Jordan Journal of Civil Engineering, Volume **6**, No. **2**, **2012**

Potential Reuse of Electric-Arc Furnace Dust (EAFD) in Concrete

Maha Alqam

Assistant Professor, Department of Civil Engineering, University of Jordan,
Amman 11942, Jordan. E-mail: m.alqam@ju.edu.jo

ABSTRACT

This study investigated electric arc furnace dust (EAFD) reuse as a raw material in concrete mixes. A comprehensive experimental program consisting of two phases of testing was carried out. The first phase included the replacement of ordinary Portland (Type I) cement by unsieved dust with the percentages of 0, 2.5, 5, 7.5 and 10%. The second phase included the replacement of quartz (filler) by sieved dust with the percentages of 0, 2.5, 5, 7.5 and 10%. Leaching tests were carried out to find out if arsenic, chromium and lead were contained in concrete. The study concluded that the workability of fresh concrete increased with increasing the percentage of used dust. The use of 2.5% dust resulted in concrete with similar compressive strength and acceptable splitting strength when compared to that of the standard mix. The concrete mixes containing sieved and unsieved EAFD were able to contain arsenic and chromium. Additionally, the concrete mixes containing sieved EAFD were able to contain lead.

KEYWORDS: Concrete, Electric arc furnace dust, Heavy metals, Leachability, Strength, Workability.

INTRODUCTION

Steel making industries result in the generation of great amounts of solid waste materials. These materials include blast furnace slag, sludge, fly ash and dust. The safe disposal of industrial byproducts is costly and is a serious problem in many countries. This is due to the lack of suitable disposal sites that do not cause damaging effects on the environment. Therefore, research has been recently directed towards investigating alternative procedures to reuse such waste materials. Electric arc furnace dust (EAFD) is produced during the process of steel making by the electric arc furnace. The dust generated by steel manufacturing contains significant levels of heavy metals (Hamilton and Sammes, 1999; Sofilic et al., 2004; de Vargas et al., 2006; Laforest and Duchesne, 2006a; Salihoglu et al., 2007; Salihoglu and Pinarli, 2008; Bulut et al., 2009). This fact, along with the huge quantities of EAFD produced, bestow a serious nature to this byproduct.

According to the UN CEC (1999), the process of steel making generates a total of 20 kg of dust per ton of steel, which resulted in a world-wide EAFD production of 4.72 million tons. The EAFD produced by steel industry in the European Union alone was estimated at 700000 tons/year (Barna et al., 2000). Steel industry in the United States produces approximately 613000 tons of EAFD annually, of which 190000 tons are recycled and the rest is disposed of (USEPA, 2007). Jordan has many manufacturing plants of iron and steel. A plant located in the middle of the country was chosen for this study. The dust collected in the bag house filtering system of the plant contains arsenic, chromium and lead and is estimated at 2 to 3 tons per day.

The presence of heavy metals in the dust renders it as a hazardous substance (Sofilic et al., 2004) and

Accepted for Publication on 21/11/2011.

prevents conventional management practices from being applied for its disposal. As a result, innovative approaches become a necessity for the solution of management problems. Investigation of literature reveals that most of the management procedures adopted for the electric arc furnace dust can be categorized as recycling of the dust or some of its contents for beneficial use or stabilization of the dust prior to final disposal.

Hilton (1998) proposed a method that utilizes EAFD as part of the raw materials in the production of Portland cement. The method employs a mixture of water and lime to stabilize EAFD. The proposed method recommends the addition of EAFD to the cement raw materials to achieve an iron content of 2% to 5% measured as iron oxide. Mcdevitt et al. (2006) developed a process that aims at recovering desired metals from EAFD prior to final disposal. The process relies on washing the dust, solubilizing and electrowinning some metals and extracting other metals from the solids left after the solubilizing step. Similarly, Dutra et al. (2006) investigated the alkaline leaching of zinc from EAFD with the objective of reducing environmental impacts and generating revenue. The alkaline leaching methods investigated included conventional agitation leaching, pressure leaching, conventional leaching following a microwave pretreatment and leaching with agitation provided by an ultrasonic probe. The study showed that the highest zinc recovery from the EAFD, containing about 12% of zinc, was about 74%.

In the absence of potential beneficial use, the adopted management option of EAFD is stabilization or solidification prior to disposal. This option mandates the assurance that heavy metals in the dust are fixated and will not leach to the surrounding environment. Available literature shows that some investigations were carried out to investigate the leachability of heavy metals from EAFD when disposed of as is, and to study potential impacts on the surrounding environment (Sofilic et al., 2004; Laforest and Duchesne, 2006b; Oresanin et al., 2007). Other studies investigated the effect of encapsulating the EAFD with cement pastes, cement mortar, cementitious materials, glass cullet and sand (Hamilton and Sammes, 1999; Pelino et al., 2002; Laforest and Duchesne, 2006a; de Vargas et al., 2006; Pereira et al., 2007; Laforest and Duchesne, 2007; Salihoglu et al., 2007; Salihoglu and Pinarli, 2008; Bulut et al., 2009).

