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# Evaluation of pavement performance for reclaimed asphalt materials in different layers

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## HIGHLIGHTS

- The pavement performance of RAP materials in the top and middle layers was studied.
- Four laboratory tests were performed to evaluate the behavior of RAP mixtures.
- The results of RAP mixture performance were compared with those of new mixtures.

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## ABSTRACT

Most of highways with asphalt pavements in China, especially in the developed areas, are facing serious pavement distresses such as rutting at high temperatures, cracking at low temperatures, moisture damage and fatigue cracking. The maintenance and rehabilitation of existing pavements has been the most urgent problem to solve for the transportation department. This paper aims to study the pavement performance of Reclaimed Asphalt Pavements (RAPs) materials in the top and middle layers, compared with the corresponding new asphalt mixtures with or without the same initial gradation as RAP mixtures. Four laboratory tests, including dynamic creep test, semi-circular bending (SCB) test, freeze-thaw indirect tension test and semi-circular fatigue test, were adopted to evaluate the pavement performance of asphalt mixtures. Based on the results of laboratory tests, it was found that high temperature performance of RAP mixtures declined due to the finer gradation, which means the coarse aggregates decreased and fine aggregates increased. The SCB test results showed that RAP mixtures performed worse at low temperatures, and the gradation had little impact while the asphalt binder had a large contribution to the low temperature performance. The moisture stability and fatigue performance of RAP mixtures also declined and the fatigue life had worse susceptibility to stress compared with the new asphalt mixtures.



## 1. Introduction

China began its current highway improvement construction efforts in the early 1980s and extensively expanded the highway system beginning in the year of 2000. Currently, China is ranked first place in the world for the largest highway system with over 130,000 km in 2017. Most of highways in China are asphalt pavements, especially in the developed areas, which are now facing serious pavement distresses such as rutting at high temperature, cracking at low temperature, moisture damage and fatigue cracking. For this reason, the maintenance and rehabilitation of existing pavements is the most urgent problem for the transportation departments in the future. One useful approach to rehabilitate pavements is to mill the damaged layers and replaced with new asphalt mixtures. Whereas, this approach will be costly, create more pollution and possibly cause health problems [1,2]. With the emphasis on the sustainable and eco-friendly development, it is necessary to reuse the Reclaimed Asphalt Pavement (RAP) mixtures to capture the cost savings and protect the environment. Therefore, it is necessary to study the pavement performance of RAP mixtures, especially in the top and middle layers, because pavements in these two layers are usually susceptible to deformation and otherwise damaged.

The recycling technology of asphalt pavements was first adopted and used in America in 1915 with increasing emphasis and attention after the oil crisis in the 1970s. In 2001, Basic Asphalt Recycling Manual published by Asphalt Recycling and Reclaiming Association made a comprehensive description on project comparison, material design and construction quality assessment, which

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meant the research on pavement recycling had been well developed [3]. Also, National cooperative highway research program (NCHRP) provided a guide for reference about the mix design and tests with the addition of RAP materials in Superpave mixtures [4,5]. By now, many researchers have found that the recycled asphalt concrete pavements have almost the same pavement performance as those without RAP mixtures [6–8] and in certain performance tests like creep stiffness at low temperatures they have found improved performance [9].

The aim of improving the existing pavement recycling techniques is not only confined to protecting environment or reducing economic and social costs, but also making recycled asphalt mixtures produced at a lower temperature than the traditional hot mix asphalt (HMA) pavements. For this reason, several materials are used to reduce the viscosity of binders, which enable aggregates to be fully coated by asphalt bingers at lower mixing temperatures [10–12].

Before adding RAP into the new layers, the mechanical properties and pavement performance of RAP mixtures must be verified by several tests, including sieve test, resilience modulus test, frost sensitivity test, shearing strength and shock loading strength test [13,14]. While fatigue cracking is a major problem when reclaimed asphalt shingles (RAS) and/or RAP are used in mixes, no specific test is recommended for fatigue evaluation of these mixes at the mix design stage. Researchers found that the fatigue life of mixes with a non-polymer-modified binder containing a blend of 5% RAS and 5% RAP could lead to an increase in fatigue life [15]. Dinis-Almeida et al. (2016) presented a study that combined warm mix asphalt with the use of RAP aggregates produced at lower temperature than the traditional hot mixtures contain 100% RAP [16]. The warm mix recycled asphalt (WMRA) specimens were prepared with 100% RAP and different emulsion contents. The behavior of WMRA specimens was assessed by means of laboratory tests such as water sensitivity, stiffness, fatigue performance and rutting resistance. The obtained results showed that WMRA could be successfully used in road pavements in substitution of conventional HMA.

This paper focused on the pavement performance of RAP mixtures in the top and middle layers by conducting four different laboratory tests. All the RAP specimens in each test are compared with the corresponding new asphalt mixtures with or without the same initial gradation as the RAP mixtures.

## 2. Objectives

The overall objective of this paper is to study the pavement performance of three asphalt mixtures, including milled Reclaimed Asphalt Pavement (RAP) mixture from the aging pavements, a new asphalt mixture with and without the same initial gradation as RAP mixtures. Four pavement performance tests, including high temperature stability, low temperature, moisture susceptibility and fatigue, were studied.

