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Clogging evaluation of open graded friction course mixes with EAF steel slag and modified binders

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HIGHLIGHTS

- The physical properties of the EAF steel slag were assessed.
- Effect of percentage replacement of aggregate with EAF steel slag was investigated.
- De-clogging process restores permeability on average of 86% for PMB OGFC mixes.
- Initial clogging rate is 2 times of secondary clogging rate.

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ABSTRACT

The open graded friction course (OGFC) mix performance and its effectiveness mostly depend on its permeability characteristics. Clogging of OGFC (due to deposition of sand and debris), resulting in the reduction of permeability characteristics, plays an important role in its consequential performance. In this study, the investigation was carried out to analyze the influence of electric arc furnace (EAF) steel slag, which is considered as a partial replacement of coarse (size above 2.36 mm) natural aggregates, on the clogging of OGFC mixes. OGFC mixes were designed using two types of aggregates viz. natural and EAF steel slag, and two modified bituminous binders viz. polymer modified and crumb rubber modified bitumen. The physical properties of the EAF steel slag were assessed to determine its suitability for OGFC mixes. Steel slag in five different percentages, viz. 0, 25, 50, 75 and 100% were used as the replacement of natural aggregates in the design of OGFC mixes. The falling head concept was used to measure the permeability on cylindrical OGFC specimens. Graded sand was used to determine the effect of clogging and de-clogging on the permeability of OGFC mixes. The percentage of EAF steel slag replacement was found to be strongly correlated to the porosity, which directly relates to its permeability of the OGFC mixes both before and after clogging. The secondary clogging rate is approximately fifty percent of the initial clogging rate for both polymer modified and crumb rubber modified OGFC mixes. The de-clogging process could be able to restore approximately an average of 86% and 93% of the initial permeability respectively for PMB-OGFC and CRMB-OGFC mixes.

1. Introduction

Moisture-related damages in asphalt pavements such as durability and loss of strength in hot mix asphalt (HMA) owing to the presence of water, is a global concern. This type of damage includes loss of bond between aggregate and binder surface (adhesive failure) and loss of bond within the binder itself (cohesive failure). Open graded friction course (OGFC) pavements can be considered as a promising solution to avoid infiltration associated distress. OGFC mix is a special type of hot mix asphalt characterized by high interconnected air voids and a coarse granular skeleton with proper stone-on-stone contact. The presence of a larger percentage of internal air voids leads to a relatively highly porous structure of OGFC mixes, which helps in quick and effective removal of surface water from the pavement. These mixes are used to improve wet weather skid resistance, minimize hydroplanning, reduce splash and spray and enhance the visibility of pavement marking during the rainy season [1,2]. The hydraulic gradient is one of the important properties that have a direct impact on vehicle safety as well as influence the performance of HMA. The permeability is the ability to transmit fluids through the interconnected voids of the structure when it is subjected to different hydraulic loads. It is a

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function of the compaction, characteristics of the mix ingredients and geometrical parameters, i.e. layer thickness of HMA which needs to be taken care in the process of mix design.

The clogging characteristic of the open graded asphalt pavement is a common problem owing to deposition of sediments on the pavement surface, the storm water and vehicles. It happens over time. When the pores of pavement become clogged it makes the open graded pavement impermeable and it performs as an ordinary dense graded bituminous pavement, due which the advantages of the open graded mixes are no longer comprehended. The weakening of the cohesive bond within the bituminous mixture is also one of the foremost reasons for clogging of porous asphalt pavements [1]. The high air void content of OGFC mixtures allows the movement of air within the mixture, which can result in enhanced aging of the binder film, thereby causing a reduction in air voids and reduced permeability.

Also, the transportation system plays a main role in the growth of the country. A good road network system enhances the mobility of goods and facilities which promote economic activities. A good road transportation system can be considered as the one having quality road and highway pavement. With an aim to achieve this criterion, a significant quantity of aggregates is required yearly for the construction of roads and highways which in turn leads to massive depletion of natural aggregates. Also, the disposal of the waste requires a large area of land and associated with environmental and economic concerns. Aggregates are the major constituent of asphalt mix in terms of volume and weight thus, recycled aggregates and industrial waste are imperative in constructing and maintaining works for roads and highways. The use of industrial waste is a promising solution to minimize environmental pollution by sinking the accumulation of waste materials, which results in a reduction of the construction costs.