Reuse of waste byproduct materials in construction has recently become widely-spread. However, the use of EAFD in such application has not received enough attention. Sikalidis and Mitrakas (2005) investigated the use of EAFD as a raw material for the production of clay-based pressed ceramics. Their investigation showed that ceramics produced with recycled EAFD were acceptable in terms of strength limits specified for these products, and resulted in stabilization of zinc and toxic metals within the sintered ceramic structure. Kavouras et al. (2007) studied the potential use of EAFD in the production of glass-ceramic materials. Their investigation results showed that the vitreous materials were transformed into glass-ceramics by two-stage heat treatment under thermal conditions. The leaching tests carried out on the produced materials showed that they were chemically durable. Moosberg-Bustnes et al. (2004) studied the influence of 10 different byproduct dust and sludge on the cement hydration and strength development by replacing a percentage of cement volume by a byproduct dust or sludge. EAFD was one of the used byproducts in this research. The tests conducted showed that samples with 25% of cement replaced by EAFD have higher long-term strength than the reference samples in spite of their retarding effect on the cement hydration.

The objective of this research study is to investigate the potential use of EAFD, generated during the melting and production of steel ballets and reinforcing bars, as a raw material in concrete mixes. A comprehensive experimental program was carried out to investigate the effect of cement partial replacement and filler partial replacement by EAFD on the properties of fresh and hardened concrete mixes. The study aimed at (1) characterizing dust produced during steel production for its physical properties, (2) exploring the potential of reusing this dust for partial replacement of cement during concrete production, (3) investigating the potential of reusing this dust for partial replacement of fillers during concrete production and (4) investigating the potential environmental impacts as a result of these two replacement proposals through leaching to the nearby environment.

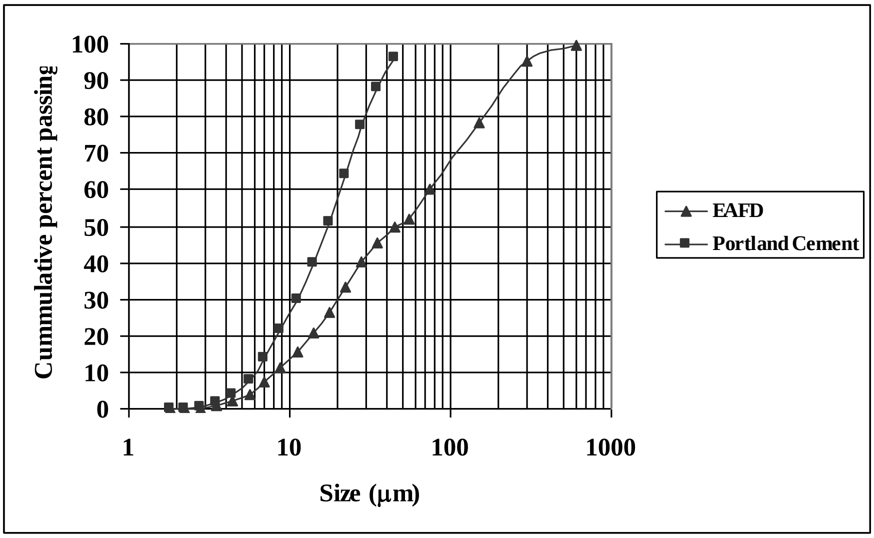

Figure 1: Particle size distribution for unsieved (as is) dust (EAFD) and Portland cement

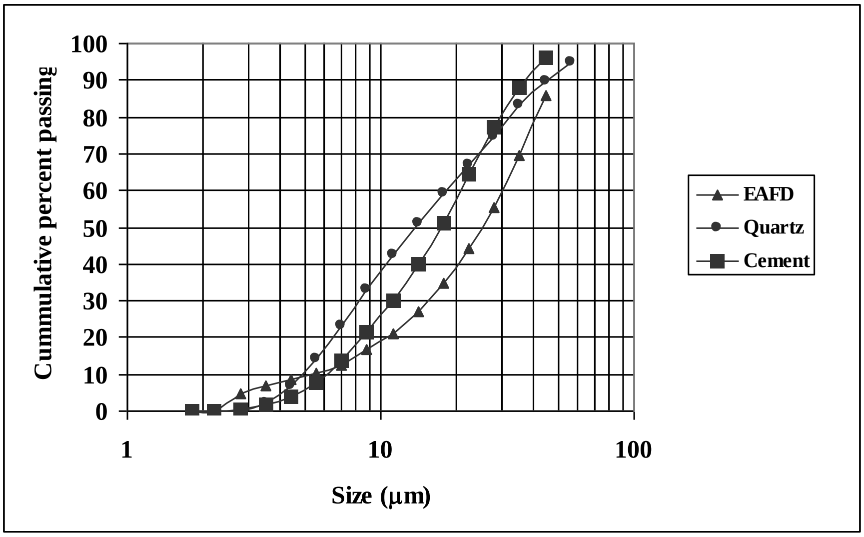

Figure 2: Particle size distribution for sieved dust (EAFD passing sieve #200), quartz and Portland cement

