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White Ordinary Portland Cement blended with superfine steel dust with high zinc oxide contents

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ABSTRACT

The addition of steel waste in the form of slags and dust to cement is beneficial to the environment because waste can be immobilized, and thus, decreasing the waters contamination. In this paper, paste and mortar-based Portland cement samples with up to 70.0 wt% of steel dust were investigated. Since it is known that for one ton of Portland cement fabricated 900 kg of CO_2 are emitted to the environment, the addition of steel waste to cement is very beneficial. Moreover, since steel dust reduces the amount of needed cement in concrete, it reduces the final cost of concrete significantly. Additionally, the manufacturing processing was conducted entirely at room temperature; therefore, the negative impact of cement in the environment is reduced.

Scanning electron microscopy and X-ray diffraction characterization were conducted in order to investigate the microstructure of the samples. In addition, compression, density, and flow table tests were done over all samples. Thermo-gravimetric tests were performed to analyze the waste thermal stability. The effect of the potential hazardous components of this waste in water was analyzed through leachability tests. For all samples, compressive strength ranged from 73 to 2.5 MPa. The lowest strength value corresponded to 70 wt% of waste. Results show a solution for using this waste as admixture in cements and concrete, and therefore as a method for reducing cement paste in buildings and infrastructure.

1. Introduction

The utilization of diverse forms of hazardous wastes in new materials, or recycling of them into the original components is a critical factor in the sustainability of our planet [1]. Competitive industrialization and stronger regulations are now forcing companies around the world to have zero waste. Metallurgical wastes are among those with the most negative impact on the environment by the dumping of tons of wastes per year, which contain hazardous metals and compounds [2]. Among them, steel slag is substantially concerning nowadays due to the amount generated worldwide; e.g., more than fifty million tons per year of steel slag are produced as waste material in the world [2]. Steel slag is a by-product of the conversion of iron to steel process [3]. Because of its variations in the chemical composition, its properties can vary depending on the raw materials and manufacturing process. Slag usually is classified from either the conversion process of iron to steel in a basic oxygen furnace (BOF), or the melting of scrap to fabricate steel in an electric arc furnace (EAF) [4].

Metallurgical wastes such as steel slag and dust wastes are an international issue because steel consumption is increasing around the world. Since cement and concrete are the most widespread used material of the planet, and it is well known that for a ton of cement, about 1 ton of CO_2 is released to the environment. Therefore, the use of steel slag as concrete admixture, as filler or as raw material for concrete production, represent an important beneficial manufacturing process for our environment. Taken this into the account, it has been given little attention to the use of steel slag in the production of Portland cement and concrete [5]. Therefore, more research is needed and developments that utilize different steel slag formulations.

Steel slag has been used in applications such as Portland cement [1,5], asphalt concrete [6,7], and wastewater treatment [8,9]. Few investigations using steel slag with high ZnO contents have been reported. Alsheyab and Khedaywi [10] used steel slag with 29 wt % content of ZnO in asphalt cement mixture. Further, Alsheyab [11] in another research used steel slag with 18.7 wt% in asphalt mixtures. Most researchers have used steel slag with content less

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than 1% of ZnO in concrete [12–24]. In contrast, typical steel slag contents have been 45 wt% [24] to 80 wt% [18] in cements, and 50 wt% in concrete [12,23].

On the other hand, steel dust is a solid industrial hazardous waste generated in the collection of particulate material during the steel making process mostly referred as Electric Arc Furnace Dust (EAFD) [25], and it is classified as a hazardous waste by the Environmental Protection Agency (EPA), designated as K061 [25], because it contains hazardous metals, such as lead and Cadmium. More than 3.7 million tons per year is the estimated worldwide production of EAFD [26]. In an EAF about 15–25 kg of dust is produced per ton of steel [27]. High zinc contents appears in the waste because when galvanized steel is used in the electric arc furnace (EAF), most of the zinc is emitted as dust and fume. It is because the zinc vapor pressure is higher than iron vapor pressure [27]. Mainly, zinc is emitted as ZnO and $ZnFe_2O_4$ compounds [26]. Among few investigation of EAFD as an admixture, additive or filler for construction and building materials, ecological bricks have shown to be a promissory solution for the utilization of this waste [28].

Additionally, few studies involving leachability tests over the steel dust byproducts with cement and concrete have been conducted when superfine steel dust particles were used. Most research deal with micro and macro slag particles in cement and concrete [15–17,21]. Some studies about superfine steel slag have been reported, but those studies have been focused in the pozzolanic activity [29,30].

Although environmental regulations are becoming tougher around the world [1], many countries still do not have waste management laws over many hazardous solid wastes. In fact, many environmental regulations are only in the planning stages, as in the case of Colombia, South America, were regulations have not only limited scope, inadequate administrative support and the inexistence of effective control mechanisms and public participation [31]. In Colombia, slags are mostly unused, and particularly steel slag is only dispose in government disposal facilities. From there, this hazardous wastes could reach water sources in the worst case.

