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Review

Effect of field compaction mode on asphalt mixture concrete with basic oxygen furnace slag

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ABSTRACT

Basic oxygen furnace (BOF) slag is applied as an aggregate to construct an asphalt concrete test pavement road, which is constructed using static, vibratory, and semi-static-vibratory rolling at various compaction numbers. The effects of field compaction numbers, rolling methods, and cooling time on BOF slag asphalt concrete pavement are evaluated. This study suggests that, if the pavement is opened to traffic and the strength development and stability of BOF slag asphalt concrete are simultaneously considered, the pavement should first be compacted by vibratory rolling approximately 3–4 rounds, followed by static rolling to complete the construction of the pavement.

Contents

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1. Introduction

To improve the pavement quality or increase the reuse of industrial waste, a number of novel pavement materials and aggregate gradations have been developed for asphalt concrete. An example is the application of basic oxygen furnace (BOF) slag to asphalt concrete. Shen et al. [1]. studied the properties of BOF slag. These authors observed that slag possesses rough surface texture and a good interlocking mechanism among aggregates, internal friction, and skid resistance. Xue et al. [2] discovered that BOF slag exhibits adhesive forces and can steadily adhere to asphalt binder. Wu et al. [3] indicated that BOF slag is a porous material and contains CaO. Moreover, slag is hydrophobic and can effectively adsorb asphalt, which can reduce the permanent deformation of asphalt concrete at high temperatures. Xue et al. [4] applied BOF slag as an aggregate to asphalt mixture. These authors found that BOF slag has a coarser surface texture than that of natural aggregates. Therefore, the following properties are characteristic of BOF slag when applied as coarse asphalt concrete aggregates: less abrasion loss, low flattening and elongation rates to increase rutting resistance, and hydrophobic character to improve water erosion on pavement.

When a new material is applied to asphalt concrete, related simulation test runs under laboratory conditions are required. However, it is important to conduct a road test of the pavement with the new or recycled applied materials. During pavement construction, the compaction stage primarily aids in the dense compaction of aggregates, increases the shear strength for asphalt mixture, reduces plastic deformation to stabilize the pavement volume, decreases pavement permeability, and improves pavement durability. Huang and Kang [5] applied a portable falling weight deflectometer to run pavement stress analyses. These authors observed that approximately 70% of vehicle loadings are transferred to the pavement via contact between the tires and asphalt concrete pavement layer. Hence, pavement quality is determined using rolling compaction. If the pavement compaction is insufficient, the asphalt mixture volume becomes unstable. After being repeatedly compacted by different vehicles, horizontal stress would be generated, leading to pavement rutting deformation.

In their study, Delgadillo and Bahia [6] suggested that increasing the compaction number might improve the asphalt concrete density and enforce the packing level between the aggregates and asphalt binder. This packing level improvement is better than that obtained by selecting a higher viscosity grade of asphalt binder. Hunter et al. [7] studied the effects of the different types of rolling devices on the properties of asphalt mixtures. These authors found that vibratory compaction improves the asphalt mixture on the resistance of permanent deformation. Moreover, the pavement rolling quality is determined by the compaction value. The common rolling equipment used in the construction of pavement is either static or vibratory.

Shen et al. [1] concluded the following by setting constant rolling temperatures and compaction numbers to simulate tests: BOF slags are similar in shape and have higher specific gravity and hardness than those of natural aggregates, which can improve the bearing capacity of asphalt concrete. Because properties such as specific gravity, hardness, and flattening and elongation rates of BOF slag are different from those of the natural aggregates, special considerations regarding the inclusion of BOF slag as a part of asphalt concrete aggregates are necessary. The effects of compaction number and type of rolling equipment on the properties BOF slag asphalt concrete pavement must be especially understood during the construction. However, few literature reports relating to the field compaction of BOF slag asphalt concrete pavement currently exist.

Furthermore, because asphalt is temperature sensitive, the rolling temperature changes the relationship between its properties, such as the asphalt aging level, amount of asphalt absorption, aggregate structure, and asphalt mixture density, and the pavement efficiency. A decrease in rolling temperature leads to an increase in air voids and a reduction of stability. Xue et al. [8] showed that when BOF slag is heated to a certain high temperature, the heat energy absorption of the slag increases. This result implies that BOF slag has good heat storage abilities.

In this study, a BOF slag asphalt concrete test pavement road is constructed. Samples of BOF slag asphalt concrete are collected in the paver for further analysis. Specimens are then generated from these samples based on the Marshall mix design. These specimens are compacted based on the design of heavy traffic flow. Each side of a specimen is compacted 75 times to determine how the properties of BOF slag mixture are affected by compaction under laboratory conditions.

Moreover, this test pavement road is based on the AASHTO T230 standard [9]. Before constructing this test road, several density steel rings are embedded in designated locations. During field compaction, two types of rollers, static and vibratory, are used, and various compaction numbers are applied by combining the application of these two rollers. The effects of different combinations of rolling methods on the variation in BOF slag asphalt concrete temperature reduction, the heat lost of the BOF slag asphalt concrete, and the working temperature reducing speed to open traffic are investigated. To compare the pavement performances of the BOF slag asphalt concrete under field and laboratory compactions, the specimens obtained from the density steel rings after field compaction are further studied to investigate such properties as stability and air voids. These test results are then analyzed to determine the influences of different compaction numbers and rolling methods on pavement performances. The differences in performance under field and laboratory conditions are also investigated. This study suggests suitable compaction numbers and combinations of rolling methods to avoid insufficient or excessive compaction for BOF slag asphalt concrete pavement.

2. Materials and methods

2.1. Asphalt and aggregates properties

The BOF slag samples applied in this study are collected from China Steel Corporation, Taiwan, and AC-20 asphalt binder is used. The asphalt binder and BOF slag and aggregate properties are presented in Tables 1 and 2, respectively.

Moreover, the aggregate flat and elongated ratio is a basic index for the evaluation of asphalt concrete bearing capacity. If the ratio is large, the aggregate is easily broken. As a result, the aggregate bearing capacity decreases and the pores and permeability of the aggregates increase. In general, approximately 7% of natural aggregates have a flat and elongated shape. However, BOF slag is a rolling-controlled product and has a lumped shape. Small flat and elongated shapes are observed for BOF slag. Hence, using BOF slag as part of aggregates increases the interlock action between the aggregates and improves the rutting resistance and life cycle of asphalt concrete.

2.2. Marshell mix design of asphalt mixture with of BOF slag

The aggregate gradation is regulated by the ASTM D3515 specification [10], and the nominal maximum size of aggregate is 19.5 mm. Moreover, 20% of the coarse natural aggregates are replaced by BOF slag, and the remaining aggregates, fine and coarse, are natural aggregates. As seen in Table 2, the specific gravity of the natural aggregates and BOF slag are 2.6 and 3.31, respectively. To meet the requirements of the volume distribution of each aggregate size, which is specified in the Marshall mix design method, traditionally, the weight ratio of each aggregate size is obtained from the volume of aggregates left in each sieve. Because these specific gravities are very different, the traditional method for obtaining the weight ratio for the mix design is not suitable. To meet the aggregate gradation distribution requirement, the volume ratios of the natural aggregates and BOF slag are used to obtain aggregate gradation for the BOF slag asphalt concrete mix design.