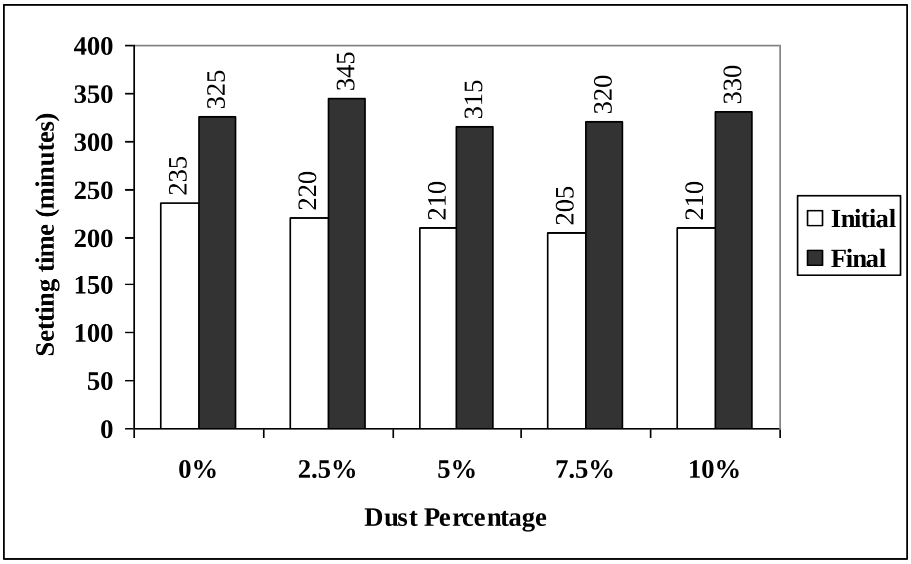

Figure 3: Initial and final setting times for cement pastes prepared from ordinary Portland cement with different percentages of unsieved (as is) dust replacement

Table 1. Physical properties of aggregates

Property	Coarse aggregates		Fine aggregates	
	19mm aggregates	**12.5mm aggregates**	**4.75mm aggregates**	**Standard sand**
Unit weight (kN/m^3)	13.2	14.3	16.1	16.8
% Absorption	3.2	3.7	4.3	1.7
Specific gravity (SSD)	2.65	2.63	2.62	2.61

Table 2. TCLP concentrations of arsenic, chromium and lead for different EAFD replacements along with TCLP regulatory limits

Specimen Type	Percent replacement	As (mg/L)	Cr (mg/L)	Pb (mg/L)
Unsieved EAFD replacement of cement	2.5	<0.005	0.04	0.49
	5.0	<0.005	0.11	2.88
	7.5	<0.005	0.12	3.56
	10.0	<0.005	0.15	5.08
Sieved EAFD replacement of quartz	2.5	<0.005	0.04	0.26
	5.0	<0.005	0.04	0.50
	7.5	<0.005	0.03	1.06
	10.0	<0.005	0.06	1.23
TCLP Limit		5.0	5.0	5.0

METHODOLOGY

Raw Materials

The tested dust was collected from the Jordan Iron and Steel Industrial Company located in Jordan. The dust collected in the bag house filtering system of the plant contains arsenic, chromium and lead. The dust was employed in two forms: sieved using sieve number 200 and unsieved (as is). Additionally, the particle size distributions of the dust were carried out using Coulter Counter and mechanical shaking and are shown in Figures (1 and 2).

The aggregates used consisted of coarse and fine aggregates. The coarse aggregates were crushed limestone with a maximum aggregate size of 19 mm and a maximum aggregate size of 12.5 mm. The fine aggregates were crushed limestone with a maximum size of 4.75 mm and natural standard sand. The grading and the quality of aggregates and standard sand meet ASTM C 33/ 33M (2008) and ASTM C 778 (2008) standards. The unit weight, percent absorption and saturated surface dry (SSD) specific gravity were measured for aggregates according to ASTM C 29/ C29M (2008), ASTM C 127 (2008) and ASTM C 128 (2008) requirements. Results are shown in Table (1).

Ordinary Portland (Type I) cement was used in this study. Additionally, local type quartz was used as filler in the concrete mix. The particle size distributions of cement and quartz were carried out using the Coulter Counter. The particle size distributions of EAFD, cement and quartz are shown in Figures (1 and 2). Figure (1) shows that Portland cement has smaller particle size when compared to EAFD, while Figure (2) shows that the sieved dust, cement and quartz all have comparable sizes.