The aim of this investigation is to incorporate steel dust to White Ordinary Portland Cement (WOPC) in order to reduce the current negative impact of this waste in the environment. WOPC was used in order to qualitatively see the color changing in samples as the waste content increases, which could lead in a new set of inorganic colorants for cements. Overall, this research focused in two main goals. First, to immobilize the steel slag in concrete; thus, to reduce the risk of waters contamination. Second, to reduce the amount of cement in concrete, which can be done using this waste material as an admixture. This contributes to the reduction of the CO_2 released to the atmosphere by the utilization of less cement binder in concrete, particularly when the admixture has pozzolanic properties.

For structural applications, it is necessary to determine some optimal formulations with a compressive strength as the main criteria. From the environmental remediation point of view, it is better to incorporate as much waste as possible in the cement paste; however, a large amount no necessarily provides the maximum strength. Thus, in this research many samples were prepared with different waste loadings and water to cement (W/C) ratios. This could allow to find good formulations for structural applications and optimizing its positive impact on the environment. For planning the sampling and experiments, some of the methods applied to phosphate cements [32–34] were used, since it is common in phosphate research to used loadings up to several times those used with traditional Portland cements with wastes.

2. Experimental

White Ordinary Portland Cement (WOPC) from Holcim S.A., Colombia (with max. 6.0 wt% MgO, and max. 3.5 wt% SO_3) was used in combination with steel slag, a solid waste from Ternium Colombia. WOPC was used in order to qualitatively see the color changing in samples with the addition of slag waste. Two types of samples were investigated: cement paste with waste and cement mortar with waste.

Samples of Portland cement paste with steel slag contents were obtained first by mixing mechanically the cement powder with deionized water, and then by adding the powder waste. For some compositions, sand was added as well. In order to cover many possible compositions and Water to Cement ratios (W/C), two experiments were made: a) samples keeping constant the water content over the total amount of solid powders, and b) samples keeping constant the W/C ratio. Thus, ratios from 0.4 to 1.8 of W/C were used, and content waste from 0.0 wt% to 80 wt % over the total powders content were reached. Sample compositions for cement paste with the slag using constant W and W/C ratios are summarized in Table 1a and b respectively, for which W: water, C: cement, and SL: steel slag.

Table 2 summarizes the sample composition for the cement mortar with waste. These proportions for the mortar samples were one part of cement to one part of graded standard sand by weight and contaminant [36]. In the preparation of the mortars, the water/cement ratio (W/C) was kept constant as 0.485, and the cement was replaced by the contaminant; always keeping constant the sand-(cement + waste) ratio in 1.0. Initially, it was attempted to manufacture mortars with sand-(cement + waste) ratios of 1:2.75 at the same water-(cement + waste) ratio used for preparation of the grouting samples (0.485). However, these combinations resulted in mortars with poor fluidity to prepare mortar cubes for compressive strength tests. Then, in order to prepare the mortars keeping the same percentage of waste used in the preparation of grouting samples, it was found that sand-cement + waste) ratios of 1:1 with a constant water-(cement + waste) ratio of 0.485 resulted in good mortar fluidity (around 100%), which allowed the preparation of mortar cubes for the compression test. Also, it made consistent the water-(cement + waste) ratio for the mortar test preparation, like the water-(cement + waste) ratio used for the grouting samples. For all samples, mixing was conducted mechanically. To evaluate the effect on the contaminant on the fresh mortar, flow table tests were conducted following the ASTM C 230 standard [37].

All cement paste samples were released from molds and tested after 28 days. Compression tests were conducted in an Instron machine 3382. A set of 5 samples (diameter 20 mm × length 30 mm) was evaluated for each composition, using a crosshead speed of 1 mm/min. Modulus of elasticity was evaluated with the extensometer fixture. For cement mortar samples, immediately upon completion of

Table 1
Samples of Portland cement paste with steel dust contents: a) keeping constant W; and b) keeping constant the W/C ratio. W: water, C: cement, SD: steel dust.

a) W = Const.				b) W/C = Const.			
Sample	C (wt%)	SD (wt%)	W/C	Sample	C (wt%)	SD (wt%)	W/C
W1	100	0	0.4	W/C1	100	0	0.4
W2	99	1	0.4	W/C2	99	1	0.4
W3	97.5	2.5	0.4	W/C3	97.5	2.5	0.4
W4	95	5	0.4	W/C4	95	5	0.4
W5	90	10	0.5	W/C5	90	10	0.4
W6	80	20	0.5	W/C6	80	20	0.4
W7	60	40	0.6	W/C7	60	40	0.4
W8	50	50	0.7	W/C8	50	50	0.4
W9	40	60	0.9				
W10	30	70	1.2				

Table 2
Cement mortar with sand/(C + SD) = 1.0. W: water, C: cement, SD: steel dust.

Sand/(C + SD) = 1.0			
Sample	C (wt%)	SD (wt%)	W/C
M1	100	0	0.485
M2	99	1	0.485
M3	97.5	2.5	0.485
M4	95	5	0.485
M5	90	10	0.485
M6	80	20	0.485
M7	60	40	0.485
M8	50	50	0.485