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ARTICLE

Analytical Study on the Effect of Electric Arc Furnace Dust (EAFD) on the Rutting of Asphalt Concrete Mixtures

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ABSTRACT

As a byproduct of the steelmaking process, significant amounts of hazardous electric arc furnace dust (EAFD) are produced. Utilizing the solidification/stabilization technology with asphalt mix is one way to safeguard the environment from its negative effects. Rutting was used as an indicator to assess the asphalt mixture with EAFD since it is an important factor in pavement design. This study's major goal is to ascertain how EAFD affects the rutting of asphalt-concrete mixtures. To evaluate the ideal asphalt content, the Marshall test method was applied to asphalt-concrete mixtures. EAFD was added to the asphalt cement in four different volume percentages as a binder addition. Then, using the Universal Testing Machine, participants were exposed to a replica of the rutting test (UTM). Experiments were conducted at 25 °C, 40 °C and 55 °C, and at frequencies of 1 Hz, 4 Hz and 8 Hz. Rutting was measured for each specimen. Test results showed that rut depth has a negative correlation with EAFD% and a positive correlation with temperature. The use of EAFD has dual advantages, protecting the environment from the adverse impact of EAFD and reducing the cost of asphalt mix without jeopardizing pavement performance.

Keywords: EAFD; Rutting; Asphalt mixtures; Temperature; Loading frequencies

1. Introduction

Electric arc furnace dust (EAFD) is classified as a pollutant that the steelmaking sector is most concerned about. It is categorized as hazardous waste

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from a characteristic standpoint, based on its chemical and physical characteristics, according to the environmental protection agency (EPA) of the US [1]. From a quantity perspective, it has been reported that for every ton of steel manufacturing, approximately 15-20 kg are generated as a by-product [2,3]. According to recently published research, only about 2.5 of the 6 Mmt of EAFD produced annually worldwide are recycled [4].

The main concern comes from the fact that it contains iron oxide, lead, cadmium, and a high level of zinc which makes it highly hazardous if not managed properly [5].

Four common methods were reported to manage the hazardous content of the EAFD properly. These include: (1) The stabilization/fixation processes where the hazardous components such as zinc, cadmium and lead are encapsulated in a binding agent such as cement, asphalt, fly ash, and clay; (2) Acid based extraction where metals of interest are dissolved, however this method requires excessive amounts of acid as the average pH of dust is more than 11, (3) Pyrometallurgical processes where lead and zinc are removed by fuming and then condensing, however there is a high concern of possible contamination of neighboring areas due to lead fall out, and (4) Caustic based processes which employ simple chemistry for the recovery of amphoteric nature of the hazardous metals [6,7].

Asphalt is known as exceptional binder due to its unique characteristics, which include its high degree of hydrophobicity, extraordinary chemical and biological stability, creep, inertness, and environmental stability, widespread production, ease to segregate the waste from the asphalt matrix relatively easily in the future, and exceptional resistance to chemical and biological influence [8,9].

Additives may be utilized to improve the performance of asphalt concrete mixtures, according to numerous research. The effects of different extenders and fillers on the properties of asphalt concrete mixtures have been the subject of numerous investigations [10].

Results from an earlier study on the combination of asphalt and EAFD by Alsheyab and Khedaywi (2017) showed that the addition of EAFD has a favorable impact on improving the resilient modulus and creep stiffness and lowering the accumulated micro-strain in the majority of operating conditions at different temperatures and frequencies [11].

One of the challenges of asphalt pavement is rutting, which is the term used to describe the permanent deformation or consolidation in asphalt pavement over time. It can be caused by a lack of compaction, insufficient pavement thickness or weak asphalt mixtures. This research study will be analyzing the asphalt concrete mixture with EAFD on rutting formation.

2. Material used

2.1 Aggregate

In this investigation, limestone material that was imported from Jordan's northeast was utilised. Aggregate was graded in accordance with Jordan's Ministry of Public Works and Housing (MPWH) regulations. **Table 1** provides a summary of the overall gradation. **Table 2** lists the aggregate's characteristics.

Table 1. Gradation of aggregate used in the mixtures.

Sieve size	Specification limits* (Passing %)	Passing % (midpoint)
2.54 cm	100	100
1.905 cm	90-100	94
1.75 cm	71-90	81.5
0.952 cm	56-80	67
0.508 cm	35-65	51
0.238 cm	23-49	37
0.085 cm	14-43	27.5
0.03 cm	5-19	11
0.018 cm	4-15	9
0.0075 cm	2-8	5.5

*Ministry of Public Works and Housing (MPWH) specification wearing mix.

