Construction and Building Materials 187 (2018) 1–13

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Recycled stone mastic asphalt mixtures incorporating high rates of waste materials

Sara R.M. Fernandes *, Hugo M.R.D. Silva, Joel R.M. Oliveira

CTAC, Centre for Territory, Environment and Construction, University of Minho, 4800-058 Guimarães, Portugal

HIGHLIGHTS

- Different waste engine oil and polymer products can be used to rejuvenate bitumen.
- Recycled binders can have better rheological performance than conventional bitumens.
- SMA mixtures can be improved with 50% recycling and waste modified bitumens.
- Waste engine oil improves water sensitivity and fatigue cracking resistance.
- Recycled engine oil bottoms and crumb rubber reduce permanent deformation.

ARTICLE INFO

Article history:
Received 14 March 2018
Received in revised form 24 May 2018
Accepted 21 July 2018

Keywords:
Stone mastic asphalt (SMA)
Recycled mixtures
Reclaimed asphalt pavement
Aged bitumen
Waste engine oil
Recycled engine oil bottoms
Polymer modification
Waste polymers
Rheology
Mechanical performance

ABSTRACT

The new environmental targets set to save natural resources and recover waste materials have been the basis for several scientific studies in different research areas. Consequently, this work aims at developing recycled stone mastic asphalt mixtures with high rates of waste materials, including reclaimed asphalt pavements, waste engine oil products, waste polyethylene and crumb rubber. This new solution was compared with a conventional stone mastic asphalt mixture. Several blends of high penetration bitumens modified with waste materials and reclaimed aged bitumen were evaluated through basic and advanced tests, and the most promising solutions were selected to produce recycled stone mastic asphalt mixtures for further characterization. The water sensitivity, permanent deformation and fatigue cracking performance of those mixtures incorporating high rates of different waste materials were generally improved. The exceptional behaviour of these recycled mixtures together with the high incorporation rate of waste materials demonstrate the innovative character of these solutions for the road paving industry.

1. Introduction

Stone mastic asphalt (SMA) mixtures were developed in Germany with the main purpose of resisting high loads from heavy traffic [1] and nailed tires providing a good macro texture. Due to their excellent permanent deformation resistance, several countries are applying these solutions in their road pavements. There is an increase of 20–30% in the stability of SMA mixtures when compared with conventional mixtures [2] due to the strong skeleton of interlocked aggregate particles, as well as the high coarse aggregate content [3]. Consequently, Miranda et al. [4] mentioned in their study that SMA mixtures are a very interesting economic and environmental alternative.

In addition, SMA mixtures are also known for other advantages, namely their excellent macrotexture (decreasing the water spray on wet surfaces and reducing the noise) and also their increased fatigue life. However, SMA mixtures present some disadvantages such as high production cost when compared with conventional asphalt mixture (although it could be reduced throughout the pavement life cycle due to their durability), low initial skid resistance and risk of binder drainage during transport to the construction site (due to the high binder content) [2,3].

SMA mixtures are characterized by a gap-graded particle size distribution, high content of coarse aggregates, filler and bitumen, as well as the use of stabilizers [3,5], which result in a significant consumption of natural resources to produce this type of asphalt

* Corresponding author.
E-mail addresses: id4966@alunos.uminho.pt (S.R.M. Fernandes), hugo@civil.uminho.pt (H.M.R.D. Silva), joliveira@civil.uminho.pt (J.R.M. Oliveira).

https://doi.org/10.1016/j.conbuildmat.2018.07.157
0950-0618/

mixtures. Thus, the incorporation of different waste materials in SMA mixtures could be investigated in order to develop more sustainable solutions without compromising their recognised performance.

