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Influence of six rejuvenators on the performance properties of Reclaimed Asphalt Pavement (RAP) binder and 100% recycled asphalt mixtures

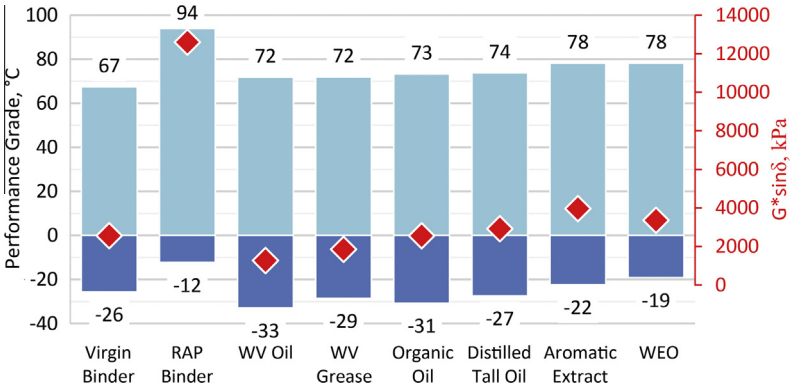
Martins Zaumanis [a,*], Rajib B. Mallick [b], Lily Poulikakos [c], Robert Frank [d]

[a] Worcester Polytechnic Institute (WPI), 100 Institute Road, Kaven Hall, Worcester, MA 01609, United States
[b] Worcester Polytechnic Institute (WPI), 100 Institute Road, Kaven Hall, Worcester, MA 01609, United States
[c] EMPA, Ueberlandstrasse 129, Dübendorf CH-8600, Switzerland
[d] RAP Technologies, 217 Belhaven Avenue, Linwood, NJ 08221, United States

HIGHLIGHTS

- Rejuvenators can reduce performance grade to the level of virgin asphalt binder.
- Use of appropriate rejuvenator dose allows to pass rutting requirement.
- Rejuvenators improve mixture cracking resistance.
- Workability or rejuvenated mixtures remained lower than for virgin mixture.

GRAPHICAL ABSTRACT



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ABSTRACT

100% recycled hot mix asphalt lab samples were modified with five generic and one proprietary rejuvenators at 12% dose and tested for binder and mixture properties. Waste Vegetable Oil, Waste Vegetable Grease, Organic Oil, Distilled Tall Oil, and Aromatic Extract reduced the Superpave performance grade (PG) from 94–12 of extracted binder to PG 64-22 while waste engine oil required higher dose. All products ensured excellent rutting resistance while providing longer fatigue life when compared to virgin mixtures and most lowered critical cracking temperature. Rejuvenated samples required more compaction energy compared to virgin and some oils reduced moisture resistance slightly.

* Corresponding author. Tel.: +1 8572648722.
E-mail addresses: jeckabs@gmail.com (M. Zaumanis), rajib@wpi.edu (R.B. Mallick), lily.poulikakos@empa.ch (L. Poulikakos), BobFrank@raptech.us (R. Frank).
URL: http://zaumanis.com (M. Zaumanis).

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1. Introduction

Although Hot Mix Asphalt (HMA) is a 100% recyclable material, the current prevalent practice in the US is to use only about 20% of Reclaimed Asphalt Pavement (RAP) in a given mix design [1]. The reluctance for higher recycling stems from the possibility that the stiff binder that is present in RAP would cause premature fatigue and low temperature cracking failures [2–6]. The increase in RAP proportion in pavements escalates the potential of such cracking [7] which is one of the main reasons for government agencies to set a limit on the maximum allowed RAP content [8,7,9]. Other reasons are the unknown amount of actual blending that occurs between virgin and RAP asphalt binders and the effective contribution of the RAP binder towards the total binder content of the mix [10,11].

The use of rejuvenators has the potential to address all of the above noted issues, by making the RAP asphalt binder effectively "available" for blending with virgin materials, reducing the RAP mixture stiffness and providing the required binder performance for another service period. These products have the potential to do so by restoring the rheology and chemical components of aged RAP binder [12,13]. Rejuvenators are sometimes also referred to as softening additives or recycling agents but due to lacking industry consensus on the means of categorizing these oils all products are called "rejuvenators" in this article.

