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Optimization of warm mix asphalts using different blends of binders and synthetic paraffin wax contents

Hugo M.R.D. Silva [a,*], Joel R.M. Oliveira [a], Joana Peralta [a], Salah E. Zoorob [b]

[a] Department of Civil Engineering, University of Minho, 4800-058 Guimaraes, Portugal
[b] Transport Infrastructure Engineering Group, CSIR Built Environment, PO Box 395, Pretoria 0001, South Africa

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ABSTRACT

In road construction, several processes and products are now available to produce environmentally friendlier warm mix asphalts, including the use of synthetic paraffin wax additives. These additives facilitate the production of energy efficient asphalt mixtures at reduced manufacturing and construction temperatures. However, their sustainability during the road life cycle can only be obtained by optimizing the mixture's performance. Thus, the objective of this work was to assess the properties of different blends of base bitumens (softer to harder ones) containing a range of synthetic wax contents, as well as the performance of the corresponding warm mix asphalts, that could ultimately lead to more sustainable mixtures. It was concluded that different blends should be selected to maximize the temperature reduction, the fatigue or the rut resistance, without compromising the other properties of the mixture.

1. Introduction

Currently, one of the most important challenges facing our society is the efficient and economic use of energy (namely by reducing the consumption of fuel), with the corresponding reduction in the emission of greenhouse gases. In response, new energy efficient technologies have been developed targeting the production and construction phases of asphalt mixes for road construction. Such technologies, which are being increasingly adopted and applied by road constructors, primarily focus on improving energy efficiency by reducing the temperature of production and application on site of the asphalt mixtures. Of particular interest, is the class of products referred to as warm mix asphalts (WMA) which is applicable to all types of asphalt mixtures applied in different thicknesses and in roads with different traffic levels.

In this study, the potential of one WMA technique is analysed, comprising the modification of the binder via the use of a synthetic wax additive. The wax reduces the binder viscosity and ensures adequate conditions of mixing and compaction at temperatures slightly above 100 °C. With the objective of optimizing this WMA technology for each specific case of application in road pavements (e.g. cold or hot climatic conditions, green production concerns), several blends of base bitumens and synthetic wax contents were prepared in order to obtain WMA modified binders comparable to bitumen grades used in conventional hot mix asphalts (HMA).

Initially, the properties of the HMA and WMA binders (e.g., penetration, softening point, rotational and dynamic viscosity) were assessed in order to select the optimum amount of additive and the permissible practical range for reduction of mixing temperature. Subsequently, the volumetric characterisation of the WMA mixtures produced at different temperatures, obtained after carrying out compactability tests, confirmed the feasibility of temperature reduction between the HMAs and WMAs. Finally, key engineering properties (water sensitivity, stiffness modulus, resistance to fatigue and permanent deformation) of the WMA mixtures produced using the range of aforementioned binders were assessed in order to determine relative levels of performance in comparison with the corresponding HMA mixtures.

2. Literature review on WMA

A number of new processes and products that have the capability of reducing the temperature at which hot mix asphalts (HMA) are mixed and compacted, apparently without compromising the performance of the pavement, have become available. Several

* Corresponding author. Tel.: +351 253 510 240; fax: +351 253 510 217.
E-mail address: hugo@civil.uminho.pt (H.M.R.D. Silva).

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methods are used to classify these technologies, for example the technologies may be classified by the degree of temperature reduction. As can be observed in Fig. 1, WMA are separated from Half WMA by the resulting mix temperature [1]. These new products can reduce production temperatures by as much as 28 °C (50 °F) [2].

Another way to classify the WMA technologies is by those that use water and those that use some other form of organic additive or wax to effect the temperature reduction. These methods are based on process engineering, aerogenous agents or special bitumens and additives [3]. Thus, several WMA techniques are available and have been studied by several authors, namely; the double-coating or 2-phase mixing method [4]; the application of the double-barrel green process [5], with reductions of 10–30 °C; the half-warm mix asphalt technologies that use water or vapour, produced at 90–100 °C with foamed bitumens [6,7] or at 70–115 °C with emulsions [8]. One commercial product "Evotherm®" uses an emulsion which is produced using a chemical package designed to enhance coating, adhesion, and workability, in which the majority of the water flashes off as steam when the emulsion is mixed with the aggregates [9]. Other WMA techniques are carried out by modifying the binder or mixture, namely by using aerogenous agents that are based on chemically bound water that is released during asphalt mixing due to the addition of zeolites (reductions of 30 °C) [10], and by using organic additives, such as Fischer–Tropsch synthetic waxes that incorporates a low melting point organic additive that chemically changes the temperature–viscosity curve of the binder [11–13] or low molecular weight ester compounds, or additives containing surface active agents that improve the asphalt workability within the production temperature range by up to 30–40 °C during mixing [14].

