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Laboratory investigation of basic oxygen furnace slag for substitution of aggregate in porous asphalt mixture

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Abstract

The purpose of this study is to investigate the mixture performance and the sound absorption characteristic of porous asphalt mixture with different percentages of basic oxygen furnace (BOF) slag. Mixtures made with 0%, 25%, 50%, 75% and 100% BOF slag by volume as a coarse aggregate substitution were considered. The packing grading mixture design method (PGMDM) was applied in the design of porous asphalt. The test results show that BOF slag has high specific gravity, high absorption, high angularity, low L.A. abrasion, and low soundness compared with crushed stone (CS). The mixtures with BOF slag enhance skid resistance, moisture susceptibility, rutting resistance and sound absorption. Scanning electron microscope (SEM) used for micrograph demonstration shows that the rough surface pores and surface texture of BOF slag have a strong bond characteristic and an excellent interfacial zone for asphalt binder. The Duncan's multiple range test results indicate that the BOF slag substitution percentage is significantly different in terms of mixture performance. The CS completely replaced by the BOF slag for porous asphalt mixture is recommended to obtain the optimum performance.

Keywords: Basic oxygen furnace slag; Porous asphalt; Mixture performance; Durability; Sound absorption characteristic

1. Introduction

In recent years, a huge number of slags have been sharply increased by the rapid expansion of the steelmaking industry due to many public construction projects being progress in Taiwan. Slag is a major by-product of the steelmaking procedure; its sources usually comes from the extraction of iron ore to pig iron in a blast furnace (BF) or the conversion of pig iron to raw steel in a basic oxygen furnace (BOF). In general, 1 ton of pig iron produces about 300 kg of BF slag and 1 ton of raw steel produces about 130 kg of BOF slag. In accordance with statistical data reported by Executive Yuan of the Environmental Protection Administration, current annual production of slags are approximately 4.6 million tons which contain 65% of BF slag, 24% of BOF slag, and 11% of other slag [1].

Reuse of BOF slag as an aggregate in asphalt pavement has been used for many years in many countries [2–4]. The inherent physical properties of BOF slag produce hot mix asphalt (HMA) with high stability, good stripping resistance and excellent skid resistance [5]. On the other hand, it has higher absorption than natural aggregate has due to its porous nature, which is increased asphalt binder demand [6]. The main concern issue about BOF slag properties is its volume expansion potential, in which mainly attributed to the amount of free calcium oxide (f-CaO) and magnesium oxide (MgO) present [7]. The f-CaO comes from residual free lime to form the raw material and precipitate lime from the molten slag, which rapidly hydrates to calcium hydroxide ($Ca(OH)_2$) and causes large volume expansion. The

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MgO comes from dolomite used as a flux, which slowly hydrates to magnesium hydroxide ($Mg(OH)_2$) and causes volume changes that continue for many years [8,9]. Hydration of the f-CaO or MgO results in volumetric expansion and cracking of the slag. When these hydration reactions happen in an asphalt pavement, they will result in distresses such as cracking and raveling [10]. Due to the BOF slag having a higher content of f-CaO and MgO than BF slag, a method has been developed to eliminate the problem of volume expansion such as age or accelerated hydration reaction. Moreover, the asphalt binder coats the BOF slag that prevents hydration of the calcium and magnesium oxide. This advantage may result in an increase of volumetric stability for asphalt mixture with the BOF slag.

Porous asphalt has an excellent advantage in that it does not only drain water from the pavement surface but it also can reduce traffic noise generation. Although many researchers have investigated the topic of utilizing the BOF slag in open-graded friction course, little work has been published on porous asphalt. Environmental protection considerations are increasingly affecting the supply of aggregate in Taiwan, which results in natural aggregate shortages. Thus, reuse of BOF slag as an aggregate is an attractive alternative to solve this problem. In this study, a laboratory investigation was undertaken to evaluate the mixture performance and the sound absorption characteristic of porous asphalt mixture which used BOF slag as a coarse aggregate substitute for mixtures. The purpose of this study was to present the effects of the BOF slag substitution percentage on porous asphalt mixture.

2. Materials and experiments

2.1. Aggregates and asphalt binder

The coarse BOF slag used in this study was obtained from commercial steel company. The product is processed by crushing and screening to manufacture products of particular maximum sizes and gradations. In order to deal with the volume expansion problem, BOF slag is stored (aging) for 3 years in an outdoor environment prior to use of the material as an aggregate substitutes. River crushed stone (CS) and crusher fines used as a mineral filler were obtained from a local aggregate supplier. A styrene–butadiene–styrene (SBS) modified polymer asphalt binder was obtained from a commercial asphalt manufacturer.

2.2. Testing program

The blending of BOF slag as a substitute for coarse CS aggregates was done on a volume basis to obtain correct volumetric proportions in the mixture. Coarse and fine aggregates were classified as materials retained on and passing through the 4.75 mm sieve (No. 4 sieve), respectively. Five different substitution percentages of porous asphalt mixtures incorporating 0%, 25%, 50%, 75% and 100% BOF slag by volume as a coarse aggregate substitution were considered. All mixtures have a nominal maximum size of 19 mm.

Two main aspects are investigated in this study. One is mixture performance. The other is sound absorption characteristic. The tests of skid resistance, moisture susceptibility and permanent deformation were used for determining the mixture performance. The sound absorption coefficient of mixtures with various BOF slag substitution percentages were measured for investigating sound absorption characteristic. Based on the laboratory test results, a statistical analysis was performed to evaluate the significant difference and to determine the optimum substitution percentage.

To observe the interface characteristic between BOF slag and asphalt binder, the fractured section of the BOF slag mixture was further investigated by use of a scanning electron microscope (SEM).

2.3. Mix design method

The porous asphalt mix design was performed through the PGMDM. The major difference from other mixture design methods is an increased stability of aggregate skeleton structure that relies on a concept of coarse aggregate packing and, hence, provides an excellent interlocking mechanism. The air void contents in porous asphalt mixture are governed by amount of filler materials [11].

To accomplish volumetric substitution of aggregate between the BOF slag and CS, the specific gravities of different particle sizes of the coarse aggregates were determined. The data regarding gravities provides the basis for blending of BOF slag as a substitution of coarse CS aggregates. In order to ensure that the interlocking mechanism of coarse aggregate was obtained, aggregate blendings incorporated different BOF slag substitution percentages were individually found out minimum voids in coarse aggregate (VCA_{min}) by performing the packing procedure. The vibrating table method (ASTM D4253) was used to compact the coarse aggregates.

The proper amount of filling materials added was determined by drawing a plotted graph, which corresponded to the amount of filler material added and air voids. The optimum asphalt contents in porous asphalt are determined in according to the standard procedures proposed by the Japan Road Association (JRA) [12]. Un-compacted porous asphalt mixtures were prepared at varied asphalt contents with 0.5% increments. Draindown tests were conducted on un-compacted porous asphalt mixtures at 175 °C following the AASHTO T305. Then, all Marshall specimens were compacted to 50 blows per face with the standard Marshall hammer.

2.4. Mixture performance and sound absorption testing

2.4.1. Skid resistance

Skid resistance tests were evaluated based on tests performed in accordance with ASTM E303 procedures. The British pendulum skid resistance device is used to measure