Cement Paste Samples

A pilot study for the determination of initial and final setting times of cement pastes was carried out for ordinary Portland (Type I) cement. A cement paste was prepared according to ASTM C 305 (2008) requirements. The samples were tested using the Vicat's apparatus according to ASTM C 191(2008). The test was carried out for cement paste samples with 0%, 2.5%, 5%, 7.5% and 10% of unsieved (as is) and sieved dust as a replacement for ordinary Portland (Type I) cement. Each setting time value was an average of four measurements for each percentage.

Concrete Samples

A concrete mix proportion was designed according to ACI 211.1-91 method for normal weight aggregate concrete with a water/cement ratio of 0.53. Each cubic meter of concrete contained 400 kg of cement, 212 kg of water, 496 kg of coarse aggregate having a maximum size of 19 mm, 496 kg of coarse aggregate having a maximum size of 12.5 mm, 382 kg of fine aggregate having a maximum size of 4.75 mm and 382 kg of natural standard sand.

An experimental program consisting of two phases of testing was carried out. The first phase included the replacement of cement by unsieved (as is) dust with percentages of 0, 2.5, 5, 7.5 and 10%. The second phase included the use of quartz in the concrete mix with a quantity equal to 10% of cement, and the experimental program included the replacement of quartz by sieved (passing sieve number 200) dust with percentages of 0, 2.5, 5, 7.5 and 10%.

Concrete specimens of 75-mm diameter and 150-mm length cylinders were prepared and cured according to ASTM C192 / C192M (2008) requirements. The concrete cylinders were capped according to ASTM C617 (2008) standard and then tested for compressive strength at 7 days, 14 days and 28 days, according to ASTM C39 (2008) standard. Splitting tensile strength at 28 days was also carried out according to ASTM C496 / C496M (2008) standard. Three concrete samples were tested for each percentage. Additionally, the workability for each mix of fresh concrete was monitored by measuring an average value of six measurements of slump. The slump test was conducted according to ASTM C143 / C143M (2008) requirements.

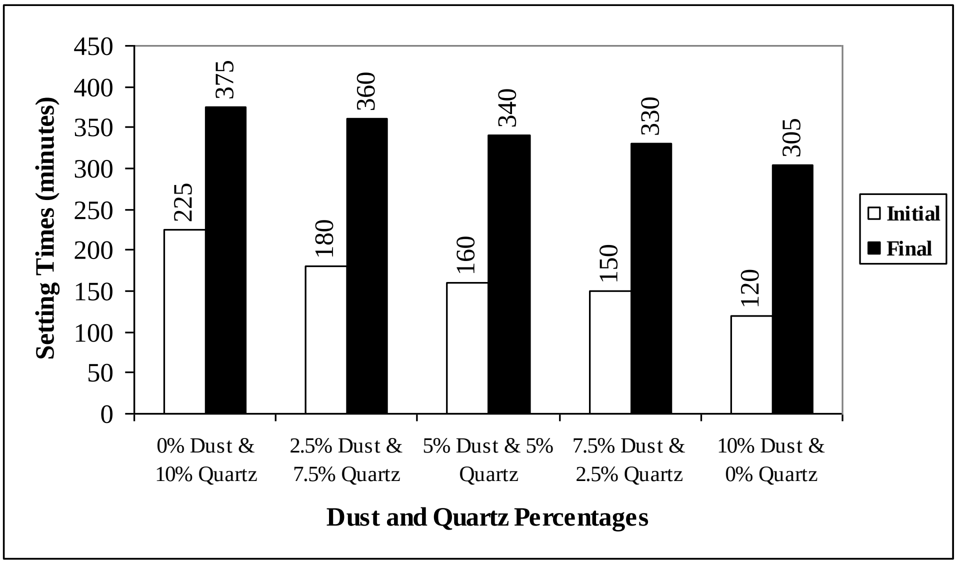

Figure 4: Initial and final setting times for cement pastes prepared from ordinary Portland cement with different percentages of sieved dust replacement

