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Use of incinerator bottom ash in open-graded asphalt concrete

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HIGHLIGHTS

- An effective and alternative way to recycle incinerator bottom ash (IBA).
- It is feasible to apply the IBA to open-graded asphalt concrete (OGAC).
- The IBA replacement improves the stability and indirect tensile strength of OGAC.
- Up to 80% of natural fine aggregates in OGAC could be replaced by IBA.

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ABSTRACT

To observe the effects of the use of incinerator bottom ash (IBA) on open-graded asphalt concrete (OGAC), natural fine aggregates are partially replaced by IBA in OGAC. The results indicate that the use of IBA helps improve the adhesive force between asphalt and aggregates. The stability and indirect tensile strength of OGAC are effectively improved by the use of IBA as a replacement material. The natural fine aggregate content in the OGAC is 25%. The results indicate that 80% of natural fine aggregates could be replaced by IBA and demonstrate the feasibility of using IBA in OGAC in engineering applications.

1. Introduction

An incineration treatment is a method whereby high temperatures are applied to solid wastes. After incineration, the solid wastes turn into stable gases or ashes. During the incineration process, the wastes can be effectively incinerated, and hazardous materials can be destroyed. Moreover, heat produced during the incineration process is converted into electrical power. Hence, incineration is a suitable method for reducing, stabilizing, detoxifying, and recycling solid wastes. According to information released by the Environmental Protection Administration in Taiwan, the ashes produced from incinerators in Taiwan totaled 902,000 tons between January and October of 2011. Of this amount, bottom ash constitutes 719,000 tons, and 429,000 tons are sent to landfill sites [1]. If bottom ash continues to be sent to landfill sites, a large environmental loading will be placed on Taiwan, which is an island with little available land. Many applications of reusing incinerator bottom ash (IBA) have been observed worldwide. The main application is in construction materials, such as backfill, base layers, and surface layers of asphalt concrete, in pavement engineering [2]. Tang et al. [3] investigated the heterogeneity and environmental properties of municipal solid waste incineration (MSWI) bottom ash from two waste plants. They found that their properties were stable and comparable to each other. Moreover, they noticed that the MSWI bottom ash exhibited a high fraction of fine particles (<125 μm), resulting in higher water absorption. When used as sand replacement, the bottom ash reduced the amount of water available for the reaction with cement in mortar. They suggested that the MSWI bottom ash fine particles, if applied as sand replacement, had a disadvantageous influence on cement hydration and strength development of the mortars. Because the MSWI bottom ash contained elemental aluminum, sulfate and harmful organics from a grate furnace (SF) and boiler and fly ash from a fluidized bed incinerator (BFA), Saikia et al. [4] pre-treated the ash samples used as the fine aggregate of sand to manufacture cement mortar. They found that the quality of the ash samples was improved for the application as a fine aggregate using a 0.25 M Na_2CO_3 solution to dissolve the Al and the sulfate-bearing minerals from the BFA. Furthermore, they noticed that the compressive strengths of the cement mortar specimens were considerably improved by replacing a portion of the sand with the ash samples and treating with heat and Na_2CO_3. Lynn et al. [5] suggested that the pre-treated municipal incinerated bottom ash (MIBA) had the potential for

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use as fine or coarse aggregate in the manufacturing of mortar, concrete, and blocks. They found that lightweight aggregate made by the pre-treated MIBA showed similar properties to Lytag, although with slightly reduced strength. Furthermore, when a portion of the sand was replaced by the fine MIBA in the manufacturing of foamed concrete, the requirements for high flowability and low strength were met using the MIBA mixes. Wu et al. [6] applied IBA to replace sandstone in the manufacturing of pervious concrete brick specimens by controlling different parameters in the various mix proportions, including water-to-cement (w/c) ratios and aggregate sizes. They found that using an IBA aggregate size of 4.76 mm and a 0.55 w/c ratio produced the maximum compressive strength for the brick specimens and was the most promising for future pavement applications. Moreover, by considering the effects of water permeability and the strength of IBA permeable bricks, they recommended that the IBA pervious concrete bricks could be applied to general bicycling paths, sidewalks, and landscaping but not for heavy traffic volume roads. IBA is a heterogeneous mixture, and its components are determined by the waste classification and affect its performance. The physical components of IBA include slag, iron, ceramics, glasses, non-combustible materials, and organic products resulting from incomplete combustion. In general, IBA is a lightweight porous polymer with a large particle size and irregular spherical shape. Its dry density is approximately 950 kg/m^3, and its specific gravity is between 1.8 and 2.4, which is lighter than natural aggregates [7]. The main chemical compositions of IBA are SiO_2, CaO, Fe_2O_3, and Al_2O_3, whose contents in the IBA are affected by the composition of the wastes. In Taiwan, IBA contains large amounts of SiO_2 and Fe_2O_3 because of the characteristics of the collected wastes. CaO and lime are also observed in IBA. These two compositions may help improve the stripping of asphalt concrete [8]. The Federal Highway Administration (FHWA) suggests that after performing a magnetic separation to remove metallic and non-metallic materials, the IBA exhibits a good particle size distribution and can be further mixed with natural aggregates to produce asphalt concrete. When applying the IBA to the mix design of asphalt concrete, the characteristics of lightweight aggregates with smaller specific weights than those of natural aggregates must be considered. This suggests that less than 25% (weight %) of IBA should be used when the IBA is applied to the binder course or base layer, and less than 15% should be used when the IBA applied to the surface layer of asphalt concrete. The performances of pavement materials are assured if the above requirements are considered [9]. Aziz et al. [10] suggested that IBA is suitable for use in low-traffic-volume roads. However, when applied to asphalt concrete, the optimum asphalt binder was shown to be 10–20%, which increases the cost of construction. In this study, as suggested in the literature, the IBA is used in open-graded asphalt concrete (OGAC) to investigate the feasibility of its application to pavement engineering.

