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Performance evaluation of asphalt concrete test road partially paved with industrial waste – Basic oxygen furnace slag

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HIGHLIGHTS

- The properties of basic oxygen furnace (BOF) slag are superior to natural aggregate.
- The rutting resistance of BOF slag asphalt concrete (AC) surpasses conventional AC.
- The pavement service performance of BOF slag AC surpasses that of conventional AC.

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ABSTRACT

In this paper, the analysis results of test roads constructed using conventional asphalt concrete (AC) and test roads constructed using basic oxygen furnace (BOF) slag AC are compared. Various lab tests, such as the Marshall test and measurements of the indirect tensile strength and resilient modulus, were performed; in situ tests measuring rutting, flatness, and skid resistance were also performed. The performances of both BOF slag and conventional AC showed minor differences after half of a year of service. However, the performance of conventional AC was worse than that of BOF slag AC after 2 years of service. These findings suggest that BOF slag AC pavement can effectively extend the service life of roads.

1. Introduction

When traffic volumes increase, the rutting and deformation of pavement and concavity are easily observed, and extending the service life of pavement has become a challenge in the field of pavement engineering. Basic oxygen furnace (BOF) slag, an industrial by-product in Taiwan, is a solid product of flux and steel slag produced through a cooling process from blowing liquid iron into steel [1]. Because the BOF slag has a coarser surface texture than that of the natural aggregates, the adhesive force between BOF slag and asphalt binder was improved when the BOF slag was applied as an aggregate to the asphalt mixture [2]. Wu et al. [3] noted that BOF slag could be characterized as a porous material and could improve the absorption of the asphalt binder in asphalt concrete. The permanent deformation produced at elevated temperatures for asphalt concrete (AC) pavement was reduced. Shen et al. [4] replaced coarse aggregate with 0%, 25%, 50%, 75%, and 100% BOF slag by volume in porous asphalt concrete. Their test results showed that BOF slag was characterized by a low L.A. abrasion and soundness and high angularity, absorption, and specific gravity when compared with crushed stone. Mixtures utilizing a BOF slag replacement performed better than conventional aggregates in terms of rutting resistance, moisture susceptibility, sound absorption, and skid resistance. Yuan [5] utilized BOF slag in porous AC. He noted that the addition of BOF slag did not increase the amount of asphalt used in porous AC. Moreover, the rutting and surface friction in an AC pavement increased when the amount of BOF slag introduced was increased, and the noise generated by vehicles on pavement was decreased. Chen et al. [6] studied the bonding behavior between BOF slag and an asphalt binder using X-ray diffraction (XRD), a modified boiling water test, and a self-designed tensile test. The test results showed that because the BOF slag was encapsulated by hydration products, the binder was protected by the BOF slag from being stripped by boiling water. In their study, Lin et al. [7] suggested that BOF slag is suitable for application to porous asphalt pavement. Haritonovs et al. [8] used BOF slag and three other materials to manufacture dense graded AC 11 mixtures. They noted that the use of BOF slag mixed with dolomite waste sand and other unconventional aggregates for manufacturing asphalt mixtures could provide a high resistance to plastic deformations and to fatigue failure. Moreover, Hsu [9]

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noted that when BOF slag was utilized in dense graded AC pavement, the required amount of asphalt binder decreased with increased amounts of BOF slag added as a replacement. Because the BOF slag had a larger specific gravity and a small volume, the amount of binder utilized was reduced. Lin et al. [10] applied BOF slag to stone mastic asphalt (SMA). They found that the rutting resistance of SMA with the BOF slag replacement was better than that of the SMA with natural aggregates. In this case, they suggested that the BOF slag was superior to natural aggregates.

When the same distance and time for transporting the asphalt mixture were considered, Huang et al. [11] noted that an asphalt mixture with 40% BOF slag replacement provided better heat storage and presented a longer paving time than did a conventional asphalt mixture. Moreover, the temperatures of pavements with BOF slag replacement at 3 cm and 5 cm below the surface were 2–4 °C lower than those of conventional pavement. Xie et al. [12] studied the moisture sensitivity and permanent deformation of BOF-slag-based pavements and conventional pavements and found that BOF-slag-based asphalt pavements presented better resistance to moisture and permanent deformation than did conventional asphalt pavement. Huang et al. [13] used BOF slag as an aggregate to construct a test AC pavement road. Three rolling methods, static, vibratory, and semi-static-vibratory, were utilized in the construction of the test road. A better performance for BOF-slag-based AC pavement was obtained by first compacting the pavement using approximately 3–4 rounds of vibratory rolling. Then, the construction of the BOF slag AC pavement was completed by static rolling.

As presented above, the properties of BOF slag applied as an aggregate to AC pavement have been demonstrated to be better than those of natural aggregates. However, very few in situ test road studies related to BOF slag applied as an aggregate to AC pavement have been performed. In this study, two test road sections were constructed using BOF slag and conventional AC. The objectives of this study are as follows:

(1) The two-year performances of BOF slag and conventional AC pavements are compared.
(2) The properties of in situ drilled core specimens for BOF slag and conventional AC pavements are studied.
(3) The differences in pavement mix designs for BOF slag and conventional AC pavements are discussed.
(4) The temperature drops with BOF slag and conventional AC pavements are investigated.

