Journal of Hazardous Materials 166 (2009) 277–283

Contents lists available at ScienceDirect

Journal of Hazardous Materials

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

The use of EAF dust in cement composites: Assessment of environmental impact

Tina Šturm [a], Radmila Milačič [a], Simona Murko [a], Mitja Vahčič [a], Ana Mladenovič [b], Jerneja Strupi Šuput [b], Janez Ščančar [a,*]

[a] Department of Environmental Sciences, Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia
[b] Slovenian National Building and Civil Engineering Institute, Dimičeva 12, 1000 Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 28 July 2008
Received in revised form 2 October 2008
Accepted 9 November 2008
Available online 17 November 2008

Keywords:
Cement composites
Cement composites with addition of EAF dust
Leachability
Cr(VI)
Metals

ABSTRACT

Electric arc filter dust (EAF dust) is a waste by-product which occurs in the production of steel. Instead of being disposed of, it can be used in cement composites for civil engineering, and for balances in washing machines. To estimate the environmental impact of the use of EAF dust in cement composites leachability tests based on diffusion were performed using water and salt water as leaching agents. Compact and ground cement composites, and cement composites with addition of 1.5% of EAF dust by mass were studied. The concentrations of total Cr and Cr(VI) were determined in leachates over a time period of 175 days. At the end of the experiment the concentrations of some other metals were also determined in leachates. The results indicated that Cr in leachates was present almost solely in its hexavalent form. No leaching of Cr(VI) was observed in aqueous leachates from compact cement composites and compact cement composites to which different quantities of EAF dust have been added. In ground cement composites and in ground cement composites with addition of EAF dust, Cr(VI) was leached with water in very low concentrations up to 5 $\mu g\,L^{-1}$. Cr(VI) concentrations were higher in salt water leachates. In compact and ground cement composites with addition of EAF dust Cr(VI) concentrations were 40 and 100 $\mu g\,L^{-1}$, respectively. It was experimentally found that addition of EAF dust had almost no influence on leaching of Cr(VI) from cement composites. Leaching of Cr(VI) originated primarily from cement. Leaching of other metals from composites investigated did not represent an environmental burden. From the physico-mechanical and environmental aspects EAF dust can be used as a component in cement mixtures.

1. Introduction

In the developed countries waste products like recycled building rubbles [1,2], waste glass [3], crumb rubber [4], quarry waste [5], shingle waste [6], sewage sludge [7], non-metallic automotive shredder residues [8] as well as industrial by-products such us steel slag [9–14], filter dust from steelworks [15], cement kiln dust [5,16], asphalt dust [5], coal fly ash [5,18], coal bottom ash [5] and municipal solid waste incinerator bottom ash [19] are widely used in civil engineering, especially for road construction. In the last decades these waste products are being exploited as alternative materials that successfully substitute natural raw materials. Re-use of recycled waste materials and industrial by-products leads to preservation of natural resources [11], substantial reduction of landfills load and protection of the terrestrial environment. The use of materials originating from industrial by-products is possible when such materials posses appropriate technical qualities [11,14] and are environmentally acceptable [7,11,12,15,17]. Waste materials and industrial by-products that can be potentially re-used may contain different pollutants like metals and organic compounds. The toxicity of the pollutant depends not only on its total concentration, but also on the chemical form and its mobility in the environment. When waste materials and industrial by-products are re-used for road construction and in civil engineering, toxic substances may be successfully immobilised with asphalt [15] and cement [20,21]. Nevertheless, before the use, the environmental risk due to the potential release of contaminants from alternative aggregates should be critically evaluated [12,13,15,21–26]. The major potential hazard to terrestrial and aquatic environment is the leaching of toxic substances from such alternative materials [15,22–26]. In order to estimate the long-term environmental impact, leaching tests based on diffusion were proposed in the Netherland's NEN 7345 standard [27] and applied in the leaching protocol developed for concrete [28]. Similar leaching protocol was used also to evaluate the environmental acceptability of the asphalt composites with addition of filter dust [15].

In Slovenia, as by-products of the steel industry, about 200,000 tons of steel slag and 9000 tons of EAF dust from the

* Corresponding author. Tel.: +386 1 4773900; fax: +386 1 2519385.
E-mail address: janez.scancar@ijs.si (J. Ščančar).

0304-3894/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhazmat.2008.11.015

electric arc furnaces are generated per year. For the time being EAF dust was disposed in landfills or recycled abroad. Disposal of EAF dust in landfills represented the environmental hazard due to its dusty nature and the presence of potentially toxic metals. Since landfills in Slovenia are overloaded and recycling is expensive, the alternatives for re-use of EAF dust were examined. EAF dust represents an appropriate material for incorporation into asphalt or cement. In our previous investigation the potential of the use of EAF dust in asphalt composites was critically evaluated [15]. It was demonstrated that from the physico-mechanical as well as from the environmental point of view, EAF dust can be used as an additive to asphalt for road construction.

The aim of the present investigation was to critically evaluate the potential use of EAF dust as additive to cement that may be used in civil engineering and for balances in washing machines. The physico-mechanical characteristics of cement composites with addition of EAF dust were evaluated and the long-term environmental impact investigated by the use of leachability tests based on diffusion. Water and salt water were applied as leaching agents. Compact and ground cement composites and cement composites with addition of 1.5% of EAF dust by mass were studied. The experiment was carried out over a time period of 175 days, following the concentrations of total Cr and Cr(VI) in leachates. Finally, the concentrations of some other metals were also determined in leachates at the end of the experiment.