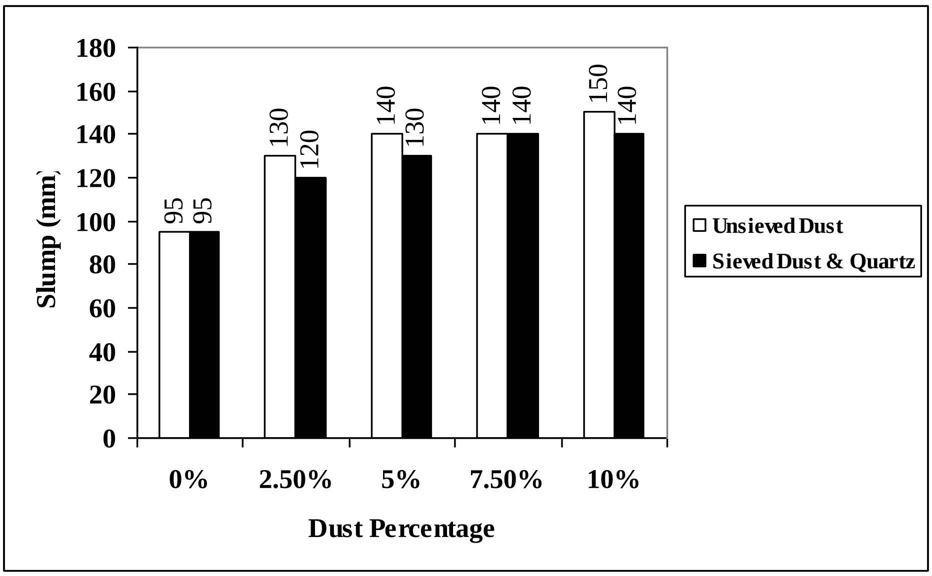

Figure 5: Slump test results for cement pastes prepared with unsieved (as is) dust and sieved dust with quartz (filler)

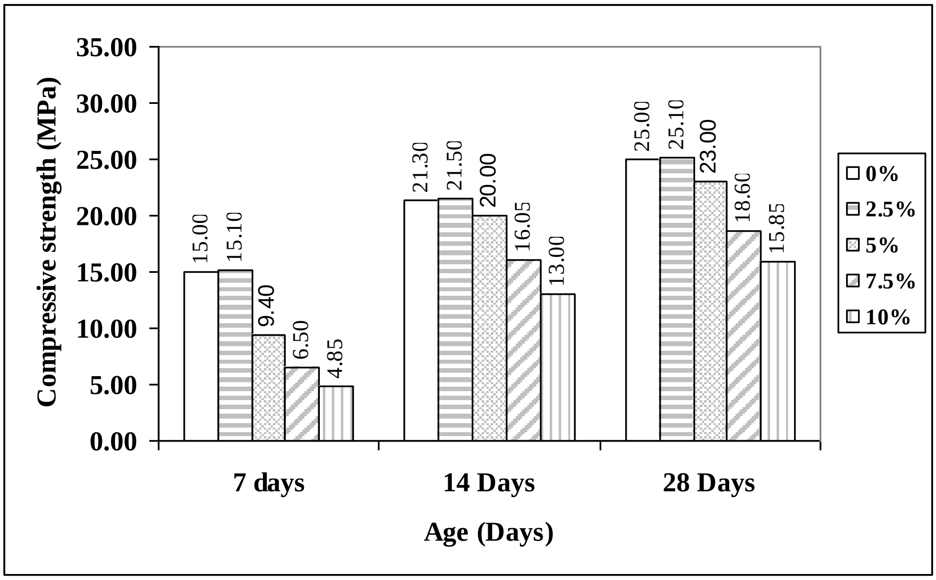

Figure 6: Compressive strength of concrete specimens prepared with different percentages of unsieved (as is) dust *versus* age

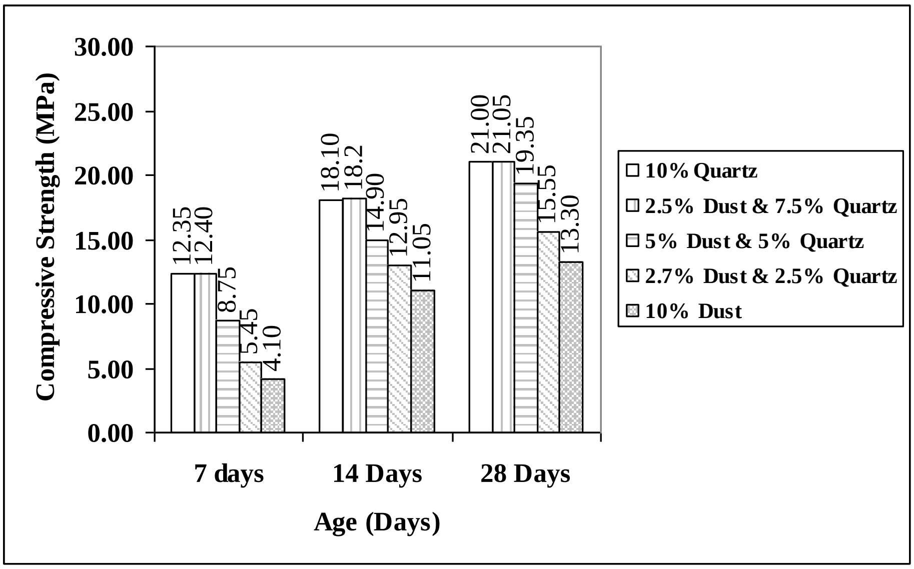

Figure 7: Compressive strength of concrete specimens prepared with different percentages of sieved dust with quartz (filler) *versus* age

