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Mechanistic-empirical pavement performance of asphalt mixtures with recycled asphalt shingles

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HIGHLIGHTS

- The effect of recycled asphalt shingles on pavement performance was evaluated.
- Pavement Mechanistic-Empirical (ME) predicted rutting performance correctly.
- There was an inconsistency in fatigue cracking prediction for mixes with RAS.

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ABSTRACT

As highway agencies are in the process of adopting the new mechanistic-empirical pavement design guide, Pavement ME, it is unclear how asphalt mixtures incorporating Recycled Asphalt Shingle (RAS) will influence the design when mechanistic-empirical approaches are used. In this study, Pavement ME was used to evaluate the effects of RAS (with or without recycling agents [RAs]) on pavement performance. Furthermore, a cost analysis was conducted to assess the life-cycle cost of asphalt pavements constructed with RAS. Three different pavement structures were analyzed at three traffic levels (low, medium, and high) and for two climatic regions (cold and hot). Pavement ME predicted that the mix with 5% Post-Consumer Waste Shingle (PCWS) and 5% RA would be the best performer against roughness, rutting, and fatigue cracking. This is due to the stiffening effect of RAS, which is reflected in the dynamic modulus inputted in the software. While one would expect RAS to improve rutting performance, the superior fatigue performance of mixes with RAS was not expected given that the binder in RAS is an air-blown asphalt binder with poor elongation and relaxation characteristics. Results were compared to the Semi-Circular Bending (SCB) test results, which realistically predicted that the mixes with RAS and recycling agents would be the worst performers against cracking. This can be explained by the increased availability of aged RAS binder in these mixes when a recycling agent is used. Results of the cost analysis showed that the mixtures with RAS are more economical to produce. When considering the predicted performance of the mixes, the mix with 5% PCWS and 5% RA had the lowest cost over the pavement service life.

1. Introduction

The sustainability movement in road applications aims to achieve production, distribution, and construction of asphalt mixtures designed to last longer with less impact on ecological systems. Sustainable pavements would also minimize the use of natural resources, reduce energy consumption and greenhouse gas emissions, limit pollution, improve health and safety, and ensure a high level of user comfort [1]. Utilizing recycled materials to decrease the amount of virgin asphalt binder or aggregate used in the production of asphalt mixtures is an example of sustainable pavement technologies.

Studies have shown that using recycled materials, such as recycled asphalt shingles (RAS), reduces the environmental impacts related to extraction, transportation, and processing of virgin materials [2]. Different recycling agents (RAs) may also be used in the asphalt mixtures containing RAS to improve the blending between recycled and virgin materials [3]. Recycling agents may also have the ability to reverse the aging process by softening or

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rejuvenating the aged binder [4]. In addition to the environmental benefits, cost reduction associated with the use of RAS as well as the cost increase due to the use of recycling agents are important factors that should be evaluated when studying asphalt mixtures incorporating RAS and RAs.

Traditionally, pavements were designed based on empirical principles, which used road tests results conducted by the American Association of State Highway Officials (AASHO) in the late 1950s and early 1960s in Ottawa, Illinois. The limitations of empirical design include that: (1) the design considers pavement performance through a subjective rating; (2) it offers limited attention to failure modes; and (3) it depends on conditions remaining the same, similar to the original field conditions. Yet, a 54% increase in the number of vehicles using the roads and a 75% increase in the vehicle miles traveled was observed between 1973 and 1993; thereby making today's traffic loads significantly higher than the ones utilized to develop the semi-empirical 1993 AASHTO design method [5]. Based on these limitations, a Mechanistic-Empirical (ME) design method was developed, which accounts for variability in material properties, traffic loads, and construction procedures. In this new approach, both mechanical and empirical methods are incorporated by calculating pavement responses due to loading then relating those responses to pavement performance. Previous studies have evaluated the mechanistic properties, economic benefits, and ecological impacts from sustainable pavement technologies [6–15]. Yet, the incorporation of RAS and RAs in pavement design has not been thoroughly evaluated using ME design approaches.

2. Objectives and scope

This study had two main objectives: (1) to evaluate the effects of RAS (with and without recycling agents) on the predicted performance from Pavement ME; and (2) to assess the life cycle cost of pavement constructed with RAS and recycling agents. An evaluation of the effects of RAS and RAs was conducted using Pavement ME for two different climatic conditions (cold and hot regions). Furthermore, the analysis encompassed three traffic levels (low, medium, and high) to evaluate the effect of traffic load on the performance of RAS materials. Level 1 inputs were used to describe the asphalt layers while Level 2 inputs were used to describe the granular base and subgrade layers.

