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Marshall stability and flow tests for asphalt concrete containing electric arc furnace dust waste with high ZnO contents from the steel making process

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HIGHLIGHTS

- EAFD waste with high ZnO content was successfully used with asphalt concrete.
- From different mixtures of asphalt and EAFD, the optimum asphalt content was calculated.
- According to MANOVA analysis, the most influencer factor is the content of EAFD, rather than asphalt content.

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ABSTRACT

Metallurgical industries worldwide produce many hazardous wastes with terrible consequences for the environment. In this research, Electric Arc Furnace Dust (EAFD) has been mixed in asphalt concrete. EAFD is a hazardous waste containing heavy metals. EAFD modified asphalt was fabricated by mixing asphalt binder 60/70 with in 1, 5, 10 and 20 wt%. Asphalt concrete samples were fabricated with EAFD modified asphalt and mineral aggregates with 0.0 (neat asphalt), 10, and 20 wt% of EAFD. Marshall stability tests were used to evaluate stability, flow, stiffness, bulk specific gravity, maximum theoretical gravity, density, air voids percentage, voids in mineral aggregate, and voids filled with binder. The optimum asphalt content for mixtures with 10 and 20 wt% of EAFD was found at 6.0 and 5.45 wt%, respectively, while for the mix without EAFD the optimum asphalt content was at 5.61 wt%. Stability, stiffness, bulk specific gravity, and air voids contents, increased with the addition of EAFD. Maximum theoretical gravity and voids filled with binder decreased with the addition of EAFD content. Voids in mineral aggregates increased and then decreased with the increase of EAFD content. Flow and density decreased and then increased with the addition of EAFD content. MANOVA analysis was conducted to study the effect of each factor. All data was adjusted, and the corresponding model equations are presented and can be easily applied in industry.

1. Introduction

Asphalt concrete is a composite material itself containing asphalt cement as binder, coarse and fine aggregates, fillers and admixtures. Asphalt cement is the binder material and aggregates and fillers are the skeleton of asphalt concrete [1,2]. Asphalt binder is integrated by asphaltenes, which are the hardest part in the asphalt, and by maltenes, which are the less viscous and can be divided into resins, aromatics and saturates [3,4]. A typical 60/70 asphalt cement contains 2% of saturates, 73% of aromatics, 7% of resins and 18% of asphaltenes [3].

Asphalt concrete is one of the common materials used by mankind in very large scale applications including roads and waterproofing, due to its high resistant to durability, water resistant and good stability properties [5–7]. Nevertheless, asphalt cement is a material with some limitations such as its low thermal stability and high degradation by UV radiation and thermal susceptibility [8,9]. Since asphalt is used in large scale applications, solutions for its limitations require inexpensive ways to solve problems in order to be feasible as pavement.

There are different strategies to improve the asphalt performance and to deal with the above and other limitations. Among them is introducing modifiers or admixtures to asphalt binder

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[10–13]. Polymer modifiers are the most used, such as styrene-butadienestyrene (SBS) and polyethylene (PE) used to improve the high temperature performance of asphalt and used to increase its compressive strength [13,14]. Mineral fillers have been commonly used in asphalt as modifiers as well [5,6,15–23], such as rice husk ashes and andesite, which have improved Marshall stability in asphalt concrete [5,7].

Ceramic nano-additives have been very successful in diverse composite materials improving their properties [24,25]. Typically asphalt is in combination with other materials and although asphalt concrete is used in large scale applications, its macroscopic properties directly depend from its micro and nanoscale properties. Thus, it is not a surprise that nano-additives have shown substantial improvement in asphalt properties in durability, fatigue life and routing were mainly obtained with nanoadditives (such as nanoclay, carbon nanotubes, and other nano structures made of silica, alumina, and titanium dioxide), [26–29].

Today, there is a new need in the world regarding the utilization, stabilization, and disposal of wastes, and due to the amount of asphalt used, its impact in environment can be quite significant in holding some of these wastes. Therefore, there is an increase of using diverse materials as a solution to hold wastes [30–34] and asphalt as one of the most important material worldwide by production has not been the exception [35–40].

On the other hand, Electric Arc Furnace Dust (EAFD), is a waste byproduct from metallurgical industry [3,41–43] and it has been used into asphalt cement showing improvements in some features such as viscosity, penetration and softening point [3,44]. Other researchers have stabilized EAFD in other matrix such as cement [33,45] and others have recovered the worth material from this waste by hydrometallurgical and pyrometallurgical means but sometimes those processes are quite expensive, less efficient and sometimes they produce other undesirable wastes [41,46,47].

