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Laboratory evaluation of warm mix asphalt incorporating high RAP proportion by using evotherm and sylvaroad additives

Dai Xuan Lu *, Mofreh Saleh

Department of Civil and Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand

HIGHLIGHTS

- Two different types of additives were used to produce WMA mixtures incorporating high RAP content.
- The effect of WMA additives on the binder's viscosity.
- Laboratory performance evaluation on moisture susceptibility, fatigue cracking and rutting resistance.

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ABSTRACT

Warm mix asphalt (WMA) has gradually become more popular in the roading industry as compared to HMA, WMA can bring numerous benefits, such as lower energy consumption, lower emissions, and higher ability of incorporating a high proportion of reclaimed asphalt pavement (RAP) in WMA mixtures. Incorporating RAP in WMA can increase the sustainability benefits and enhance the performance of WMA. This study investigated the performance of WMA adding RAP with different proportions, from 0 to 70% by mass of WMA. The performance of mixtures was compared with a control HMA. One type of binder, 80/100 penetration grade, and two types of additives were used, including a chemical warm mix additive and a rejuvenator. Tests were done on the binder's viscosity and mechanical performance of mixtures such as moisture resistance, fatigue cracking and rutting resistance. The results showed that the two additives reduced the viscosity of the binder. Mixtures with the chemical additive performed better than other mixtures in terms of moisture resistance. Only WMA mixture with the rejuvenator showed a higher number of cycles to fatigue failure than the control HMA. For rutting resistance, the increase in RAP proportion greatly improved the performance of WMA mixtures. WMA without RAP had a lower number of cycles to reach maximum rut depth than the HMA. All WMA-RAP mixtures showed considerably better rutting resistance than the HMA.

1. Introduction

Warm mix asphalt (WMA) technologies were introduced for the first time in Europe in 1996 [1], and have become increasingly popular in the roading industry in the United States and Europe [2]. There have been numerous trial road sections paved with WMA in Europe [3] and the United States [4]. WMA is usually produced at lower temperatures, from 30 °C to 50 °C lower than conventional hot mix asphalt (HMA) [1,3]. There has been limited information about long-term performance of WMA so far [3,5], but using WMA clearly has many benefits compared to traditional HMA, such as lower energy consumption, lower emissions, better working conditions [3,5]. Moreover, WMA enables to add high proportions of reclaimed asphalt pavement (RAP) to asphalt mixtures. Using RAP in the mix design utilizes the aggregate and binder of reclaimed asphalt. This reduces the material requirement for new materials as well as the amount of old pavement going to landfill.

During pavement service life, the binder in asphalt concrete is oxidized and aged. Thus, the binder in RAP becomes stiffer. At lower mixing temperatures than HMA, the binder in WMA is less aged and softer than the binder in HMA. When adding RAP into WMA, the aged binder in RAP will mix with the binder in WMA, making the binder of the final product stiffer than the binder in WMA alone. This improves rutting resistance of WMA-RAP mixtures [6–9]. However, aged binder in RAP also makes mixtures harder and more brittle which may reduce the fatigue [8,10] and low temperature cracking resistance [10].

* Corresponding author at: Room E329, Civil and Mechanical Building, Canterbury University, Christchurch, New Zealand.

E-mail addresses: xuan.lu@pg.canterbury.ac.nz, dai_ct@hcmutrans.edu.vn (D.X. Lu), mofreh.saleh@canterbury.ac.nz (M. Saleh).

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In 2013, Arizona Chemical Company released a WMA technology product called Sylvaroad™ RP 1000. This product is made from Crude Tall Oil and Crude Sulphate Turpentine, pine chemicals produced by the pulp and paper industry [11]. The product was developed to increase the ability of adding higher RAP proportion while still maintaining good performance of asphalt mixtures [12]. So far, there have been limited published research articles about this new product although its information can be found on unpublished media such as the company's website. The objective of this study is to investigate the potential of Sylvaroad as a warm mix additive and compare it with other additives such as Evotherm. In order to do so, WMA and WMA-RAP mixtures using Evotherm 3G, and HMA were prepared for comparison with WMA and WMA-RAP mixtures using Sylvaroad. The authors carried out the investigation into the effect of additives on binder's viscosity, moisture susceptibility, fatigue and rutting resistance based on laboratory tests.

2. Materials and mixture designs

2.1. Materials

To prepare specimens for testing, one type of bitumen with penetration grade 80/100, two types of chemical additives, Evotherm 3G and Sylvaroad were used. Virgin aggregates, bitumen and 12 year-old RAP were secured from a local contractor in Christchurch, New Zealand. The basic properties of RAP are shown in Table 1.

Evotherm and Sylvaroad are used to enhance coating and workability of mixtures at lower production temperatures. Both of the two additives are in liquid form. In this research, both Evotherm and Sylvaroad were directly added to the heated binder at 115 °C before mixing. The addition percentages of Evotherm and Sylvaroad were 0.5% and 2% by mass of the total binder, respectively. The dosages of additives were chosen based on the recommendations of the contractor and additive producers.

