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High and low temperature properties of crumb rubber modified binders containing warm mix asphalt additives

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HIGHLIGHTS

- The four additives reduced the viscosity of the CRM binder.
- The four additives worsened the characteristics of the binder at low temperatures.
- The four additives increased stiffness obtained with the BBR test.
- The four additives decreased the *m*-values obtained with the BBR test.
- Mixtures containing these binders are more prone to cracking at low temperatures.

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ABSTRACT

In recent years, warm mix asphalt (WMA) has become an important new research topic in the field of pavement materials due to a growing concern over global warming. Though this technology is being incorporated to reduce emissions and improve workability by lowering the production and compaction temperatures of asphalt mixtures without significantly affecting their mechanical properties, the influence of WMA additives on the properties of crumb rubber modified (CRM) binders has not yet been clearly identified. The main objective of this study is to investigate the effect of different types and quantities of WMA additives on the high and low temperature properties of a 20% CRM binder. Statistical analysis of variance (ANOVA) was applied to determine the significance level of testing temperature and additive content. The results of this study indicate that though the additives lower the viscosity of the CRM binders, they increase the stiffness at low temperatures, therefore increasing the likelihood that the asphalt binder and pavement will crack.

1. Introduction

Previous studies have demonstrated that crumb rubber modified (CRM) binders produce pavements with good mechanical behavior [1]. They offer improved resistance to rutting, better resistance to low temperature cracking, reduced fatigue/reflection cracking and temperature susceptibility, decreased traffic noise and maintenance costs, and prolonged pavement life. These pavements also save energy and natural resources by making use of waste products. Because of these advantages, CRM asphalt mixtures are increasingly used as a green material in the highway pavement construction industry in many countries. However, these mixtures require higher mixing and compaction temperatures than conventional mixtures [2], which means that more energy is consumed and aging may be a more serious issue [3,4].

Warm mix asphalt (WMA) technology offers promising solutions to the CRM drawbacks thanks to the use of fluidifying additives which were found able to guarantee lower viscosity of bitumen at mix production temperatures without affecting bitumen performance at pavement service temperatures. To this aim, waxes are suitable thanks to their melting and crystallizing properties. Several studies have been carried out about wax in bitumen, focusing on the determination of the wax content [5,6], the crystallization properties [7,8], chemical structure [9] as well as their influence on bitumen and asphalt performance [10–13]. Concerning wax performance, several experiences have shown that the presence of wax in bitumen can be associated to different side effects influencing pavement quality and durability. More specifically, wax melting could affect the rutting resistance of the pavement while wax crystallizing can increase mixture stiffness and its sensitivity to fatigue and thermal cracking at low

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temperatures. A univocal definition of the effect of wax in the asphalt binder performance cannot be outlined, being strictly dependent on the physical and chemical characteristics of the wax. In order to achieve optimum production and compaction temperatures of asphalt rubber comparable to those of conventional binders, warm asphalt additives should be chosen on the basis of their ability in reducing the viscosity of the blend. Different kinds of waxes proposed and commercialized as bitumen flow improvers exist: Montan waxes, Fischer-Tropsch (FT) waxes, and functionalized waxes. Montan wax is a combination of non-glyceride long-chain organic acids, long-chain alcohols, and other organic compounds with complex structure. Montan waxes are obtained from fossilized vegetables by solvent extraction of certain types of lignite and brown coal [14]. FT waxes are produced by synthesis process and are characterized by a high molecular weight distribution and a fine microcrystalline structure at low temperature [14]. Thanks to this smaller crystalline structure, FT waxes were characterized by a reduced brittleness at low temperatures. Finally, functionalized waxes consist of waxy amides obtained by amidation of fatty acids and are characterized by a great assortment in chemical structure leading to very different physical properties.

Thus, different kinds of wax are nowadays available as bitumen modifiers in WMA technology and different waxes lead to different effects on bitumen rheology, as well as on asphalt mixtures performance and durability, being the final result mainly governed by the composition and physical properties of the wax [15,16]. The possibility of reducing the mixing and compaction temperatures of asphalt mixtures represent a practical chance of decreasing energy consumption, greenhouse gas emissions, and fumes and odors from asphalt plants, as well as improve the working conditions at plants and paving sites [17]. These benefits, combined with the effective reuse of a solid waste product, would make CRM asphalt mixtures with WMA additives an excellent, environmentally-friendly material for road construction.