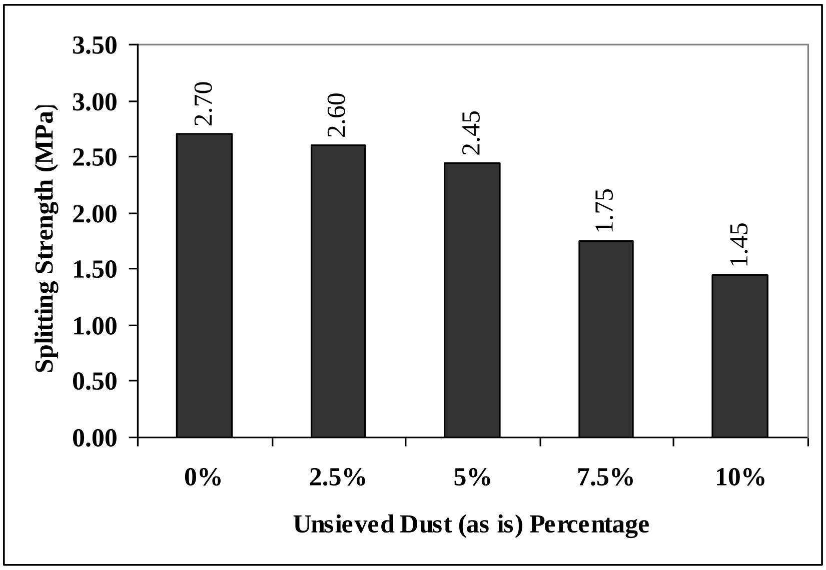

Figure 8: The 28-day splitting strength of concrete specimens prepared with different percentages of unsieved (as is) dust

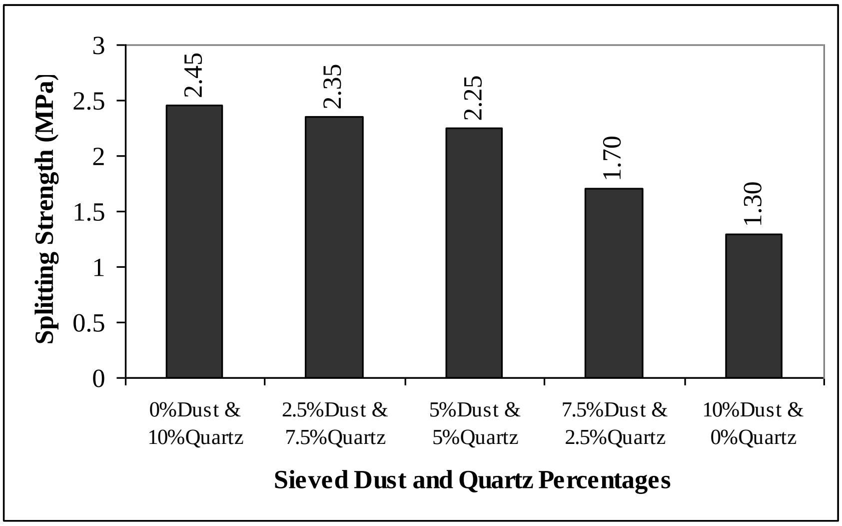

Figure 9: The 28-day splitting strength of concrete specimens prepared with different percentages of sieved dust with quartz (filler)

Leaching Tests

Leaching of certain metals (arsenic, chromium and lead) from concrete specimens was investigated using the Toxicity Characteristic Leaching Procedure (TCLP), which was proposed by the USEPA (EPA, 1992). The test was carried out on eight concrete specimens that were crushed at 28 days. The specimens represented unsieved (as is) and sieved EAFD replacements of 2.5%, 5%, 7.5% and 10%. Ten grams of each of the crushed specimen and the appropriate extraction fluid were combined with a ratio of 1:20 and placed into polypropylene extraction bottles. The bottles were sealed and placed on an agitator with a rotational speed of 59 rpm for a period of 18 hours. All samples in this study were ground to <0.85 mm, which is sufficiently small to assume that steady-state conditions were met. At the end of agitation, liquid in each bottle was separated from solid phase. The pH of the separated TCLP extracts was then measured and all extracts were acidified to pH less than 2 for long-term preservation. Heavy metal concentrations were then measured by ICP.

RESULTS AND DISCUSSION

Setting Time

The initial and final setting times for ordinary Portalnd (Type I) cement were determined using the Vicat needle and the results are shown in Figures (3 and 4). Each reported setting time value presented in the figures is an average of four samples. Figure (3) shows that unsieved (as is) dust had no significant effect on initial and final setting times. Additionally, Figure (4) shows that sieved dust resulted in a decrease in the initial and final setting times. Both figures indicate that initial setting time is appropriate and final setting time is not significantly affected.

Workability

The slump test results carried out for concretes prepared with unsieved (as is) dust and sieved dust with quartz (filler) are shown in Figure (5). The figure indicates that the workability of the fresh concrete is expected to improve with the increased use of dust. The slump of concrete specimens prepared with unsieved (as is) dust increased from 95 mm to 150 mm for the percentages of cement replacement by dust percentages ranging from 0% to 10%. Similarly, the slump of concrete specimens prepared with sieved dust and quartz increased from 95 mm to 140 mm for the percentages of quartz replacement by dust ranging from 0% to 10%. The slump values of the six workability test measurements for each mix were within 5 mm from the reported average value, indicating repeatability of these results.

