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Evaluation of Basic Oxygen Furnace (BOF) material into slag-based asphalt concrete to be used in railway substructure

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HIGHLIGHTS

- Evaluating the performance of BOF asphalt concrete for railway track.
- Proposing a new index to evaluate the waterproofing properties of asphalt concrete.
- Using Basic Oxygen Furnace-asphalt concrete has a better insulation effect.
- The improved endurance of trackbed through the use of BOF asphalt concrete.
- Increased efficiency of BOF as a waste material in railway engineering.

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ABSTRACT

The endurance of a high-speed railway asphalt concrete reinforced trackbed is improved through the use of various percentages of Basic Oxygen Furnace (BOF) slag to replace the coarse natural gravel aggregate of asphalt concrete (replacement rate is 0%, 25%, 50%, 75% and 100%, respectively). We evaluated the performance of BOF-asphalt concrete (which is used as a reinforced trackbed) by performing a modified penetration test, dynamic triaxial test, tensile stress restrained specimen test (TSRST), thermal conductivity test, and dynamic model test. The results show that the penetration time is an alternative index, and all of the BOF-asphalt concretes have a waterproof function. With the increase in the BOF replacement rate, the vibration attenuation, bearing capability, antifreeze capability, and insulation effect are improved, while with the BOF replacement rate increase, the flexural tensile strength loss rate is increased during the long term freeze-thaw cycles.

1. Introduction

With the development of Chinese railways from conventional railways to high-speed railways, the requirements for the substructure become higher and higher. For different severe geographical and environmental conditions, the security, stability and durability of the substructure has necessitated higher requirements under high speed operating conditions. Currently, in the seasonal frozen soil area, the durability and stability of the embankments at very low temperatures has been highlighted for a number of high-speed railways, such as the Harbin-Dalian ballastless track high-speed railway constructed in a seasonal frozen soil area, which highlighted the issue of frost heaving and shrinkage cracking. The major form of the Chinese ballastless track consists of concrete, but concrete may shrink in winter, exhibits poor resistance to deformation, and is difficult to repair when cracking has occurred. In addition, the noise and vibration are generated when high-speed trains run through the area. For a high speed railway trackbed in a seasonal frozen soil zone, extreme low temperatures can reach −48 °C, and traditional anti-frost measures have encountered difficulty in meeting the requirements. Therefore, further research is needed to identify better trackbed materials. Compared with concrete, dense graded asphalt concrete, due to its small porosity and hydrophobic properties, makes it difficult for moisture to enter the internal structure, meaning that dense graded asphalt concrete has a better frost resistance performance than concrete. Moreover, asphalt concrete thermal conductivity is considerably lower than the thermal conductivity of concrete; therefore, asphalt concrete has excellent insulation properties.

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Regarding the application of asphalt concrete to railways, different researchers have performed extensive studies. Lee et al. [1] developed the asphalt mixtures that were suitable for the surface of asphalt concrete directly fastened to the track (ADFT) system. Many studies show that application of asphalt concrete to replace or partially replace the traditional track bed surface structure under the railway foundation base can increase the bearing capacity, dissipate load, decrease vibration and have a waterproof function [2–8]. Recently, some researchers have explored the use of waste materials for railways. Kucera and Lidmila [9] used reclaimed asphalt pavement (RAP) in the asphalt concrete subballast using the warm mix technology and showed that the use of RAP in asphalt concrete subballast is a feasible solution. Herráizet al. [10,11] studies have shown that asphalt mixtures with Polyethylene Terephthalate (PET) have high vibration attenuation capacity when substitute the concrete in the slab track design. Additionally, a larger study dealt with crumb rubber used in railway track. Lee et al. have evaluated the use of crumb rubber modified (CRM) to make asphalt concrete mixtures for the railway track [12]. The results show that CRM asphalt binders could perform well for the application to railway substructures. Laboratory tests on rubber-modified asphalt mixes have been performed to simulate the typical railway foundation, and the results show that adding crumb rubber to asphalt increases the damping ratio of the asphalt mixes and increases the stiffness that is adequate for use in railway track structures [13]. Di Mino et al. analyzed the mechanical behavior of the rubber asphalt via a dry process for subballast [14] and showed that use of Dry Asphalt Rubber Concrete (DARC) demonstrates better fatigue performance than conventional asphalt concrete. In addition, rubber content equal to 1.5% in the asphalt mixture is suitable for subballast to reduce the vibration level [15].

Basic Oxygen Furnace slag (referred to as BOF) is a by-product commonly produced by steelmaking processes, and there are many publications addressing macroscopic or microscopic characteristics of BOF that have evaluated the performance of BOF in pavement engineering [16–18]. Aziz et al. considered that the hydrophobic properties of BOF provide a good adhesion to asphalt binder and help to resist the stripping and other distresses of roads [19]. Huang et al. evaluated the rolling method for the pavement performance of asphalt mixture concrete with Basic Oxygen Furnace slag [20].

