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Effect of electric arc furnace dust (EAFD) on properties of asphalt cement mixture

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ABSTRACT

Electric arc furnace dust (EAFD) is one of the by-products of steelmaking industry which has been classified as hazardous due to containing some heavy metals such as Zinc, Cobalt, Copper, Lead or Cadmium. This research aims at solving the problem of this hazardous waste by solidification/stabilization through mixing it with asphalt cement to be used for road construction. EAFD was used as an additive to the asphalt concrete mixtures with five percentages (0%, 5%, 10%, 15% and 20%) by volume of binder. Penetration, ductility, specific gravity, softening point, flash point, fire point and rotational viscosity were analyzed. It was found that while the penetration and ductility were decreasing with the increase of EAFD concentration in the binder, specific gravity, softening point, flash point, fire point and rotational viscosity were increasing. Finally it has been concluded that the results are promising for dual achievement (1) to solve an environmental problem and (2) to use the EAFD for road construction.

1. Introduction

The use of Electric Arc Furnace technology in the steelmaking industry has been increasing considerably over the last four decades, it increased from being 14% in 1970 to 34% in 1998 of the total technologies used for steel production (Sofilić et al., 2004). As a result of this increase, it has been reported that many pollutants are released to atmosphere during the steelmaking process when using this technology such as dust, carbon and nitrogen oxides and organic compounds where the amount of dust generated per ton of steel product is estimated to be 15–20 kg. The world generated electric arc furnace dust (EAFD) per year is estimated to be around 3.7 million tons (Néstor and Borja, 2003).

This dust is classified by the European Waste Catalogue and the Environmental Protection Agency as a hazardous waste, not disposable in the environment, because it contains hazardous, leachable elements such as zinc, lead or cadmium (Guézennec et al., 2005; Cubukcuoglu and Ouki, 2009; Pavao et al., 2009). Fig. 1 shows formation of EAFD from the steelmaking process.

It has been also reported that the recycling of these hazardous metals is still expensive and therefore alternatives should be analyzed and investigated; one of these alternatives is the waste immobilization techniques to prevent the free movement of these hazardous elements in the solid waste. There are three major types of immobilizing techniques: (1) the temporary containment technique, (2) cost effective solidification/stabilization techniques and (3) permanent techniques (Pavao et al., 2009; Jay et al., 2003).

It has been reported that EAFD is treated in different ways, such as: (1) recovery of valuable metals (iron, zinc and lead) before land disposal (MacRay, 1985), (2) additive to cement/concrete industry (Vargas et al., 2006; LIST., Paluchewiczz, 2007; Holter and Malinowska, 2005), (3) glass-ceramic industry (LIST., Paluchewiczz, 2007; Kavouras et al., 2007) and (4) additive to asphalt cement (ŠTUrM et al., 2009).

An estimation study of the environmental impacts of cement and asphalt with EAFD was conducted and showed that EAFD can be safely used as a component in asphalt and cement mixtures.

This study will focus on using the technology of solidification/stabilization to prevent migration and exposure of contaminants from the EAFD by mixing a binding agent with the hazardous EAFD waste. These binders could be organic binders that include asphalt, organophilic clay, oractivated carbon; and inorganic binders that may include cement, fly ash, lime, phosphate, soluble silicates, or sulfur. This study will focus on using asphalt as the binding agent (Šelih et al., 2004).

Many researchers indicated that it is possible to use additives to improve the performance of asphalt cement mixtures. There are a number of asphalt additives (or modifier) in the market.

Terrel and Epps (1998) classified modifiers which can be used in bituminous mixtures. The generic classification of asphalt

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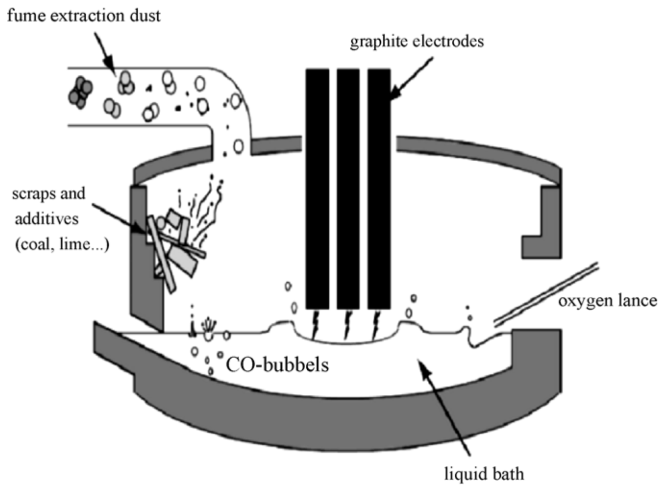

Fig. 1. Formation of EAFD from the steelmaking process (Guézennec et al., 2005).

modifiers are crushed fines, lime, portland cement, fly ash, carbon black, sulfur, lignin, natural rubber, styrene-butadiene (SB), styrene–butadiene–styrene (SBS), recycled tires, polyethylene, polypropylene, ethyl-vinyl-acetate (EVA), polyvinyl chloride (PVC), rock wool, polyester, fiberglass, manganese salts, lead compounds carbon, calcium salts, recycling and rejuvenating oils, hardening and natural asphalt, amines, and lime.