3. Background

New methodology, developed as part of NCHRP Project 1-37A, (Development of the 2002 AASHTO Guide for Design of New and Rehabilitated Pavement Structures: Phase II), sought to relate pavement distresses to pavement responses (stress, strain and deflection); this process is based on traffic loading, climate data, and material properties. These distresses may be used to predict pavement damage over time. Pavement ME is based on an iterative process, which initiates the analysis with a trial design and then evaluates the distress susceptibility of the primary design. If the predicted distresses meet the specified performance criteria, the primary design is accepted; otherwise, the evaluation process is repeated with a revised design. To utilize available data in the most efficient way, three different levels of input are considered in Pavement ME. This approach provides the user with the ability to set the level of input data according to pavement importance. Level 1 inputs evaluate pavement performance with respect to the mechanistic properties of the different layers, which in turn can be measured through laboratory or field testing. Therefore, Level 1 input has the highest accuracy, coupled with the highest expenses. Level 2 input addresses those predicted mechanistic values, which may be obtained from different databases or extrapolated from less extensive tests. Level 3 input considers the typical default values and therefore displays the lowest accuracy. Interestingly, the computational methodology used for distress prediction is the same for all input levels [16].

3.1. Recycled asphalt shingles

Recycled asphalt shingles, which represent one of the largest municipal solid wastes, can be used as a virgin binder replacement in asphalt pavements [17]. Every year, 11 million tons of waste shingles are produced, which results in 22 million cubic yards of waste materials, which must be landfilled [18]. Nineteen to 36% of RAS consist of a relatively hard asphalt binder; 2–15% fiberglass or cellulose backing, 20–38% fine aggregate, ceramic-coated natural rock, and the remainder of 1–12% is a mineral filler or stabilizer [19]. Reusing this waste material in asphalt pavement construction could present significant environmental and economic benefits.

Starting from the 1980s, researchers evaluated the use of RAS in HMA production. Several studies were conducted to evaluate the impact of RAS on asphalt mixture performance [20–25]. Anurag et al. utilized the indirect tensile strength test to determine the effect of roofing waste with polyester fibers with different fiber lengths and different fiber contents on the moisture sensitivity of the mix. The study concluded that polyester fibers could improve the wet tensile strength and tensile strength ratio of the mixture [26]. More recently, Maupin used 5% RAS in asphalt mixture to evaluate the effect of RAS on the mix durability [27]. Results from the extracted binder material showed that the high-temperature grading of the binder was improved, while the low-temperature grading was not affected. Maupin also used mixture laboratory testing to evaluate the rutting, cracking, and tensile strength of the asphalt mixtures. Results of rut testing indicated that the mixes would perform satisfactorily on high traffic conditions. Similarly, the mixes were expected to perform satisfactorily against fatigue failure.

Cooper examined the performance of different mixtures containing RAS with and without recycling agents [28]. The tests encompassed laboratory mechanistic tests to characterize the low, intermediate, and high temperature performance of mix, including the dynamic modulus test, semi-circular bending (SCB) test for intermediate temperature, thermal stress restrained specimen tensile strength test (TSRST) for low temperature, and a Hamburg type Loaded Wheel Tracking (LWT) test to evaluate rutting resistance. Results showed that although RAS caused a reduction in virgin binder, the extracted binder did not blend completely with the virgin binder. While there was no improvement in intermediate temperature cracking, the rutting resistance was improved [28].

Robinette and Epps studied the influence of RAS on energy consumption, emissions generation, and natural resource consumption [29]. They also reviewed the price of construction for mixtures containing RAS as compared to conventional materials and construction. Results indicated that in most cases, RAS addition could reduce energy consumption, generated emissions, and preserve natural resources such as aggregate and asphalt binder. By virtue of these processes, RAS can reduce the price of asphalt mixture production and construction as well as alleviating the overall environmental impacts.

Arnold et al. examined the low-temperature cracking characteristics of asphalt mixtures containing various amount of RAS (0–12.5%) using the Disc-shaped Compact Tension (DCT) and acoustic emission (AE) tests. Result showed that the mixtures with RAS had lower fracture energies and higher peak loads. The increase in peak load with the increase in RAS content indicated that the use of RAS did not affect the HMA's high-temperature performance. However,