The effect of WMA additives on the high and low temperature properties of rubberized binders has not yet been established in detail, although some research has been done into the influence of WMA additives on CRM binders [18] and their high-temperature properties [19,20] as well as on mixtures containing theses binders [21]. Some authors state that while the WMA additive Sasobit® has a positive effect on the softening point and the penetration index of a CRM binder, it cannot dramatically reduce its viscosity at high temperatures or improve low temperature properties [22] and seems to increase the stiffness of the binder [23]. Other researchers state that WMA additives decrease the high temperature viscosity of CRM binders and achieve better resistance to permanent deformation of the asphalt mixtures at high temperatures [24].

The objective of this study is twofold: first, to establish if the WMA additives studied here are effective in reducing the viscosity of CRM binders at high temperatures, which would thereby allow for a reduction of mixing temperatures; and second, to determine the influence of these additives on the behavior of the material at low temperatures, as asphalts with a high rubber content are often used in the production of cracking-resistant asphalt mixes and cracking is a problem usually associated with low temperatures.

In order to evaluate the high temperature properties of the binders, a rotational viscometer was used to determine their dynamic viscosity. A bending beam rheometer (BBR), developed by the Strategic Highway Research Program (SHRP) and used extensively with aged and unaged binders, was used in this study to measure the propensity to thermal cracking at low temperatures. BBR test indicators – creep stiffness S and creep rate or *m*-value – were measured and assessed.

Twenty percent was selected as the most appropriate amount of crumb rubber with respect to viscosity and workability [25], reflective cracking [26] and cost efficiency [27]. Sasobit®, Asphaltan A®, Asphaltan B® and Licomont® were selected from among a number of WMA additives to be used for this study. The statistical significance of the selected factors – test temperature and additive content – were analyzed comprehensively using two-factor ANOVAs.

2. Materials and preparation of CRM binders containing WMA additives

2.1. Materials

The virgin binder used in this study is a B 50/70 (50/70 × 10^{-1} mm of penetration), which is widely used to produce asphalt mixes at normal temperatures. Twenty percent by weight of rubber was added to the B 50/70 in order to obtain the CRM binder used in this study (80% bitumen, 20% rubber), referred to hereafter as ‘B + 20%R’. Table 1 summarizes the basic specifications of the virgin binder. Penetration grade was assessed according to UNE-EN 1426 standard (Bitumen and bituminous binders – Determination of needle penetration) [28], while the Softening Point was measured according to UNE-EN 1427:2007 (Bitumen and bituminous binders – Determination of the softening point – Ring and ball method) [29]. The asphalt bitumen was also subjected to a fractionation analysis as specified in the NLT 373/94 standard [30].

The crumb rubber modifier was manufactured by mechanical grinding at ambient temperature (50% from truck tires and 50% from car tires) and was supplied by the Renecal company in Guardo, Spain. To ensure consistency, only one batch of crumb rubber was used in this study. The gradation of the crumb rubber is provided in Table 2 and the thermogravimetic analysis in Table 3, both provided by the supplier.

Four different organic or wax additives – Sasobit®, Asphaltan A®, Asphaltan B® and Licomont BS 100® – were added to B + 20%R to produce the binders. 2% and 4% of each additive were used and percentages are referred to the bitumen weight. While Sasobit® is a F-T wax created by treating hot coal with steam in the presence of a catalyst, Asphaltan A® is a Montan wax, which is produced by solvent extraction of lignite or brown coal. Asphaltan B® is a refined Montan wax blended with a fatty acid amide and Licomont BS 100® is a synthetic fatty acid amide that is manufactured by reacting amines with fatty acids.

2.2. Preparation of CRM binders containing WMA additives

An oil bath with a maximum temperature of 225 °C, a mixer with a maximum velocity of 15,000 rpm, fitted with a propeller agitator and a one-liter metal container for mixing was used for the preparation of the binders. The oil bath has a

Table 1
Specifications of the B 50/70 bitumen.

Properties	Unit	Test results
Penetration (25 °C)	0.1 mm	55.4
Softening point	°C	51.1
Asphaltenes	(%)	13.8
Saturates	(%)	9.7
Naphthene-aromatic	(%)	48.5
Aromatic-polar	(%)	28.0

Table 2
Gradation of crumb rubber.

Sieve (mm) (UNE 933-2)	Accumulated (%)
2.0	100.0
1.5	100.0
1.0	100.0
0.50	94.1
0.250	23.7
0.125	3.7
0.063	0.4

Table 3
Thermogravimetic analysis of crumb rubber.

TGA	Rubber
Plasticizer + additives (%)	4.67
Polymer (rubber) (%)	57.41
Carbon black (%)	32.22
Ash (%)	6.02