Rejuvenators would also allow a significant increase in the amount of RAP used in HMA mix design, and, perhaps even provide a chance for total (100%) hot-mix recycling [14]. This would require ensuring homogeneous RAP material with low fines content, adequate mix design, and modified production plants as demonstrated in video: http://youtu.be/coj-e5mhHEQ. Despite the economic and environmental benefits that the increase in RAP content promise, some state agencies are reluctant to allow the use of rejuvenators, mostly due to potential rutting damage [15], which may result from ineffective blending of the rejuvenator with the RAP asphalt and resultant low stiffness micro-layer on the surface of the RAP [16]. Hence, careful selection of the rejuvenator is required to provide the pavement the necessary short and long term properties, as follows:

- Short term. Rejuvenators should allow the production of high RAP content mixture by rapidly diffusing into the RAP binder and mobilizing the aged asphalt in order to produce uniformly coated mixtures. Rejuvenator should soften the binder in order to produce a workable mixture that can be easily paved and compacted to the required density without the hazard of producing harmful emissions. Major part of diffusion process should be completed before the traffic is allowed to avoid reduction of friction and increased susceptibility to rutting.
- Long term. Rejuvenators should reconstitute chemical and physical properties of the aged binder and maintain stability for another service period. The binder rheology should be altered to reduce fatigue and low temperature cracking potential without over softening the binder to cause rutting failure. Sufficient adhesion and cohesion have to be provided in the mix to prevent moisture damage and raveling.

2. Objective

The objectives of the research are as follows:

- Evaluate and compare the use of various rejuvenators for restoring the properties of aged RAP binder to satisfy Superpave requirements.
- Evaluate the use of rejuvenators to produce 100% recycled hot mix asphalt with performance properties similar to those of virgin mixture.

3. Materials and methods

3.1. Materials

3.1.1. RAP and mixture design

The mixture was produced from re-graded 100% RAP that had been milled from pavements of various layers and locations in the state of New Jersey (NJ). The original RAP was crushed and screened in asphalt production plant to nominal maximum aggregate size of 9.5 mm. This is probably the reason for high dust (filler) content (10.5%) in the resultant mix which did not meet the Superpave gradation requirements (Fig. 1) for 9.5 mm Nominal Maximum Aggregate Size (NMAS) mixture. The RAP also had a relatively high binder content of 6.2%. In order to reduce the binder and dust content and to meet the requirements of a 9.5 mm NMAS design the RAP was screened. A proportion of 85% remaining on 2.36 mm sieve and 15% passing it were used for the re-graded design. The final RAP aggregate composition satisfied Superpave gradation requirements (Fig. 1) having asphalt binder content of 5.3% and a dust content of 7.9%. The total binder content increased to 5.94% after the addition of 12% rejuvenator by mass of the binder and this rejuvenator content was kept constant for all mixtures evaluated in the study.

3.1.2. Asphalt binder

Typically a virgin PG 64-22 binder is used in the climatic area where the RAP was obtained (New Jersey, US) and therefore this grade was selected as a reference binder. This binder was also used for design of virgin reference mixture.

3.1.3. Rejuvenators

Six different rejuvenators were used in the study and their origins are briefly described below. These products were chosen by screening eleven products at an earlier stage of the research which is described in Zaumanis et al. [17]. The measured kinematic viscosity and specific gravity of the rejuvenators are included in Table 1. This table also contains some basic characteristics that were obtained from manufacturers and the approximate cost of each product. For comparison, the table includes characteristics of the virgin binder that was used in the study.

3.1.3.1. Waste Vegetable Oil (WV Oil). WV Oil is increasingly used for bio-diesel production with compositional specifications including low free fatty acid content (<15%), less than 2% MIU (Moisture, Impurities, Unsaponifiables) [18]. Derived from fast and

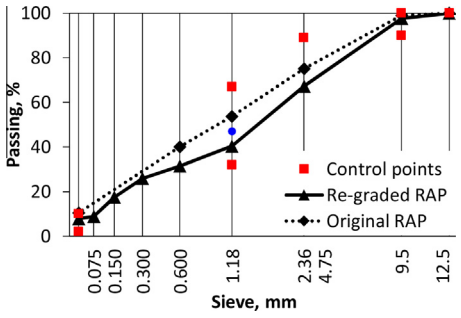

Fig. 1. RAP gradation before and after re-grading according to Superpave 9.5 mm design.