2.2. Mix design

There were five mixtures designed in this study, comprising HMA, WMA and WMA with 25%, 50% and 70% of RAP. New Zealand standard AC 10 dense graded asphalt mix was used in this research. The AC 10 is a dense graded mix with a maximum nominal aggregate size of 10 mm. For HMA, the mixing and compacting temperatures were same at 142 °C according to the AS/NZS 2891.2.1:2014 [14] and AS/NZS 2891.2.2:2014 [15]. The WMA and WMA-RAP mixtures were mixed and compacted at 115 °C and 110 °C respectively, for both Evotherm and Sylvaroad. The WMA aggregate gradation was utilized the same as the HMA. The WMA-RAP aggregate gradations were almost the same as HMA and WMA as shown in Fig. 1.

The gyratory compactor was used to compact the asphalt mix specimens in this study. All asphalt mix specimens for the mix design purpose were prepared with a height of 85 mm and a diameter of 150 mm. According to the AS/NZS 2891.2.2:2014 [15] standard, the ram pressure was 240 kPa; and the gyration angle was maintained at 3°. For New Zealand and Australian standards, the ram pressure of 240 kPa is much less than the 600 kPa recommended by Superpave. However, the angle of gyration for New Zealand and Australian standards is 3°, which is much larger than the angle of gyration (1.25°) recommended by the Superpave. The larger angle of gyration compensates for the low ram pressure. The difference in compaction for different levels of traffic is the number of gyrations, which is specified in "Specification for dense graded and stone mastic asphalts – NZTA M10: 2014" [13]. In this study, the gyration number of 120 was chosen for heavy traffic.

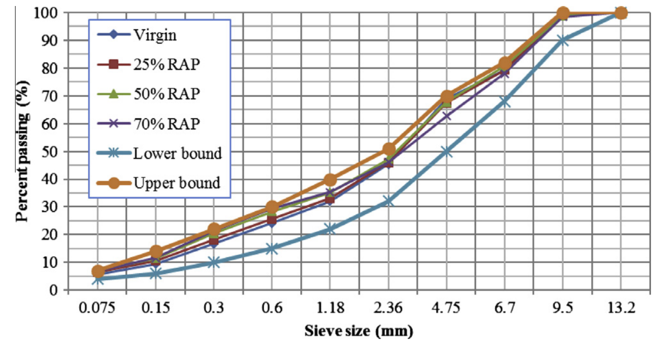

Fig. 1. Gradation curves of mixes.

Optimum binder contents were chosen at the target air void of 4% as shown in Table 2. In the case of WMA and WMA-RAP, optimum binder contents were firstly designed for mixtures with Evotherm. As this study primarily concentrate on the effect of additives on the mechanical performance of WMA and WMA-RAP mixtures, such as moisture susceptibility, rutting resistance or fatigue cracking, rather than the compatibility, the optimum binder contents for Evotherm mixtures were adopted for mixtures with Sylvaroad.

3. Test methodology

3.1. Viscosity test

In this study, the viscosity test was carried out on the unaged and aged binder, with and without Evotherm and Sylvaroad, to evaluate the effect of the two additives on the binder's consistency. The testing procedure was in accordance with ASTM D4402M-13: "Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer" [16]. In the case of unaged binder, the additives were added directly into the heated virgin binder for testing. In the case of aged binder, the virgin binder was aged before adding the additives and testing.

During the production and compaction of asphalt concrete, the binder in asphalt is oxidized and aged. This phenomenon is called short-term aging. In laboratory, short-term aging of binder is simulated by using the rolling thin film oven test, which can be carried out in accordance with ASTM D2872-12 "Standard test method for effect of heat and air on a moving film of bitumen (Rolling thin-film oven test)" [17]. During the service life, the pavement is oxidized and aged, which is called long-term aging. The long term aging of asphalt binder can be simulated by using presser aging vessel (PAV). In this study, the rolling thin film oven was utilized to simulate the long-term aging of asphalt concrete. This method was ultilised in a previous study [18]. For this method, the aging temperature was at 125 °C, and the tests were conducted for 24 h. The authors mainly aimed to age binder to a certain level of aging happen in the field, to study the effect of additives to the

Table 1
Basic properties of RAP.

Sieve size (mm)	Percentage passing of extracted aggregates	New Zealand specification for AC10 aggregate gradation [13]	RAP properties
13.2	100	100	
9.5	98	90–100	Bitumen content in RAP
6.7	83.3	68–82	P_b = 4.8 (%)
4.75	68.3	50–70	
2.36	49.3	32–51	Extracted aggregate bulk specific gravity
1.18	36.9	22–40	
0.6	30.2	15–30	G_{sb} = 2.607 (g/cm^3)
0.3	23.3	10–22	
0.15	15	6–14	
0.075	9.7	4–7	