The use of reclaimed asphalt pavements (RAP) in new asphalt mixtures brings environmental advantages, such as, a reduction on the volumes of waste sent to landfill as well as on the extraction of new natural resources, and also a reduction on the energy consumption. Moreover, recycled asphalt mixtures could be an economic solution in comparison to traditional asphalt overlay because it eliminates cracking, unevenness and/or other types of pavements distresses [6,7]. As bitumen is one of the most valuable materials used in pavements [8], the study of recycled mixtures that incorporate a lower amount of new bitumen is essential, both by reusing aged bitumen (from RAP material) and by modifying the new bitumen with some waste materials, due to the associated economic and environmental advantages.

In the recycling process, it may be necessary to restore the initial properties of the aged bitumen by adding a rejuvenating agent or a chemical additive [9]. Several studies mentioned the use of different types of rejuvenators such as high penetration bitumens, vegetable oils [10,11], extender oils [12] and waste engine oil [13,14]. Fernandes et al. [15] studied bitumens modified with waste engine oil products, namely waste engine oil and recycled engine oil bottoms, and polymers (waste polyethylene, crumb rubber and styrene-butadiene-styrene), which were evaluated through a basic characterization. From that study, it was possible to obtain high penetration bitumens modified with waste materials that could be used to restore the properties of the aged bitumen present in RAP material. In order to achieve that, higher contents of waste engine oil products (higher than 15%) were used together with a certain content of polymer.

Additionally, and according to Fernandes et al. [16] the eco-friendly bitumens produced with waste materials (waste engine oil, waste polyethylene and crumb rubber) show low thermal susceptibility, upraised values of high temperature performance grade and also low non-recoverable creep compliance values. When used in the production of SMA mixtures, those bitumens modified with waste materials revealed to be excellent solutions for road paving works due to their good mechanical and surface performance without affecting the environment or the human health.

Therefore, the main purpose of the present work was to develop recycled SMA mixtures produced with high rates of waste materials in order to increase the incorporation of end-of-life materials and minimize the extraction of new materials, according to the new circular economy paradigm. The high rates of waste materials should be achieved by using 50% RAP material, as well as, high penetration bitumens modified with waste engine oil products and waste or virgin polymers. According toWang et al. [17], Noferini et al. [18] and EP [19], the common rates of RAP material used nowadays are limited to up to 30% and this works intends to go beyond this limit. Furthermore, these recycled mixtures produced with waste modified bitumens should present a performance similar to or even better than a conventional SMA mixture to assure an adequate performance when applied in road pavements.

2. Materials and methods

2.1. Materials used in this study

The materials used for partially replacing virgin bitumen, as well as the waste and virgin polymers used in this study were similar to those used in the work carried out by Fernandes et al. [15] and Fernandes et al. [16]. Thus, waste engine oil (EO), recycled engine oil bottoms (RB), waste high density polyethylene (HDPE), crumb rubber (CR) and styrene-butadiene-styrene (SBS) were used for bitumen modification. The EO and RB were supplied by a certified waste engine oil collection company (Sogilub, Lda), and their properties can be seen in the previously mentioned works. Additionally, the waste polymers (HDPE and CR) were supplied by Gintegral S.A. and Recipneu Lda, respectively, while SBS was supplied by Industrias Invicta, S.A.

The bitumen used for the modification process was a conventional bitumen with a penetration between 35 and 50×10^{-1} mm, hereinafter referred to as B35/50. This conventional bitumen was supplied by Cepsa Portugal and showed a penetration value of 35×10^{-1} mm and softening point temperature of 54 °C, according to EN 12591 standard. In addition, a softer conventional bitumen with a penetration grade between 160 and 220×10^{-1} mm (according EN 12591 standard) was also studied to rejuvenate the aged bitumen. These binders were also used for comparative purposes in both bitumen and asphalt mixtures characterization.

Regarding the new aggregates used in this work for production of SMA mixtures, whose requirements fulfil those established by the EN 13043 standard, only one fraction (6/14 mm) of crushed granite supplied by Bezerras, Lda. was selected. Additionally, limestone filler supplied by Omya Comital S.A. was also used.