Lower plant mixing temperatures mean fuel cost savings to the contractor and trials have shown that lower plant temperatures can lead to a significant reduction in fuel consumption [15] and emissions that may contribute to health, odour problems, or greenhouse gas emissions [16]. In this context, typical expected reductions are 30–40% for CO_2 and SO_2, 50% for volatile organic compounds, 10–30% for CO, 60–70% for nitrous oxides, and 20–25% for dust. Furthermore, savings in the amount of fuel consumed in the burner devices for warming the aggregates in an asphalt plant, that can reach 35%, are an important argument. On the other hand, a lower production temperature allows the compaction of the mixture at a lower temperature on site, without compromising the desired densities of the resulting layers. The reduction in the exposure to fumes by the workers is another important advantage of this type of mix, with reductions of 30–50% in comparison with conventional mixes [17]. WMAs also allow longer haulage distances, a longer construction season and minimized oxidative hardening, since the mixes are produced closer to the operating temperatures.

Reducing the environmental impacts caused by industrial activities is a basic condition to adapt the new circumstances of development to the present requirements of sustainability. According to Park et al. [18], the emissions resulting from the production of HMA can significantly vary according to the selected materials, equipment or production modes. However, as stated earlier, it is essential that the overall performance of WMA is at least as good as HMA. On a life-cycle basis, if WMA does not perform so well, there will no longer be long term environmental benefits or energy savings. Several investigators have therefore been studying the performance of the WMA additives, binders [19] and mixtures [20,12,17,21], in order to improve their behaviour. Thus, whilst there is a great deal of promise that can be associated with lower temperatures, there are also concerns [22,2] about some of the field performance characteristics of WMA mixtures.

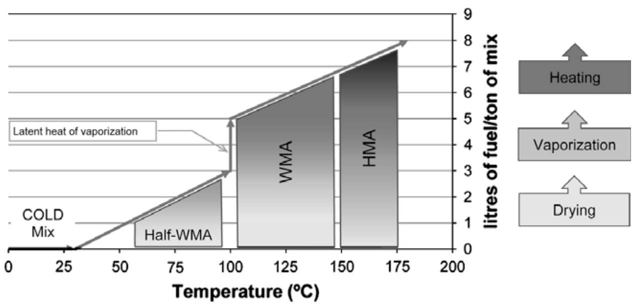

Fig. 1. Classification of WMA technology based on the reduction of mixing temperature [1].

3. Binders characterisation and selection of additive contents

3.1. Laboratory tests description

3.1.1. Rheology tests

In order to determine any changes in the behaviour of the binders due to the addition of the synthetic wax, the base bitumens, the modified binders and the wax additive were tested in a Dynamic Shear Rheometer (DSR) capable of measuring the rheology of these materials (EN 14770 standard).

Measurement of the rheological properties of the binders was carried out in a stress controlled rotational DSR with parallel plate sample geometries of 40 mm diameter and 1 mm gap (with manual gap compensation at each test temperature). The rheometer was set up to test in an oscillatory mode so as to guarantee a dynamic response from the specimen, ensuring that the specimen was tested in the linear region over the temperature (25–170 °C) and frequency ranges selected (0.1–10 Hz). Thus, preliminary tests were carried out at different temperatures and frequencies in order to determine the stress range within which the binders remain in the linear viscoelastic range (complex modulus must not differ by more than 5% of their value over the stress range chosen). Based on this preliminary study, the stress values selected to carry out the DSR tests varied between 1000 Pa at 25 °C and 3 Pa at 170 °C.

The DSR frequency sweeps were initiated at the lowest selected temperature, starting from the lowest frequency and proceeding to the highest. After the completion of each test temperature, it was possible to proceed to the next test temperature at a rate not exceeding 5 °C per minute. During the test, the selected oscillatory shear stress is applied to the specimen and the resulting shear strain is measured.

3.1.2. Softening point and penetration tests

In order to classify the binders used in this study, a basic characterisation was performed in accordance with the EN 12591 standard. This included the tests of penetration at 25 °C (following the EN 1426 standard) and of softening point (also known as Ring & Ball temperature, R&B, according to the EN 1427 standard). These tests were also used to compare the basic characteristics of the bitumens used in the HMAs with those of the modified binders used in the WMAs in order to select the optimum additive content.

3.1.3. Dynamic viscosity tests

In order to evaluate the properties of the several binders at higher temperatures (100–170 °C) in which the bituminous mixtures are mixed and applied, their dynamic viscosities were assessed using a rotating spindle apparatus (EN 13302 standard). The typical test temperature of a coaxial viscometer using a rotating spindle apparatus ranges from 50 to 250 °C.

During the test, the torque (relative resistance of the spindle to rotation) applied to a spindle rotating in a special sample container