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Characterizing the chemical and rheological properties of severely aged reclaimed asphalt pavement materials with high recycling rate

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HIGHLIGHTS

- A method corrects the issue that AI blending chart overpredicts the rejuvenator dose.
- The PDI from GPC analysis is a useful tool to identify the rejuvenated RABs.
- The Glover–Rowe damage zone demonstrates a clearly distinct severity of aging level.

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ABSTRACT

Frequent mill and overlay activities result in the production of a considerable amount of reclaimed asphalt pavement (RAP) materials. Many pavements that incorporated RAP exhibit a shorter service life than do those without RAP. One of the possible reasons is that certain RAP materials have already undergone multiple recycling processes during the past decade. This results in severe aging of the reclaimed asphalt binder (RAB). In this study, three severely aged RABs, two RAP blending scenarios, two virgin binders, and two commercial rejuvenators were used to investigate the feasibility of using severely aged binders for constructing pavements. The chemical and rheological properties of the rejuvenated severely aged binders were evaluated using high-performance gel permeation chromatography and a dynamic shear rheometer. The molecular size distributions of rejuvenated RABs revealed that the rejuvenators used in this study could rebalance the proportions of large, medium, and small molecular components among the rejuvenated RABs. However, the polydispersity values still enabled clearly distinguishing between virgin binders and rejuvenated RABs. Two performance parameters were used to evaluate the potential of age-induced damage as well as permanent rutting in the binders. A Glover–Rowe damage zone was evaluated, and it revealed promising results to distinguish among severely aged binders, virgin binders, and rejuvenated binders. Oscillation and multiple stress creep and recovery tests were performed to obtain rutting potential parameter $G^*/\sin(\delta)$ and J_{nr}, respectively. The results indicated that all rejuvenated aged binders exhibited higher $G^*/\sin(\delta)$ values and lower J_{nr} values compared with the control virgin binders.

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1. Introduction

Traffic loading and pavement service environments are widely considered to influence pavement performance. Taiwan is highly urbanized, with most of its population living in high-rise condominiums. Most utility lines such as water, natural gas, electricity, and telecommunication lines are embedded underneath city and county roads. Maintaining and repairing utility lines necessitates the frequent digging and patching of such roads. In addition, Taiwan lies across the Tropic of Cancer. Therefore, northern and central Taiwan have a humid subtropical climate, with substantial seasonal temperature variations. By contrast, most of southern and southeastern Taiwan are characterized by a tropical monsoon climate involving less noticeable seasonal temperature variations, with temperatures typically varying from warm to hot. Asphalt materials age faster in hot and humid climates than in other climate types. The high traffic loading, frequent utility patching, and hot and humid climate lead to faster deterioration of pavements, which consequently necessitates frequent maintenance and repair. Milling and overlay are one of the most commonly used maintenance and rehabilitation (M&R) techniques for flexible pavements in Taiwan. Frequent milling and overlay activities produce a considerable amount of reclaimed asphalt pavement (RAP).

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Therefore, since the late 1990 s, the construction specification chapter 02966 allows incorporating at most 40% of RAP into new hot-mix asphalt (HMA). Wang [1] performed a survey on RAP in northern Taiwan and found that a reclaimed asphalt binder (RAB) had an average viscosity of 18,000–34,000 P at 60 °C. Lee [2] recently conducted a survey on RAP materials in southern Taiwan and revealed that the viscosity aging of RABs could be as high as 500,000 P at 60 °C. Lee considered that such a severe aging level was because certain RAP materials, namely repeated RAP (RRAP) materials, have been subjected to a multiple recycling process during the past decade. When a severely aged RAB is incorporated into new mixes, the mixture stiffness may increase and the durability may decrease, thus resulting in premature field failure of pavements, which ultimately leads to more frequent M&R activities on pavement.

Studies have reported that when the RAP rate was less than 25%, asphalt mixtures demonstrated similar performance levels to those of mixtures without RAP [3–6]. In recent years, the demand to increase construction sustainability as well as to lower construction costs have urged the paving industry to use higher RAP percentages in the construction and rehabilitation of asphalt pavements. A recent National Cooperative Highway Research Program study defined a high-RAP mixture as that involving 25–50% or greater of RAP [7]. In general, several studies have shown using high RAP content necessitates single- or double-bumping binder grades or adding rejuvenating agents to adjust the stiffening effect of aged binders [8–10].

To restore the rheological properties of an aged binder, a softening agent or rejuvenator may be mixed with the aged RAB. A softening agent typically lowers the viscosity of aged binders. A rejuvenator lowers the viscosity of an aged binder and facilitate rebalancing the chemical composition of an aged binder that has lost its light molecular weight fractions during the construction and service periods [11,12]. Previous studies have described the effects of softening agents or rejuvenators on the physical, chemical, and engineering properties of asphalt mixes and/or binders [12–14]. Another essential purpose of integrating rejuvenators with RAP is to determine the blending dose. Shen et al. [15] reported that the quantity of rejuvenators could significantly affect the properties of rejuvenated RABs. They suggested the optimum percentages of rejuvenator required to satisfy Strategic Highway Research Program specifications. Tran et al. [16] also used a similar approach to determine the optimum quantity of rejuvenators required to restore the performance properties of RAP and reclaimed asphalt shingles [16]. In Taiwan, the optimum rejuvenator content is usually determined using the blending chart developed by the Asphalt Institute (AI) [17]. This chart shows a linear relationship between the logarithm of viscosity at 60 °C and the percentage of new asphalt or percent recycling agent in the blend. However, when the viscosity of an aged binder exceeds 100 kP, the blending chart might overpredict the rejuvenator dose, consequently resulting in rejuvenated RABs that are softer than expected.