Compressive Strength

The effect of cement replacement with dust on compressive strength of concrete is shown in Figures (6 and 7) for the unsieved (as is) and sieved dust, respectively. Each data point presented in the figures is an average test result of three specimens and all the results are within 4% of the reported average value. The figures clearly show that the use of unsieved (as is) or sieved dust yielded comparable results. Further inspection of the figures indicates that the use of EAFD in concrete production negatively affects the compressive strength of concrete. However, the use of 2.5% either for cement replacement or quartz replacement by dust resulted in concrete with similar compressive strength to that of the standard mix. Additionally, the use of 5% dust resulted in concrete with compressive strength above the 90% acceptance criterion of compressive strength of the standard mix as outlined by ASTM C1602/ C1602M (2008). The use of more than 5% dust (i.e., 7.5% and 10%) resulted in compressive strengths that are significantly lower than that of the standard mix.

Splitting Strength

The effect of cement replacement with dust on the 28-day tensile splitting strength of concrete is investigated in Figures (8 and 9). Figure (8) shows the 28-day splitting strength of concrete specimens prepared with different percentages of unsieved (as is) dust and Figure (9) shows the 28-day splitting strength of concrete specimens prepared with different percentages of sieved dust with quartz (filler). Results presented in both figures are the average test result for three specimens. It should be noted that all the results were within 2% of the reported average value in the figures. The figures show that the use of unsieved (as is) to replace Portland cement and the use of sieved dust to replace quartz (filler) yield comparable results. The use of 2.5% dust (sieved or unsieved) resulted in concrete with comparable splitting strength to that of the standard mix. Additionally, the use of 5% dust resulted in concrete with splitting strength above 90% of that of the standard mix. The use of more than 5% dust (i.e., 7.5% and 10%) resulted in splitting strengths that are significantly lower than that of the standard mix.

Leaching Test Results

The toxicity characteristic leaching procedure (TCLP) was carried out on the concrete specimens produced with EAFD replacement in order to assess the leachability of certain heavy metals. The investigated metals were arsenic, chromium and lead. Results of the TCLP are presented in Table (2), which shows TCLP concentrations of arsenic, chromium and lead for different EAFD replacements along with TCLP regulatory limits. It should be noted that the numbers presented are the average of two specimens.

Results of the TCLP test on the eight concrete specimens showed that arsenic concentrations in the TCLP leachate for all of the specimens were below the detection limit of 0.005 mg/L. Additionally, the concentrations of chromium were all below the regulatory limit of 5.0 mg/L. The table also shows that while the TCLP concentrations of lead for sieved EAFD were all below the regulatory limit of 5.0 mg/L, this regulatory limit was exceeded at least once when unsieved (as is) EAFD was used. This finding is important as it suggests that the use of sieved EAFD is environmentally safer when compared to unsieved (as is) EAFD.

CONCLUSIONS

Based on the experimental program that included testing on setting time, workability, compressive strength, splitting strength and leaching of arsenic, chromium and lead in the TCLP, the following findings can be concluded:

1- For ordinary Portland (Type I) cement, the unsieved dust has no significant effect on initial and final setting times, and the sieved dust has a decrease in initial and final setting times. In both cases, initial setting time is appropriate and final setting time is not significantly affected.

2- The results of the slump test indicate that the workability of fresh concrete is improved with increasing the dust use.

3- The use of 2.5% dust (unsieved or sieved) results in concrete with similar compressive strength to that of the standard mix, and the use of 5% dust (unsieved or sieved) results in concrete with compressive strength above 90% of that of the standard mix. The use of more than 5% of both unsieved and sieved dust (i.e. 7.5% and 10%) results in compressive strengths lower than that of the standard mix.

4- The use of 2.5% dust (unsieved or sieved) results in concrete with comparable splitting strength to that of the standard mix, and the use of 5% dust (unsieved or sieved) results in concrete with splitting strength above 90% of that of the standard mix. The use of more than 5% of both unsieved and sieved dust (i.e., 7.5% and 10%) results in splitting strengths lower than that of the standard mix.

5- The concrete mixes containing unsieved (as is) and sieved EAFD are able to contain arsenic and chromium. Additionally, the concrete mixes containing sieved EAFD are able to contain lead. This finding suggests that the use of sieved EAFD is environmentally safer when compared to the use of unsieved (as is) EAFD.

ACKNOWLEDGMENT

The author acknowledges the FFF program and the Jordan Iron and Steel Industrial Company for their follow-up and financial support. The author also acknowledges the Laboratories and Quality Department/Water Authority of Jordan for their help and cooperation. Finally, the author acknowledges Prof. Ahmad Jamrah for his appreciated help.

REFERENCES

ACI COMMITTEE 211.1-91 (Reapproved 2002) Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete, Part 1, ACI Manual of Concrete Practice.