2. Test road and materials

2.1. Test road

Because of limited construction budgets, many pavement maintenance administrations cannot follow overlay pavement design methods (set either by Asphalt Institute, AI, or AASHTO) for the maintenance of pavements when they become damaged. Maintenance administrations rely on their experiences in pavement planning or design to maintain damaged pavements. For example, when a 5-cm-thick pavement surface becomes damaged, the damaged section can be removed and repaved with AC of the same thickness. Hence, the proposed test roads were developed following this regular maintenance principle. In this study, a section of damaged asphalt pavement road was selected as the test road. A section of damaged surface pavement with a thickness of 5 cm was removed for the test road, and 5-cm-thick, 200-m-long sections of BOF slag AC and conventional AC were then paved. The IV-C dense grade mix design and an AC-20 asphalt binder were utilized with the BOF slag and conventional AC. The test road sections were categorized as two-way agricultural area roads and were located in Pingtung County, Taiwan. The original road was mainly designed for use by mid- to small-sized vehicles. However, because the test road was close to gravel exploitation sites, a few heavy trucks were observed. According to AI MS-2, the equivalent single-axle load (ESAL) for this test road was 2.97×10^6, categorizing it as suitable for a medium traffic volume.

To obtain the road base information, a dynamic cone penetrometer (DCP) was used for the test road. Based on ASTM D6951-03, the strength of the road base was analyzed using the limit values of the calculated DCP index. Moreover, a drilled core sampling method based on AASHTO T230 was utilized, and the sampling locations were determined by evaluating the strength of the road base of the damaged pavement. These evaluations were performed using various tests such as reflective cracking and road base subsidence. These tests provided information about the cause of the damage to the pavement in terms of either the weakness of the road base or the aging of the asphalt layer. Fig. 1 shows the results for the road base obtained from the DCP tests. As shown in Fig. 1, the base, subbase, and roadbed materials were 20 cm, 20–50 cm, and 50 cm below the pavement surface, respectively. Because the layer at 50 cm below the surface was fully compacted before the subbase was paved, a nearly straight line for the DCP result was obtained.

To obtain the basic properties of the BOF slag, natural aggregates, and fine aggregates, various tests, such as specific gravity, abrasion, flat ratio, and sieve analysis tests, were performed. The AC mix designs followed the standards of AI MS-20. To determine the optimal amount of asphalt binder to be used, the stability value, flowability, unit weight, air voids, VMA, and VFA were studied. Moreover, to obtain practical BOF slag AC mix designs, trial mixes and suitable adjustments were performed in the plant. In this study, the variations in temperature of the BOF slag AC and conventional AC mixtures were measured during the construction of the pavements. Furthermore, the variations in the BOF slag AC and conventional AC pavements were monitored and recorded every 3 months after the completion of construction. Drilled core specimens were also obtained during the same monitoring periods. To improve the test accuracy, the drilled core specimens were smoothly cut on the surface to lengths of 5 cm on each side. Then, the specimens were tested using the resilient modulus test, creep test, indirect tensile strength test, and tensile strength ratio test. The performances of the test roads were evaluated using various on-site tests, such as flatness measurements, rutting measurements, damage observations, and skid resistance tests. The standards related to this study are listed in Table 1.

2.2. Basic properties of materials

Table 2 shows the basic properties of the natural aggregates and the BOF slag. As seen in Table 2, the specific gravity of the BOF slag was 3.41, which was larger than that of the natural aggregate (2.60). Because the difference in specific gravity between these two aggregates was 0.81 and was relatively large, it was not appropriate to use the weight ratio method to obtain the aggregate gradation for the mix designs. If the weight ratio method had been used in this study, more fine aggregates would have impacted the aggregate gradation for the BOF slag AC mix design. As a result, the final aggregate gradation curves for the BOF slag AC mix designs may not have satisfied the requirements of the previously mentioned specifications. To ensure that the aggregate gradation curve for the BOF slag AC mix design satisfied the specifications, instead of using the weight ratio method, the volume ratios of the aggregates for the mix design of the BOF slag AC were utilized. Fig. 2 shows the aggregate gradation curves for the AC mix designs, and the dotted line in the figure is the curve obtained using the volume ratio method. As shown in the figure, natural aggregates with sizes ranging from 3/4″ to #4 were all replaced by BOF slag in the BOF slag aggregate gradation curve. The slag replacement content was approximately 60% of the total aggregate weight. Because aggregate smaller than #8 was too small to be replaced by the BOF slag, natural sand was utilized for aggregate sizes smaller than #8 in the BOF slag AC mix design. Moreover, natural aggregates and sand were utilized in the conventional AC mix design.

As shown in Table 2, the abrasion of BOF slag was approximately 8.9%, which is smaller than that of natural aggregates (25.7%) and could help improve the durability of AC. Moreover, the flatness and slenderness ratios of the BOF slag were smaller than those of the natural aggregates. The flatness and slenderness ratios were the basic indexes for the bearing capacity of the AC. The aggregates can be broken easily when the flatness ratio is large. As a result, the bearing capacity of AC was reduced,

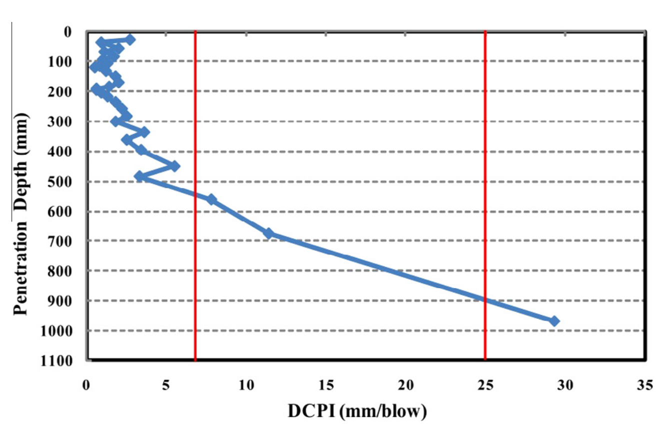

Fig. 1. The results of the dynamic cone penetrometer (DCP) for the test road sections.