The acrylic fibres used in the control recycled SMA mixture presented a length between 6 and 12 mm and a nominal diameter of 14.4 µm. This control recycled SMA mixture was produced with a conventional B160/220 bitumen according to the results of a previous study [16], where 0.3% fibres (by mass of aggregates) were used in the control SMA mixture produced with a conventional B35/50 bitumen.

Since the main goal of this work is to study recycled SMA mixtures, a reclaimed asphalt pavement (RAP) material obtained from an end-of-life highway surface course was also used and evaluated in this study. The RAP material was divided into two main fractions (fine and coarse fraction), through an industrial material classifier with an 8 mm mesh size, and then supplied by the company ELEVO Group. This separation allowed a better adjustment of the grading curve because SMA mixtures are known for their gap-graded particle size distribution.

2.2. Methods

2.2.1. Characterization of reclaimed asphalt pavement

Since both RAP fractions comprise particles of different dimensions, the proportion of aged bitumen and aggregates is different between them, as the smaller aggregate particles are usually covered by a higher amount of bitumen due to their higher specific surface area. Thus, it is necessary to determine the binder content (EN 12697-39) and aggregates gradation (EN 12697-2) of each RAP fraction. This information is crucial for the recycled asphalt mixtures design. In addition, the aged bitumen should also be recovered (according to EN 12697-3) in order to characterize its properties and to study the interaction between this binder and the new bitumen/modifiers.

To determine the binder content (EN 12697-39) a dry sample of RAP material was placed in a furnace and heated up to 540 °C until all the bitumen had been burned. The bitumen weight is obtained by the difference between the total weight of the sample and the weight of the sample after burning. The fine fraction of RAP presented a binder content of 6.0%, while the coarse fraction showed a binder content of 4.1%. The particle size distribution of the aggregate present in the fine and coarse fractions of the RAP material can be seen in Fig. 1.

Although the fraction separation has been made in an 8 mm sieve, the coarse fraction is essentially comprised of aggregates with a dimension between 4 and 10 mm, having yet 30% of material with a dimension smaller than 4 mm (related to fine material that is involving the coarser aggregates). On the other hand, the fine fraction showed a continuous grading with a higher percentage of thinner material (maximum dimension of 6 mm).

The RAP characterization also consists in recovering the aged bitumen through rotary evaporator method, according to EN 12697-3. Since both fractions were used in this study, each fraction was added in the respective content, according to the selected recycled SMA 14 mixture gradation (shown in Table 1). Within the RAP material incorporated in the final mixture (corresponding to 50% of the final recycled mixture), the proportion of the coarse fraction was 70%, while the proportion of the fine fraction was 30%.

The aged bitumen recovery is a three stage process. The first stage consists in placing the RAP material in a container together with a suitable solvent until all bitumen has visibly been dissolved, followed by a separation by centrifugation and filtration (to separate the coarse aggregates). In the second stage, the fine material is separated from the bitumen/solvent solution through an additional centrifugation process at a higher speed (3000 rpm), during 10 min. The last stage of the process includes a distillation process, where the solvent is separated from the aged bitumen in a rotary evaporator.

To characterize the aged bitumen, penetration at 25 °C (EN 1426 standard), softening point temperature (EN 1427 standard) and dynamic viscosity (EN 13302 standard) tests were carried out. The aged bitumen presents a penetration value of 8.8×10^{-1} mm and a softening point temperature of 74 °C, confirming the hardness of the bitumen present in the RAP material. In relation to dynamic viscosity, at the temperatures of 135 °C and 180 °C, the aged bitumen shows a dynamic viscosity of 3.8 Pa.s and 0.3 Pa.s, respectively. The mixing temperature of the aged bitumen is clearly higher than the mixing temperatures needed for the conventional bitumens most typically used for road paving in Portugal (between 150 and 165 °C). The properties of the aged bitumen are essential for further characterization and selection of the bitumens modified with waste materials.