American Society for Testing and Materials, Standards. 2008. Section 4-Connstruction, ASTM.

Barna, R., Ryong Bae, H. and Mehu, J. 2000. Assessment of chemical sensitivity of Waelz slag. *Waste Management*, 20: 115-124.

Bulut, U., Ozverdi, A. and Erdem, M. 2009. Leaching behavior of pollutants in ferrochrome arc furnace dust and its stabilization/solidification using ferrous sulphate and Portland cement, *Journal of Hazardous Materials*, 162: 893-898.

de Vargas, A., Masuero, A. and Vilela, A. 2006. Investigations on the use of electric-arc furnace dust (EAFD) in Pozzolan-modified Portland cement I (MP) pastes. *Cement and Concrete Research*, 36: 1833-1841.

Dutra, A., Paiva, P. and Tavares, L. 2006. Alkaline leaching of zinc from electric arc furnace steel dust. *Minerals Engineering*, 19: 478-485.

Hamilton, I. and Sammes, N. 1999. Encapsulation of steel foundry bag house dusts in cement mortar. *Cement and Concrete Research*, 29: 55-61.

Hilton, R. 1998. Use of stabilized EAFD as a raw material in the production of a Portland cement clinker. United States Patent 5853474.

Kavouras, P., Ioannidis, Th., Kehagias, Th., Tsilika, I., Chrissafis, K., Kokkou, S., Zouboulis, A. and Karakostas, Th. 2007. EAFD-loaded vitreous and glass-ceramic materials. *Journal of the European Ceramic Society*, 27 (5): 2317-2323.

Laforest, G. and Duchesne, J. 2006a. Stabilization of electric arc furnace dust by the use of cementitious materials: Ionic competition and long-term leachability. *Cement and Concrete Research*, 36: 1628-1634.

Laforest, G. and Duchesne, J. 2006b. Characterization and leachability of electric arc furnace dust made from remelting of stainless steel. *Journal of Hazardous Materials*, B135: 156-164.

Laforest, G. and Duchesne, J. 2007. Investigation of stabilization/solidification for treatment of electric arc furnace dust: Dynamic leaching of monolithic specimens. *Cement and Concrete Research*, 37: 1639-1646.

Mcdevitt, B., Karkkainen, R., Sacris, E., Nahmad, D. and Sendil, E. 2006. Process for hydrometallurgical treatment of electric arc furnace dust. United States Patent, Publication Number WO/2006/084273.

Moosberg-Bustnes, H., Lind, L. and Forssberg, E. 2004. Fine particulate metallurgical by-products' influence on cement hydration and strength development: an initial study. *Scandinavian Journal of Metallurgy*, 33: 15-21.

Oresanin, V., Mikeli, L., Sofili, T., Rastovan-Mio, A., Uzarevi, K., Meduni, G., Elez, L. and Luli, S. 2007. Leaching properties of electric arc furnace dust prior/following alkaline extraction. *Journal of Environmental Science and Health, Part A*, 42 (3): 323-329.

Pelino, M., Karamanov, A., Pisciella, P., Crisucci, S. and Zonetti, D. 2002. Vitrification of electric arc furnace dusts. *Waste Management*, 22: 945-949.

Pereira, C., Galiano, Y., Rodriguez-Pinero, M. and Parapar, J. 2007. Long- and short-term performance of a stabilized/solidified electric arc furnace dust. *Journal of Hazardous Materials*, 148: 701-707.

Salihoglu, G., Pinarli, V., Salihoglu, N. and Karaca, G. 2007. Properties of steel foundry electric arc furnace dust solidified/stabilized with Portland cement. *Journal of Environmental Management*, 85: 190-197.

Salihoglu, G. and Pinarli, V. 2008. Steel foundry electric arc furnace dust management: Stabilization by using lime and Portland cement. *Journal of Hazardous Materials*, 153: 1110-1116.

Sikalidis, C. and Mitrakas, M. 2005. Electrical arc furnace dust as raw material for powder pressed ceramics. *Proceedings of the 9th International Conference on Environmental Science and Technology*, Rhodes Island, Greece, September 1-3, 2005.

Sofilic, T., Rastovcan-Mioc, A., Cerjan-Stefanovic, S., Novosel-Radovic, V. and Jenko, M. 2004. Characterization of steel mill electric-arc furnace dust.

Journal of Hazardous Materials, B109: 59-70.

UN ECE Steel Series. 1999. Iron and steel scrap 1999. New York/Geneva, 141-155.

United States Environmental Protection Agency (US EPA). 2007. Regulatory impact analysis for USEPA's 2007 supplemental proposed revisions for the industrial recycling exclusions of the RCRA definition of solid waste. Economics Background Document, Office of Solid Wastes (OSW), Economic, Methods and Risk Analysis Division (EMRAD), Washington DC 20460, USA, page 235.

US EPA. 1992. The toxicity characteristics leaching procedure, US Code of Federal Regulations, 40th ed., Part 261, Appendix II.