The objectives of this study were threefold: (1) to develop a method, which is a modified version of the viscosity blending chart, with high repeatability to determine the appropriate blending dose of severely aged RABs; (2) to study the change in the molecular weight distribution of rejuvenated RABs; and (3) to evaluate the performance-based rheological properties of rejuvenated high-percentage severely aged RABs.

2. Materials and methodology

2.1. Raw materials

Asphalt materials with three aging levels (RAB100, RAB300, and RAB500) recovered from RAP materials were blended with one type of virgin asphalt (A1) and two types of rejuvenator (R1 and R2). The RAP materials were obtained from the milled pavements in southern Taiwan. The target pavements have been milled and overlaid once or twice in the past 10 years. The results were compared with a control virgin asphalt binder (A2) that is widely used in Taiwan. Table 1 shows the viscosity grade and high-temperature performance grade (PG) properties of virgin and aged asphalt. The high-temperature PG of A1, A2, RAB100, RAB200, and RAB300 were 64, 70, 82, 88, and 94 respectively. This study applied two commercial rejuvenators (R1 and R2), and Table 2 shows their physical properties, which were determined according to ASTM D4552, a standard that describes the classification of hot-mix recycling agent (RA) grades. The viscosities of the R1 and R2 rejuvenators at 60 °C are approximately 60 and 15 P, which meet the specifications of RA 75 and RA 25, respectively. At 60 °C, the viscosity of RA 25 ranges between 9 and 45 P and that of RA 75 ranges between 45 and 125 P.

2.2. Experimental methods

Two blending scenarios involving 30% RAP (RAP30) and 50% RAP (RAP50) were evaluated in this study. The binder content of RAP was assumed to be 4% and the target binder content of the new mix was assumed to be 5%. Therefore, for the RAP30 blending scenario, the RAB contributed 24% of the binder content in the new mix and virgin asphalt, whereas the rejuvenator contributed the remaining 76%. In the RAP50 blending scenario, the RAB formed 40% of the binder content in the new mix and virgin asphalt, whereas the rejuvenator constituted 60% of the binder content in the new mix. The rejuvenated RABs were compared with the control asphalt binder A2 for determining their chemical and rheological properties. Fig. 1 shows the experimental procedures of this study. The molecular weight distributions of the binders were investigated using a Viscotek RImax high-performance gel permeation chromatography (HP-GPC). The system testing temperature was 40 °C. In the analysis, a 2% by weight asphalt solution was prepared in tetrahydrofuran (THF) and a 0.1-mL sample solution was injected into the column. The flow rate of the THF mobile phase was 1 mL/min. To calibrate the instrument, several polystyrene standards were used. The viscosity was measured using a Brookfield rotational viscometer (DV-III) with a spindle spinning at 20 rpm, and the spindle size was varied (#21, #27, and #29) depending on the sample's viscosity. The high and intermediate rheological properties of each binder were measured using a TA AR1500ex dynamic shear rheometer (DSR). An oscillation test was performed at temperatures ranging from 20 °C to 70 °C, with an interval of 10 °C, to measure the complex shear modulus (G^*) and phase angle (δ) of the binders according to AASHTO T315 specifications. The results were used to calculate the Superpave parameter $G^*/\sin\delta$ for potential rutting according to the AASHTO M320 specification. In addition, the permanent deformation potential of the binders was studied by conducting a multiple stress creep and recovery (MSCR) test according to the ASTM D7405 specification. In the MSCR test, a specimen was subjected to creep loading for 1 s and then unloaded and allowed to recover for 9 s. Two stress levels (i.e., 0.1 and 3.2 kPa) were applied for 10 creep recovery cycles individually. The results were used to calculate the new rutting performance parameters as an average recovery percentage, R, and nonrecoverable compliance, J_{nr}.

2.2.1. Modification of the AI blending chart

As mentioned, the most common method of determining rejuvenator dose in Taiwan is to use the viscosity-blending chart developed by the AI. In this study, the target viscosity at 60 °C was set to 2000 P. However, at the early stage of this study, the researchers noticed that the blending chart overpredicts the quantity of rejuvenators required to induce excessive binder softening. To rectify this problem, the following steps were used.

Step 1.

No rejuvenator: in this step, only the aged binder (RAB) was blended with a virgin binder (A). The Arrhenius mixing law, as shown in Eq. (1), was adopted to calculate the viscosity of the blend η_{RAB-A} [18]:

$$\ln(\eta_{RAB-A}) = f_{RAB}\ln(\eta_{RAB}) + f_{A0}\ln(\eta_A) \tag{1}$$

Step 2.

AI blending chart: according to the viscosity blending chart, the proportions of an aged binder (RAB), virgin binder (A), and rejuvenator (R) could be obtained, and the viscosity of such a blend was calculated as follows [17]:

$$\ln\eta_{RAB-A-R} = f_{RAB}\ln\eta_{RAB} + f_{A1}\ln\eta_A + f_{R1}\ln\eta_R \tag{2}$$

Table 1
Viscosity grade and PG high temperature grade of virgin asphalt and RABs.

Asphalt binder	Viscosity grade	PG grade	Viscosity (60 °C, poise)
A1	AC10	64	1155
A2	AC20	70	2350
RAB100	–	82	19,600
RAB300	–	88	31,500
RAB500	–	94	56,500

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