## 3. Materials and experimental tests

### 3.1. Materials

The RAP mixtures were collected from the S29 Highway in Jiangsu Province. The top and middle layer were sampled from aging pavements, which had served for almost 10 years. The top and middle layer, respectively, used the modified AK-13 mixture and AC-20 mixture.

### 3.2. Dynamic creep test

The repeated loading test in the dynamic creep test protocol was adopted to evaluate the rutting resistance performance of RAP mixtures in the top and middle layer. The specific test procedure was performed according to the method of permanent deformation under repeated loading and, was proposed as the Simple Performance Test in NCHRP.

A cylindrical specimen with diameter of 100 mm and height of 100 mm was compacted in the gyratory compactor, using the determined mass and compaction height to certain gyrations. The compaction height was set as 100 mm and the mass was decided by the air void of 6% approximately, according to the relationship between compaction height and air void. The mass and gyrations for different mix specimens are shown in Table 1.

According to the standard of asphalt mixture test specification, the loading period is 1 s, including 0.1 s half-sine stress and 0.9 s interval. The test ended when the loading cycles came to 10,000 or the axial strain was over 100,000 $\mu\varepsilon$. The test temperatures for the top and middle layer were 60 °C and 54 °C, respectively.

### 3.3. Semi-circular bending test

The low temperature performance of asphalt mixture refers to the ability to resist cracking at low temperatures. Due to the long-term aging of the asphalt matrix in mixtures, it is essential to evaluate the low temperature performance of RAP mixtures, which can ensure that low temperature performance will still meet the requirement for usage. In this paper, the semi-circular bending (SCB) test was chosen to evaluate the low temperature performance of asphalt mixtures from several parameters such as flexural strength, failure deformation, stiffness modulus and strain energy density.

The SCB test was originally used for the research in evaluating the mechanical properties of rock [17,18]. In this research, it is proposed to evaluate the fracture strength and anti-cracking ability of asphalt mixtures. The specimen in a semi-circular shape with or without a notch both can be tested under a bending & tensile loading mode in the SCB test.

The SCB test is suitable for testing the low temperature performance of both RAP mixtures and new asphalt mixtures. The specimens for both mixtures were compacted in the gyratory compactor. To make a comparison with pavement cores, the height of specimens in the top layer was 40 mm, and that in the middle layer was 50 mm. All the mixture mass and gyrations for the different mix specimens are shown in Table 2. The distance between two pivots was 80 mm. The specimens were conditioned for 5 h at −10 °C. The samples were loaded at a rate of 50 mm/min until the specimens were damaged, while the loading and displacement curve data were recorded.

### 3.4. Moisture susceptibility test

Moisture damage is a common failure mode for asphalt pavements, especially for climates experiencing heavy rainfall or changing subgrade due to rising temperatures in the early springs. After water permeates into the pavements, the adhesion between aggregates and asphalt matrix gradually decreases, which can lead to pavement failures such as raveling and cracking. For these reason, the freeze-thaw (F-T) indirect tension test was chosen to assess the moisture susceptibility of RAP mixtures, compared with the new asphalt mixtures.

The specimens for the F-T indirect tension test were divided into two groups. The specimens in Group 1 were immersed into water at 25 °C for 2 h before its indirect tensile strength $R_{T1}$ was determined. For the specimens in Group 2, they are immersed into the vacuum water under the pressure of 0.06Mpa for 15 min, then placed in the freezer at −18 °C for 16 h and finally immersed into water at 25 °C for 2 h. These procedures were repeated for 3 times for measuring the strength $R_{T2}$. The F-T indirect tensile strength ratio (TSR) can be determined according to the following equation:

$$TSR(\%) = \frac{R_{T1}}{R_{T2}} \times 100 \tag{1}$$

where TSR refers to the ratio of F-T indirect tensile strength; $R_{T1}$ and $R_{T2}$ refer to the strength of the specimen before and after F-T circular treatments (MPa).

### 3.5. Semi-circular fatigue test

There are two kinds of fatigue tests. One is controlled by stress and the other is controlled by strain. Compared with the latter, the fatigue test controlled by stress is easier to repeat and takes less time. In addition, since most highway pavements in China have a semi-rigid base, the allowable flexural-tensile stress at the bottom of layers is determined by fatigue life under stress. Therefore, the fatigue test controlled by stress was selected to evaluate the fatigue performance of RAP mixtures.

To decrease the variability, the semi-circular specimens used in the SCB tests were also chosen for the fatigue test at the temperature of 15 °C. The loading was a half-sine pulse with the frequency of 10 Hz, which is approximately equal to a vehicle speed of 60–65 km/h. There was no rest interval between the two loads. The fatigue test ended when the specimens were completely damaged. Three stress ratios $\sigma/\sigma_m$ were adopted to obtain the fatigue life formula, which was set as 0.25, 0.35 and 0.45, respectively, according to the transportation condition in China.