The properties of aggregate used in this research are shown in **Table 2**.

Table 2. Aggregate characteristics used in this study.

Aggregate type (Limestone)	ASTM test Designation	Bulk specific Gravity	Apparent specific Gravity	Absorption
Coarse	C127	2.54	2.67	2.1%
Fine	C128	2.49	2.71	3.9%
Mineral filler	C128	2.66	2.79	4.1%

2.2 Asphalt cement

There was only one asphalt cement grade (60-70 penetration) used. The asphalt's physical characteristics are displayed in **Table 3**.

Table 3. Asphalt's physical characteristics.

Characteristics	Methods	Test Result
Penetration (0.1 mm), 25 °C,100 g, 5 sec	ASTM D 5	66
Ductility (cm) at 25 °C	ASTM D 113	106
Specific gravity at 25 °C	ASTM D 70	1.02
Softening point (°C)	ASTM D 36	50.2
Flash Point (°C)	ASTM D 92	311.99
Fire Point (°C)	ASTM D 92	317.99

2.3 EAFD

A sample of EAFD, provided by one of the Jordanian steelmaking factories, was analyzed in the Royal Scientific Society's research facilities. The composition and main components of the EAFD samples used in this investigation are shown in **Figure 1** below, including ferric oxide (Fe_2O_3 = 32% and zinc oxide (ZnO = 29%), both of which passed through No. 200 sieve.

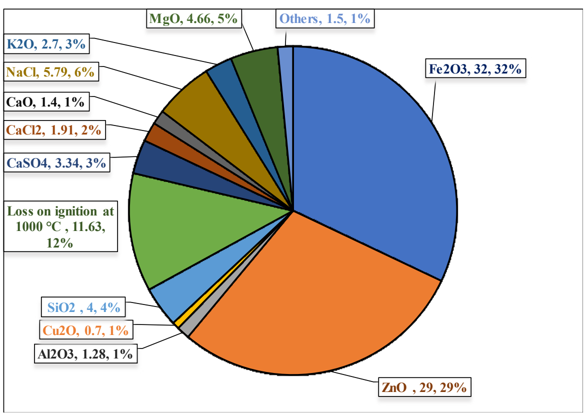

Figure 1. Electric arc furnace dust composition.

3. Laboratory experiments

3.1 Preparations of EAFD asphalt binders

To assess the effect of EAFD on the rutting of asphalt concrete, four percentages of EAFD (5, 10, 15, and 20%) by volume of asphalt were used.

For each specimen, weight volume% conversions for the asphalt and EAFD were created. For each specimen, the asphalt was heated while the corresponding volume of EAFD was added and blended, ensuring a homogeneous mixture. After the mixing procedure, the heated aggregate was blended with the EAFD-asphalt binder to produce instances of EAFD-asphalt concrete.

3.2 Determination of the optimum asphalt content for conventional mixes

Marshall test technique protocol (ASTM D1559) was used to determine the ideal asphalt percentage by weight of the entire mix. For three samples of various percentages of asphalt (4.0, 4.5, 5.0, 5.5, and 6%), the stability, flow, air voids, unit weight, and mineral aggregate voids were examined. The average of asphalt contents that satisfy optimal stability, ideal unit weight, and 4% air voids was found to be the best asphalt content. 5.4% of the asphalt concrete mixture's total weight was the best value that could be obtained.

3.3 Static uniaxial loading strain test

To determine the resistance of asphalt concrete mixtures to permanent deformation, specimens subject to unconfined uniaxial loading involve the application of an astatic load to a sample for one hour loadings at varied temperatures (25 °C, 40 °C, and

55 °C). This test was according to the UTM Reference Manual and BSI criteria (1996).

The Marshall specimens were examined using the UTM with varied concentrations of waste EAFD (0, 5, 10, 15, and 20% volume of the binder). The specimen was leveled if the difference between the two thickest measurements was higher than 2% of the mean or average outside diameter. Six measurements of the specimen height were obtained. Samples underwent a series of temperature tests after being exposed to an appropriate current of air circulation for 24 hours while reaching the test temperature (25 °C, 40 °C, and 55 °C). Grease was evenly and sparsely put to the end of the specimen to lessen friction. Grease was removed from the surface using a cloth.