EAFD is produced in the steelmaking process in millions of tons worldwide approximately 16,000–32,000 tons annually [3]. It is considered as a hazardous waste by EPA (Environmental Protection Agency), because of its high content in oxides of heavy metals [3,48]. Electric Arc Furnace dust can be produced in temperatures up to 1800 °C in the steel making process, extracted as a volatized particulate material by fume extractors and then disposed in baghouse systems [3]. Therefore, this material is stable to high temperatures because of its origin. EAFD waste is harmful for the environment and water resources because of its chemical composition contains heavy metals [49]. The amount and type of these metals will depend not only of the particular raw materials used during the process, such as the scratch used in casting but also will be a function of the process and if the waste is properly used or disposed [3,50].

There had been some attempts to stabilized EAFD in the world. For instance, Alsheyab et al. used EAFD with high FeO content to modify asphalt [44,51]. Colorado et al. stabilized this waste with cement paste [33]. Other authors have use EAFD in cement mortars to decrease its storage volume which goes to landfills [52] because it is an expensive and pollutant process due to the high volatility of some components such a chromium [53]. Others have used EAFD to produce sintering bodies with promising mechanical properties [54].

In this paper it is presented an inexpensive and effective way to treat EAFD wastes by a technology called solidification/stabilization which is a manner to solve the problem of disposal solid wastes by mixing with any material which has cementitious characteristics [55]. A high ZnO content EAFD waste was used to evaluate Marshall Stability and flow tests on asphalt cement and concrete previously modified with EAFD. The dust used in this research contains a large amount of ZnO content [56].

2. Experimental

Asphalt concrete samples were fabricated in order to evaluate stability and flow properties in asphalt cement, which is asphalt binder modified with EAFD. Mixtures were tested in a Test Universal Machine. In this research, we used the following raw materials:

2.1. Materials

2.1.1. Aggregates

The aggregates used in this research were obtained from a quarry located in Bello, Colombia. Their granulometry is shown in Table 1.

2.1.2. Asphalt

Asphalt grade 60–70 was supplied by the Colombian national oil company. Their properties are summarized in Table 2.

2.1.3. Electric arc furnace dust (EAFD)

EAFD comes from a national company which produce steel, the supplied powder corresponds to a passing the 200 sieve. EAFD composition was measured by X-ray fluorescence with a Thermo model Optim'x equipment and its results are shown in Table 3. It is observed that the main components are iron oxide (Fe_2O_3: 21.5%) and zinc oxide (ZnO: 50.4%).

The microstructural characterization of EAFD waste has been conducted in an X-ray diffraction (XRD) equipment type XPert PANanalitical Empyrean Series II. Samples were grinded a sieve 400 was obtained. CuK radiation of 0.15 nm between 2θ since 10°–80° was used and subsequently the corresponding pattern was analyzed by the HighScore Plus software.

For SEM, EAFD samples were mounted on a glass slide and sputtered in a Hummer 6.2 system (15 mA AC for 30 s) creating a film of gold approximately 1 nm thick. The SEM used was a JEOL JSM 6490LV in high vacuum mode.

2.2. Samples preparation

2.2.1. Asphalt modified

The modification of asphalt was conducted in a Velp Scientifica mechanical stirrer, by mixing EAFD with asphalt at 155 °C for 1 h at 200 rpm, this in order to reach a suitable homogeneity. The proportions used to modify asphalt were 10.0 and 20.0 wt% of EAFD. These formulations were selected because for 1 and 5 wt% of EAFD no significant changes in the mechanical properties according to analysis ANOVA were found. Table 4 shows the summary of ANOVA analysis, where the symbol * means there is a significant difference between two different levels of the experiment. Mixtures were left to cool down at room temperature to study their main properties, properties of modified asphalt can be seen in Table 5. After preparing these mixtures the modified asphalt was reheated to prepare asphalt concrete samples.

2.2.2. Asphalt concrete

After modification of asphalt, asphalt concrete samples were manufactured. Cylindrical samples of 101.6 mm diameter and 63.5 mm height. Aggregates were dried in an oven for 24 h, then aggregates were weighed to obtain the necessary weigh for every single sample and then they were taken in the furnace again for 24 h. Samples of asphalt concrete were prepared with 5.0, 5.5 and 6.0 wt% of asphalt in the mix. Two specimens for each formulation were prepared and Table 6 summarizes the proportions of each mixture. The mixture of modified asphalt and aggregates was preheated at 160 °C for one hour. For all samples, approximately 1200 g per sample were weighted and poured in cylindrical