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Optimizing rejuvenator content in asphalt concrete to enhance its durability

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HIGHLIGHTS

- Rejuvenators may reduce AC cracking susceptibility, but increase rutting potential.
- Rutting resistance more sensitive to aging than flexibility.
- A balanced mix design can be used to design an optimum AC mix when aged and unaged.

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ABSTRACT

The use of rejuvenators in asphalt concrete (AC) have been receiving greater attention recently due to their effect on improving the performance of AC mixes to control the impact of the increasing use of recycled asphalt. This study evaluates the effectiveness of a rejuvenator to reduce AC's cracking susceptibility utilizing the Illinois Flexibility Index Test (I-FIT). The AC's rutting potential was assessed using the Hamburg Wheel Track Test. Samples were prepared on unaged and short-term aged conditions to identify the effect of service time on AC mixes. This study found that increasing rejuvenator content on AC mixes may reduce cracking susceptibility, but possibly increase rutting. Both 2-D and 3-D balanced mix design interaction plots show that designing a durable AC mix with recycled material can be achieved by controlling rejuvenator content with and without aging. Contractors and agencies alike may use interaction plots to develop AC mixes with optimal balanced performance.

1. Introduction

Maintaining the serviceability and improving the durability of the road network are ongoing industry and research challenges. By enhancing the durability of the pavement, distresses will be reduced, incrementing the serviceability of the road network. To that goal, researchers, government agencies, and the industry have been working on utilizing better quality materials, developing better standards, and improving design methodologies. Maintaining the road network at an adequate service level not only benefits the immediate users, by reducing the probability of accidents and vehicle damage, but also benefits the surrounding community. Since fewer repairs are needed there is less traffic congestion, which produces greenhouse gas emissions, noise, and time delays [1]. From the various distresses that may affect asphalt concrete (AC) pavements, two have been the common focuses of research studies: cracking and permanent deformation.

Permanent deformation is associated with rutting formation along the wheel path, which is developed gradually as relatively heavy vehicle repetitions accumulate. Excessive rutting can produce a decrease in ridership safety and alternate drainage patterns. Major factors affecting permanent deformation are the pavement structure (layer thicknesses and quality), traffic volume, and environmental effects [2]. To minimize permanent deformation, strong aggregate, stiff binder, polymer modification, and/or lower binder content have been considered in the mix design [3–5].

Pavement cracking occurs when there is a separation of pavement particles; there are different types of cracks that form in AC pavements, including fatigue, low temperature, and block cracking; each has its initiation mechanism [6–8]. Different studies have been performed to control AC pavement's cracking utilizing binder modification, aggregate gradation changes, additives usage, increasing binder content, and using AC layers with crack control properties at the bottom of the pavement structure [9–11].

Incorporating recycled materials, such as reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS), crushed concrete, or steel slag, influences the AC mix stiffness. Multiple studies

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have shown that increasing amounts of recycled asphalt in AC may have a detrimental effect on its performance, particularly regarding crack formation and propagation [12,13], an effect that has been linked to the excessive aging of the asphalt present in RAP and RAS [14].On the other hand, it has been shown that the addition of recycled materials may have a positive impact on rutting performance [15].

The main contributor to the change in AC's cracking and rutting potential, when RAP is added, is related to the degree at which the asphalt binder is aged. Binder is an organic compound which naturally oxidizes with time; this oxidation is what is known as aging [16]. It has been documented that when asphalt experiences aging, there is a change in its chemical group's composition; specifically, there is an increase in the asphaltene fraction while the aromatic portion decreases [17]. Asphalt binder undergoes a rapid increase ("initial spurt") in viscosity during the first stages of aging and then the rate settles at a constant rate (steady state) [18]. This effect has been attributed to the fact that asphalt binder's more volatile parts react first and the less reactive groups experience oxidation reaction later [19]. This change in chemical groups can be measured using Infrared (IR) spectroscopy, where an increase in the carbonyl chemical functional group may be observed [20]. As carbonyl group presence increased, it suggests a higher asphaltene concentration in the binder [21].