Carbon black was used as mineral filler in a study by Rostter et al. (1977). They concluded that due to the fineness of the carbon black, it became part of the asphalt when completely dispersed in the asphalt. This increases the viscosity of the asphalt unless fluxing oil is used, which also aids in dispersion of the carbon black throughout the asphalt.

Goetzce and Monismith (1978) reported on analytical study of the applicability of asphalt rubber for reducing reflecting cracking. Asphalt–rubber interlayer was found to reduce predicted crack tip stresses which should result in reducing reflective cracking of over layer.

Khedaywi et al. (1987) have studied the effect of limestone dust on the properties of asphalt cement and shown that limestone dust caused a decrease in the penetration and the ductility values with the increase in dust concentration in the binder. The softening point and the specific gravity were increasing with the increase of limestone dust concentration in the binder.

Khedaywi and Abu-Orabi (1989) have studied the effect of oil shale ash, rubber ash, husk ash, and polyethelene on properties of asphalt cement. They concluded that penetration and ductility of the binder are inversely proportional with the increased amount of these additives in the binders. Also the softening point of these binders is directly proportional with the added amount of additives in the binder. Specific gravity of the binder is directly proportional with the added amount of ashes and inversely proportional with the added amount of polyethylene in the binder.

Khedaywi et al. (1993) have investigated the effect of rubber on properties of asphalt concrete mixtures. Results indicated that asphalt–rubber concrete mixtures have lower stability and higher flow than do asphalt concrete mixtures without rubber.

Al- Massaeid et al. (1994) have evaluated the effect of olive husk on properties of bituminous concrete. They concluded that the olive husk material improved workability and stability and reduced the optimum binder content of bituminous mixes.

Khedaywi et al. (1996) conducted a study on the effect of phosphate slimes on properties and performance of asphalt–cement and asphalt concrete mixtures. The results showed that the increase of phosphate slime showed an increase then a decrease in Marshall

Table 1
Properties of asphalt.

Property	Value	ASTM method
Penetration (0.1 mm) 25 °C, 100 g, 5 s	67	D 5
Ductility (cm) at 25 °C	110	D 113
Specific gravity at 25 °C	1.01	D 70
Softening point (°C)	50.3	D 36
Flash point (°C)	312.5	D 92
Fire point (°C)	318	D 92
Rotational viscosity (Mpa s)	330	D 4402

Stability, air voids increased, and no improvements in the moisture susceptibility of asphalt concrete mixtures. In his study, utilization of the indirect tensile test to evaluate the effectiveness of additives on moisture sensitivity of asphalt concrete mixtures, Khedaywi (1992) concluded that 1.0% lime slurry additive was the best additive to use with asphalt–crushed limestone concrete mix and 2.0% lime slurry additive was the best additive to use with asphalt–valley gravel concrete mixture.

2. Objectives

The main objectives of this research are as follows:

- To investigate the feasibility of using the EAFD as an additive to asphalt cement.
- To analyze the effect of this EAFD on the properties of asphalt cement.
- To check the applicability of the EAFD–asphalt mixture for road construction; surface treatments for roads, airfields and other trafficked areas.

3. Material used

3.1. Asphalt cement

One penetration of asphalt cement 60–70 grade of asphalt cement was used in this study. Asphalt was provided by Jordan Petroleum Refinary Company in Zarqa/Jordan, and it is widely used in flexible pavement construction. The physical properties of this asphalt cement are shown in Table 1.

3.2. Electric arc furnace dust (EAFD)

EAFD was provided by United Iron and Steel Manufacturing Company in Jordan and it was characterized at the laboratories of the Royal Scientific Society in Jordan. The results of analysis are summarized in Table 2, where it shows that the major components are ferric oxide (Fe_2O_3 = 32%) and zinc oxide (ZnO = 29%). All

Table 2
EAFD characterization.

Compound	Percentage
Fe_2O_3	32
ZnO	29
Al_2O_3	1.28
Cu_2O	0.7
SiO_2	4
Loss on ignition @ 1000 °C	11.63
$CaSO_4$	3.43
$CaCl_2$	1.91
CaO	1.4
NaCl	5.79
K_2O	2.7
MgO	4.66
Others	1.5