent mass of 5, 10, 20, 30 and 40 wt % of milled and sieved SSW. Samples with symbolic names, corresponding aggregate composition, s/c and water/cement (w/ c) ratios are reported in Table 2.

For the mixture preparation and w/c optimization a 5 L Hobart planetary conforming to ASTM C305 standards was used. The optimized amount of water was determined by the ASTM C1437 slump test performed on the reference blend R. The paste is said to have the right workability if the cake width is 150 (±20) mm according to UNI 7044:1972 and ASTM C230

Table 1
Chemical composition of the starting materials.

Component	Cement (wt%)	Aggregate (wt%)	SSW (wt%)
SiO$_2$	18.11	1.98	–
Al$_2$O$_3$	4.25	1.72	0.15
CaO	61.24	46.73	–
MgO	2.53	19.83	–
Na$_2$O	0.23	1.43	–
K$_2$O	1.10	0.74	–
FeO	–	–	96.31[b]
Fe$_2$O$_3$	3.19	2.1	–
TiO$_2$	0.34	–	0.47
MnO	0.56	–	1.55
Cr$_2$O$_3$	–	–	0.95
CuO	0.12	–	–
SO$^{4=}$	2.88	–	–
Cl$^-$	0.71	–	–
C (organic)	2.08	0.57	–
Undetermined	2.49	1.92	0.57
LOI (%)	8.24	23.55	[a]
Density (g cm^{-3})	3.08	2.46	5.65

[a] As a consequence of the thermal treatment at 1000 °C, FeO and Fe$_3$O$_4$ oxidize to Fe$_2$O$_3$.
[b] Iron is reported as FeO even if the presence of Fe$_3$O$_4$ has been detected by the XRD analysis.