2. Materials and methods

2.1. Apparatus

Total metal concentrations in leachates of cement composites and cement composites with addition of EAF dust were determined by flame atomic absorption spectrometry (FAAS) on a Varian (Mulgrove, Victoria, Australia) Spectra AA 110 atomic absorption spectrometer, and by electrothermal atomic absorption spectrometry (ETAAS) on a Hitachi (Tokyo, Japan) Z-8270 polarized Zeeman atomic absorption spectrometer equipped with an autosampler. The content of Cr(VI) in leachates of cement composites and cement composites with addition of EAF dust was determined by fast protein liquid chromatography with ETAAS detection (FPLC-ETAAS). The chromatographic system consisted of a Varian (Mulgrave, Victoria, Australia) Model 9010 HPLC inert Star Gradient Solvent Delivery System and a Rheodyne (Cotati, California, USA) Model 7161 injector using 0.5 mL loop. A strong anion-exchange FPLC column of Mono Q HR 5/5 (Amersham, Uppsala, Sweden) (column dimensions 5 mm × 50 mm, 10 μm beaded polyether resin, pH stability 2–12) was employed for the Cr(VI) separation. The separated Cr species were determined "off line" in 0.5 mL fractions by ETAAS.

A WTW (Weilheim, Germany) 330 pH meter was employed to determine the pH of leachates of cement composites and cement composites with addition of EAF dust.

2.2. Reagents

Merck (Darmstadt, Germany) suprapur acids and Milli-Q water (Direct-Q 5 Ultrapure water system, Millipore Watertown, MA, USA) were used for the preparation of samples and standard solutions. All other reagents were of analytical reagent grade.

Stock standard solutions of metals ($1000 \pm 2\ mg\ L^{-1}$ in 5% HNO_3) were obtained from Merck. Fresh working standard solutions were prepared by dilution of an appropriate stock solution with water and used in determination of metal concentrations in leachates of cement composites and cement composites with the addition of EAF dust.

For the preparation of salt water, NaCl obtained from Carlo Erba (Milano, Italy) was used.

Sartorius (Goetingen, Germany) 0.45 μm cellulose nitrate membrane filters of 25 mm diameter were used in the filtration procedure.

The certified reference materials CRM 544, Cr(III), Cr(VI) species and total Cr in lyophilised solution obtained from the Community Bureau of Reference (BCR, Geel, Belgium) and SPS-SW1, Quality Control Material for Surface Water Analysis purchased from SPS Spectrapure Standards AS (Oslo, Norway) were used to check the accuracy of the analytical procedures.

2.3. Determination of Cr(VI) in leachates

Before analysis, leachates were filtered through 0.45 μm membrane filter. The same chromatographic procedure was applied as in the determination of Cr(VI) in the highly alkaline (pH 12) quicklime-treated sewage sludge extracts [29] and cement extracts [30]. 0.5 mL of sample was injected onto the column. Buffer A consisting of TRIS-HCl ($0.005\ mol\ L^{-1}$, pH 8.0) and buffer B (buffer A plus $0.5\ mol\ L^{-1}$ NaCl) were employed in linear gradient elution from 0 to 100% of buffer B for 15 min at a flow rate of $1.0\ mL\ min^{-1}$. Cr(VI) was eluted between 10.5 and 11.5 min with a maximal peak at 11.0 min. The column was regenerated with $2\ mol\ L^{-1}$ NaCl for 5 min and equilibrated with buffer A in the following 10 min at a flow rate of $1.0\ mL\ min^{-1}$. The chromatographic run was completed in 30 min. The separated Cr species were determined "off line" by ETAAS in 0.5 mL fractions. In order to reduce the salt deposit and to obtain reproducible measurements, 5 μL of 32% HNO_3 was added to the graphite tube before each determination [31]. To overcome interference effects in ETAAS determinations, eluent-matched standard solutions of Cr(VI) were prepared in eluent solution of the same molarity that eluted Cr(VI) from the column ($0.4\ mol\ L^{-1}$ NaCl) [29,30]. All analyses were done in duplicate.

2.4. Determination of total Cr and other metals in leachates

Before determination of total metal concentrations sample leachates were filtered through 0.45 μm membrane filter. Total Cr, Mo, Co and V were determined by ETAAS under optimal measurement conditions. To reduce the salt deposit 5 μL of 32% HNO_3 was added to the graphite tube before each determination [31]. Concentrations of Cu, Zn, K, Cd and Pb were determined by FAAS in an air–acetylene flame, while Ni, Fe, Ca, Mg and Mn were determined by FAAS in a nitrous-oxide–acetylene flame.

2.5. EAF dust

EAF dust from electric arc furnaces is a waste by-product which occurs in the production of steel. In the present investigation EAF dust generated at the steelwork Štore Steel, Slovenia was used. It contains high total concentrations of metals, of which Zn (23–24%) and Fe (18–22%) are the major components. Other metals like Pb, Ca, Mg and Mn are present in concentrations below 4%, while Cr concentration is about 0.3%. Since metals in EAF dust are primarily present as sparingly soluble oxides the leaching of metals in water is in general negligible with exception of Cr(VI) that is to some extent leached with water. Concentration of Cr(VI) in aqueous leachate of filter dust (pH 7.0), determined according to the SIST EN 12457-4 procedure was found to be $0.8\ mg\ kg^{-1}$ [15]. Other detailed characteristics of EAF dust were reported in our previous work [15].

2.6. Cement samples

The cement used for preparation of cement composites and cement composites with addition of EAF dust was CEM I, which