Using software under a pressure of 10 KPa for 20 seconds, conditioning was made. For one hour, a static load of 100 KPa was applied to the sample. Then, linear variable displacement transformers were used for leveling (LVDTs). With the aid of software, measurements of temperature and rut depth were made. **Figure 2** depicts a universal testing device. (UTM) and environmental chamber.

Figure 2. Universal testing machine (UTM) and environmental chamber.

4. Results and discussion

4.1 Effect of waste EAFD on rut depth

Table 4 shows the results of rut depth at three temperatures (25 °C, 40 °C, & 55 °C).

Table 4. Effect of EAFD on rutting in (mm).

Temperature (°C)	% EAFD by Volume of Binder				
	0	5	10	15	20
25	0.2153	0.1636	0.1076	0.0883	0.0775
40	0.4305	0.2800	0.1937	0.1464	0.1119
55	0.5252	0.3487	0.2540	0.1937	0.1506

At each temperature of the three studied ones, it was realized that the rutting depth was decreasing with the increase of the percentage of EAFD as shown in **Figure 3**.

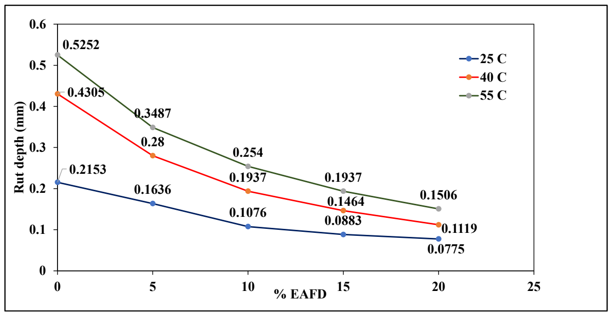

Figure 3. The effect of temperature on the rut depth.

The rut depth was decreasing with the increase of the EAFD waste content in the binder. This means that the addition of EAFD improves the characteristics of the pavement in terms of avoidance of rutting. The percentage of avoidance of rutting (reducing the rut depth) varies according to temperature and the percentage of added EAFD. The effect of increasing EAFD ON in the concrete mix is presented in **Figure 4**, which it shows that rut avoidance is improving as the EAFD percentage goes higher. Also, it shows that at 40 °C it gives the best performance in terms of rutting depth where it was the lowest at any percentage of EAFD.

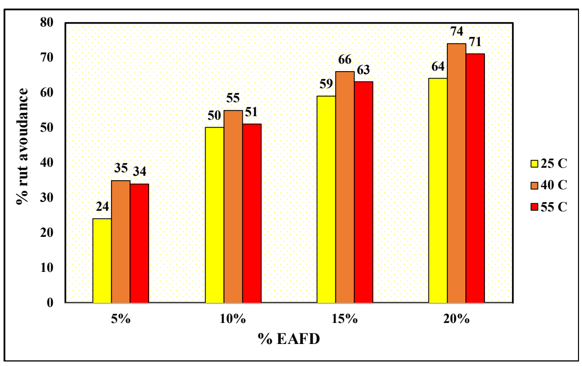

Figure 4. The effect of EAFD added percentage on the reduction of rut depth.

4.2 Regression analysis

Regression analysis was developed to be used as a technique to calculate the rutting value at any other percentage of waste EAFD. For each studied temperature, one equation was obtained as a rut depth function of waste percentage, as summarized in **Table 5**.

Table 5. Developments of models for rut depth (RD) (mm).

Temperature (°C)	(X = % waste EAFD by Volume of Binder)	R^2
25	RD = –0.0181X + 0.4753	0.9221
40	RD = –0.0154X + 0.3867	0.9151
55	RD = –0.007X + 0.2006	0.9188

5. Conclusions

Conducted research led to the following points:

1) Mixing asphalt with EAFD improves the mechanical qualities of the pavement, as the rut depth decreased as the EAFD% was increased.

2) There is a positive association between the rut depth and the temperatures that were observed; it increased as the temperature rose, reaching its highest level at 55 degrees Celsius, then 40 degrees Celsius, and so on.

3) The addition of EAFD to asphalt concrete offers a potentially effective way to address the global environmental problem brought on by this hazardous waste.

4) The asphalt mixture containing EAFD offers an affordable substitute for the pricey management and treatment of EAFD.

Conflict of Interest

There is no conflict of interest.

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