Many studies have been conducted on alternative environmental friendly materials in different kind of mixes such as warm mixes [3], High modulus mixes [4], Stone Matrix Asphalt [5,6] and Porous mixes [7,8] to check the effectiveness of steel slag. Mixtures with steel slag improve the mechanical behavior of mixtures in terms of stability, indirect tensile strength, stiffness, cracking resilience according to the investigations [3,9–12]. It also exhibited improved performance as compared to natural aggregates in terms of fatigue [4,13], rutting [3,14], thermal behavior [15]. Authors also studied on leaching parameters and concluded that bitumen efficiency immobilizes metals from slag in asphalt mixes [16]. Sorlin et al. [10] have also reported that the leachate of samples with bitumen was much little and contaminants were far below regulatory requirements. The use of steel slag has enormously paid to green technology as its use has conserved the natural ecosystem through a reduction in the amount of dumped wastes and consumption of conventional aggregates in asphalt mix production [4,17].

However, many studies demonstrated that the function of OGFC weakens rapidly due to a decrease in the effective air void contents. Mallick et al. [18] reported a significant reduction in permeability characteristics of OGFC pavement after 2–3 year of service life. Based on a Japanese study [19], clogging of the OGFC pavement in the urban area generally occurs after 3–4 year of construction. Moreover, it also reported that the OGFCs Performance life reaching more than 5 years without maintenance [19]. Hence, the clogging characteristics of OGFC mixture should be correctly deliberated in the design of OGFC pavement.

Fwa et al. [20] conducted a study on the clogging potential of porous asphalt mixtures. In this study, a method was developed to quantify the effect of clogging material on the permeability of porous asphalt mixtures prepared with four type of aggregate gradations. In this study, the permeability was measured after each addition of clogging materials to the surface of the test specimen. It was observed that with the initial application of clogging material the permeability decreased rapidly and was followed by a steady decrease of the permeability then maintained a constant value. It was also observed that mixes with the coarser, more uniform gradation were less susceptible to clogging than finer, well-graded mixtures. A similar study was performed on clogging behavior with different gradations [21]. It was found that mixes of having more uniform gradation can hold more soil before the permeability reduction. Permeability reduces with an increment of sand loading due to the filling of the surface voids of the porous specimen with clogging particles.

Suresha et al. [22] evaluated the clogging and de-clogging characteristics of open graded friction course mixtures. The aggregate gradation, bitumen content, and clogging material are the variables in this study. It was observed that mixes of initially permeability values greater than 100 m/day demonstrated good permeable characteristics after reaching stable clogged conditions. Additionally, particle size (D_{15} and D_{85}) and filter standard can be helpful in understanding the preventive behavior of porous asphalt mixtures.

Martin et al. [23] investigated the influence of aggregate gradation on clogging characteristics of porous asphalt mixtures. It was observed that the samples with the finest gradation had the lowest porosity compared to samples with the coarsest gradation. Microtexture depth was measured for porous samples and it was found to have a strong correlation with percentage passing 4.75 mm Indian Standard (IS) sieve and D_{15} of the gradation. The initial permeability followed the same trend as porosity. The samples were also tested for stepwise clogging and de-clogging. Considering the graded sand as a clogging material, it was observed that the secondary clogging rate is approximately half of the evaluated initial clogging rate. In a more recent study, Chen et al. [24] analyzed the permeability loss due to particle related clogging and the critical size of solid particles attributed to OGFC. To simulate both rainwater flowing procedure and pavement transversal slope, a special type of falling head permeameter was developed. Eight different type of mixes with gradation, air void contents, nominal maximum aggregate size (NMAS) were prepared for clogging. Chen et al. [24] concluded that the air void content and nominal maximum aggregate size are the two important parameters for checking the permeability characteristics by particle-related clogging. Many studies were conducted to check the most important functional performance i.e. permeability characteristics of OGFC mixes in relation to the effect of aggregate gradation, aggregate size [18,25–27] and aggregate source [7,8].

However, to the best of our knowledge, no work has been conducted on clogging evaluation of OGFC mixes with industrial waste. Therefore, the objective of the study was to evaluate the clogging potential of open graded friction course mixes containing EAF steel slag as a coarse aggregate. To check the feasibility, use of steel slag, the OGFC mixes were prepared by replacing natural coarse aggregates with varying percentage of steel slag (0, 25, 50, 75 and 100%) and two type of modified binders such as Polymer modified binder (PMB) and crumb rubber modified binder (CRMB).

2. Experimental materials and methods

2.1. Materials

Two types of aggregates were used in this study. First is the crushed natural aggregates (metamorphic), chosen as the main source, that was obtained from quarries around Shillong in the state of Meghalaya (India). Second is the EAF steel slag, chosen as the secondary type of coarse aggregates (sizes above 2.36 mm), was supplied by Jindal Steel, Power Limited, Angul, Orissa. Natural