To restore some of the mechanical properties of asphalt binder that have been lost due to aging, it is common to blend recycled asphalt with recycling agents known as rejuvenators. If the appropriate type and amount of rejuvenator are added and properly mixed, and the required reaction time is allowed, the recycled RAP asphalt binder may meet the target performance grade (PG), resulting in an improved cracking resistance of the AC mixture without adversely affecting its resistance to rutting [11]. In general, rejuvenators are assumed to act by replenishing the volatiles and light bitumen fractions that have been lost during construction and subsequent aging of the pavement through its service life. The recovery of the mechanical properties of binder-rejuvenator blends is commonly attributed to the restoration of the asphaltene-maltene ratio [22].

The effect and interaction dynamics between rejuvenators and recycled asphalt binder have mostly been studied at a binder level by blending different amounts and types of rejuvenator directly into binder samples and assessing the mechanical and chemical properties of the binder-rejuvenator blends [23–26]. This method permits the understanding of how much the different recycling agents can improve the condition of aged asphalt binder. However, in practice, the rejuvenators are used directly into AC mixes by combining it with RAP material at the mixing plant [15], as surface treatment [27], or as an additive while performing in-place recycling [28]. Therefore, understanding the blending quality and rejuvenator diffusion, and the impact that these variables have at mixture level, is a research area that has attracted research attention [29,30].

2. Research objectives

There are two main objectives for this study; first, to assess the capacity of rejuvenators to improve AC performance; and, second, to understand the short-term aging behavior of rejuvenated AC mix blends. This research involved two main tasks presented as follows.

2.1. Mix-rejuvenator blending and age conditioning

A set of specimens were prepared using different rejuvenator dosages, allowing the assessment of rejuvenator concentration influence. The second set of specimens were prepared and conditioned to simulate short-term aging (STA); their performance was compared to that of unaged (UA) samples.

2.2. AC mix performance evaluation

It has been discussed that using rejuvenators in AC mixes has a positive effect on cracking resistance and an adverse impact on rutting resistance; therefore, the performance evaluation was done through the Illinois Balanced Mix Design (I-BMD) approach. I-BMD involves assessing the cracking susceptibility, using the Illinois Flexibility Index Test (I-FIT), and rutting potential, by conducting the Hamburg Wheel Track Test (HWTT).

3. Materials and experimental program

This study was conducted using one dense-graded AC mix and one type of rejuvenator. The mix is a Superpave design commonly used for low to mid-volume roads by Illinois contractors. The rejuvenator is an aromatic oil, which is readily available in the market. Only one AC mix and one rejuvenator were used in the study to illustrate the methodology of evaluation, and the utilization of the I-BMD for adjusting AC mixes with rejuvenators.

3.1. Mix designs

The AC mix used in this study was designed following the Superpave design method, using 50 gyrations and a nominal maximum aggregate size (NMAS) of 9.5 mm. The binder type and content are PG 64-22 and 5.9%, respectively. RAP content is 15%. In this paper, the mix is identified as "N50".

3.2. Rejuvenator characteristics

The rejuvenator employed in this study is a heavy paraffinic distillate solvent extract with the appearance and viscosity of a dark brown lubricating oil. Chemically, it is composed of different hydrocarbons, with aromatic hydrocarbons being the primary component (>75%). It is also virtually free of asphaltenes, which are the particles that have been more closely related to increasing binder stiffness. A high aromatic fraction and a low concentration of asphaltenes are characteristics that made it attractive to include this product in the study.

3.3. Specimen preparation

All tests were performed on Plant Mix Lab Compacted (PMLC) specimens using mix already sampled for a previous project from the Illinois Center for Transportation (ICT). The mix was stored in sample bags containing 20 kg–25 kg each. The air void target range for the test specimens was 7.0% ± 0.5%, which is a common practice of laboratory testing for initial pavement performance. For this study, three different blends of mix-rejuvenator were prepared by adding 3%, 6%, and 9% of rejuvenator by weight of the total binder content, recycled and virgin binder, as reported in the mix design. The rejuvenator was directly poured into hot loose mix and stirred using a mechanical mixer. The blending of the rejuvenator was carried after the loose mix samples were split and had completed 1.5 h of conditioning in a forced-draft oven at a temperature of 135 °C ± 3 °C. After blending, the loose mix samples were reintroduced into a forced-draft oven for an extra 30 min to complete a 2-hour conditioning cycle, which was intended to allow the mix to achieve compaction temperature range. This blending method was devised to achieve a better mixing and dispersion between mix and rejuvenator. The test results of the different