2. Materials and methods

Modified type III asphalt was used in this study. The basic properties of the modified type III asphalt obtained for this study and the requirements set by the standards are shown in Table 1. The mixing temperature (170 ± 20 cSt) and compacting temperature (280 ± 30 cSt) were obtained using a linear regression on the changes in asphalt viscosity at different temperatures. Moreover, after performing the basic tests on bottom ash and natural aggregates to understand the material properties, the natural fine aggregate was replaced by bottom ash at the following contents: 0, 20, 40, 60, 80, and 100%. The suggested aggregate mix designs are provided in Table 2. The optimal asphalt contents were obtained from an analysis of mix designs. The compaction method was based on the Standards of Provision 101.02798 (the general requirements of porous asphalt concrete) of the Highway Construction Technical Provisions set by the Directorate General of Highways [11]. The specimens were compacted 50 times on each side. Then, the mechanical properties of IBA asphalt concrete were evaluated through various tests, such as indirect tensile strength, static creep, dynamic creep, tensile strength ratio, and resilient modulus tests.

Table 1
The basic properties of the modified type III asphalt.

Test	Results	Criteria
Specific gravity	1.039	–
Viscosity (60 °C, poise)	9800	>8000
Mix temperature (170 ± 20cSt, °C)	181–187	170 ± 20
Compact temperature (280 ± 30cSt, °C)	166–172	280 ± 30
Penetration (25 °C, 100 g, 5 s 0.1 mm)	52.2	>35

2.1. Tests of the material properties

The properties of bottom ash and natural aggregates were obtained from sieve analyses, specific gravity tests, water absorption tests, and Los Angeles abrasion tests. Moreover, the toxicity characteristic leachate procedure (TCLP), scanning electron microscopy – energy-dispersive X-ray spectroscopy (SEM-EDS), and pH tests were performed on the bottom ash. Table 3 presents the tests, including their respective standards, performed on the bottom ash and natural fine and coarse aggregates.

2.2. Asphalt concrete mix design

The main objective of the mix design for OGAC is to ensure that the asphalt concrete specimens have a sufficient asphalt content to increase the strength and avoid stripping of the OGAC. Moreover, the draindown of asphalt in the OGAC is prevented during the high-temperature transport of the asphalt mixture from plants to construction sites. According to Provision 089.02741 (the general requirements of asphalt concrete) of the Highway Construction Technical Provisions set by the Directorate General of Highways, Ministry of Transportation and Communications in Taiwan, the draindown for OGAC is required to be less than 0.3%, and the amount of abrasion must be less than 20% [12].

3. Results and discussion

3.1. Basic properties of aggregates

Table 4 shows the results of the TCLP for the IBA and demonstrates that the results meet the requirements set by the Environmental Protection Agency in Taiwan. Table 5 shows the basic properties obtained for IBA and natural fine and coarse aggregates. The standard values of the Los Angeles abrasion, fracture (with 2 rupture surfaces), and flat and slenderness ratios are also provided in Table 5.

The IBA constitutes the residuals obtained from thermal melting and subsequent performance of instant water cooling processes. Hence, numerous pores are produced on the surfaces of the IBA particles. As observed in Table 4, the water absorption of the IBA was higher than that of natural aggregates because the pore ratio of the IBA was larger than that of the natural aggregates. Moreover, because of the porous nature of the IBA, the specific weight of the IBA was small, thus resulting in the specific gravity of IBA being smaller than that of the natural aggregates.

The pH of the IBA was higher than that of the natural fine aggregates because the IBA contained more alkali metals or alkaline-earth metals than the natural fine aggregates. Fig. 1 shows the results of the sieve analyses obtained for the IBA and natural fine aggregates. Because the passing ratios of the IBA were smaller than those of the natural fine aggregates, the particles of the IBA were coarser than the particles of the natural fine aggregates.

3.2. Chemical composition analyses of the IBA and natural fine aggregates

The chemical components of the natural fine aggregates and IBA obtained using 2.38 mm and 1.19 mm sieves and the bottom tray in the SEM-EDS analyses are shown in Table 6. The weight percentages of the main components of the IBA, such as Si, Al, and Ca, are similar to those of the natural fine aggregates. Among them, the