Although there is a large body of research on the BOF-asphalt mixture in pavement engineering, to the best of our knowledge, no publications have addressed the use of BOF-asphalt mixtures in railway engineering. Railway asphalt mixtures have obvious different failure modes, loading modes, location of structure layers and environmental impact compared with pavement asphalt mixtures. The Chinese asphalt pavement design period is 15 years, whereas railway subgrades for high-speed railway are generally designed for more than 100 years according to the Chinese Code for Design on Railway Subgrades [21,22]. In addition, with the accelerated construction of Chinese high-speed railway, large amounts of natural aggregates are required; therefore, it is necessary to further evaluate the feasibility of using BOF-asphalt mixtures as trackbeds for the railway track.

In this paper, Basic Oxygen Furnace (BOF) slag was used to displace coarse aggregate for asphalt concrete materials to improve the durability of the railway track constructed in seasonal frozen areas and to achieve the purpose of recycling. Modified penetration tests, dynamic triaxial tests, tensile stress restrained specimen tests, thermal conductivity tests, rapid freeze-thaw cycle tests, and dynamic model tests were performed to evaluate the relevant long time performance of BOF-asphalt concrete used in railway trackbeds. The scheme of the railway track cross-section can be seen in Fig. 1.

2. Materials and methods

2.1. Materials

2.1.1. Aggregate

BOF was supplied by one Iron and Steel Company in China and natural (gravel) aggregate were provided by a expressway asphalt mixing plant in China. To analyze the chemical composition of the BOF and the natural (gravel) aggregate (NA), the additional detectors, the Scanning Electron Microscope (SEM) and the Energy Dispersive Spectrometer (EDS) were employed. The results are shown in Table 1. In addition, the results of the determination of the physical and mechanical properties of BOF and natural aggregate are shown in Table 2.

As seen from Table 1, there is a higher proportion of SiO_2 in the natural gravel. SiO_2 is a hydrophilic molecule, meaning that it is easier to combineSiO_2 with water than asphalt, leading to asphalt concrete stripping more easily. BOF contains a higher proportion of CaO. Because CaO is a lipophilic molecule, BOF can be more closely integrated with the asphalt, reducing the phenomenon of stripping and enhancing the ability to resist water. Furthermore, BOF contains a large amount of metal compounds such as Fe_2O_3, MnO, and MgO, meaning that BOF has a higher proportional specific gravity, as seen from Table 2.

2.1.2. Asphalt

Unmodified asphalt binder#90 (Chinese technical specification for construction of highway asphalt pavements) [23,24] was used for the asphalt mixture design. The asphalt binder was supplied in Heilongjiang province. The test results for #90 asphalt are shown in Table 3.

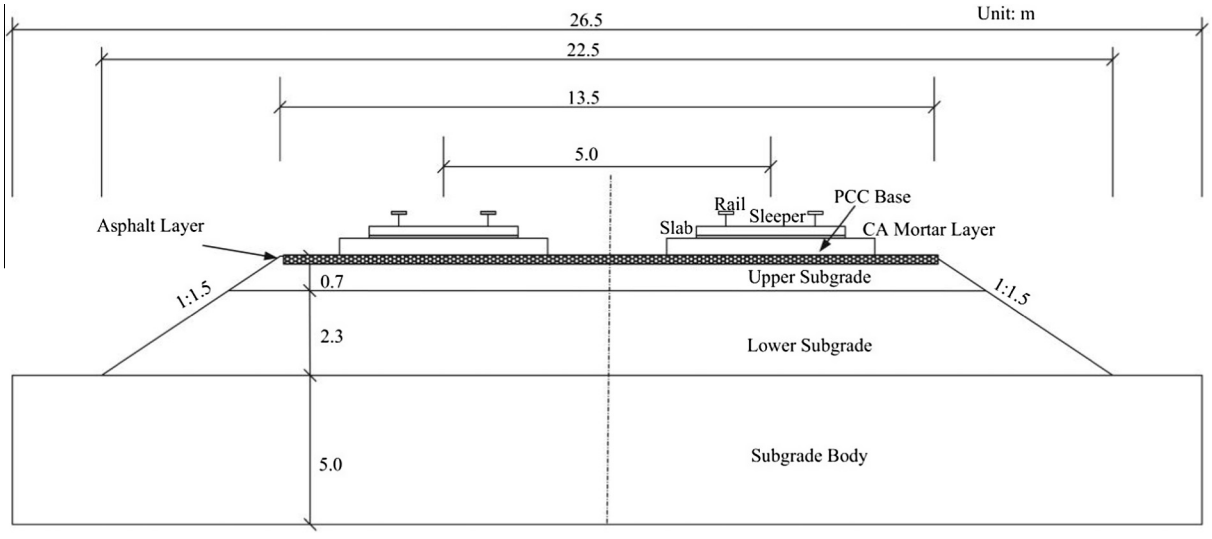

Fig. 1. The scheme of the railway track cross-section.