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Evaluation of sun-oxidized carnauba wax as warm mix asphalt additive

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HIGHLIGHTS

- CW T4 was evaluated as warm mix additive in asphalt cement.
- Modified asphalt cement showed improved elastic properties.
- Modified mixtures showed significant reductions of 25–35 and 35 °C.
- CW may offer benefits such as energy saving and lowering of pollutants levels.

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ABSTRACT

In the present work, carnauba wax (CW) type 4 was used as an additive in warm mix asphalt (WMA) technology. Rheological experiments were performed with the binders to determine viscoelasticity properties such as complex shear modulus (G^*) and phase angle (δ). Binders were also evaluated in terms of its penetration and softening point. Master curves of G^* and δ were obtained from the rheological data. Multi-stress creep and recovery (MSCR) test was used for determination of percent recovery and non-recoverable creep compliance of modified and neat asphalt cements. The effect of CW addition produced higher values of complex modulus when compared to the neat asphalt cement. The CW modified asphalt cement has also shown small values of δ in the range of frequency investigated, showing improved elastic properties. The use of CW as an additive allowed the hot mix asphalt (HMA) to be mixed and compacted using lower temperatures. Those values of reduction in mixing and compaction temperatures were obtained comparing the compaction densification index (CDI) and the traffic densification index (TDI) results with the ones found for conventional HMA.

1. Introduction

Warm mix asphalt (WMA) is a technology, which is being considered a cleaner production method of bituminous mixes compared to conventional hot mix asphalt (HMA). The importance of using WMA technology is emphasized by many authors, pointing out aspects such as reduction of environment impact due to the need of lower temperatures, the lower bitumen viscosity and consequent improved mix workability, and production of fewer emissions, generally creating better working conditions [1–3].

In order to reduce compaction and mixing temperatures (CT and MT, respectively), chemical additives can be added to the asphalt cement (AC) resulting in a mixture with improved properties e.g. better workability, reduction of compaction and mixing energies and, consequently, emissions [3,4]. Bahia et al. [5] first introduced the concepts of CDI (compaction densification index) and TDI (traffic densification index) parameters, calculated from output data from the Superpave gyratory compactor. They are obtained by the number of gyrations at varied percent of maximum specific gravity (Gmm) values [6,7]. These parameters are used in the present study to determine the mixing-compaction temperatures for WMA.

Different WMA technologies such as water/vapor, emulsions, zeolites and organic additives have been studied [8]. Carnauba wax (CW) exudates from the palm of carnauba tree (*Copernica Prunifera*) and it is formed by long paraffinic chains showing fatty acids, amides, ester carbonyl, unsaturated carbons of olefins/aromatic and aliphatic carbons linked oxygen in esters/ethers/alcohol [9,10]. Fig. 1 shows CW palm and leaf. CW can be categorized in different types depending on its extraction origin or purification method. Type 4 CW is obtained from the carnauba palm outer side

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Fig. 1. Illustration of carnauba tree (A), palm and leaf (B).

and it presents a characteristic dark brown color as it is more exposed to sun radiation and also to the fact that it does not go through any purification method.

The present study was performed using CW type 4 to modify asphalt cement in order to reduce its viscosity and to investigate its use as WMA additive. Reductions in viscosity and mixing-compaction temperatures values are expected to reduce asphalt plant fuel costs, to reduce emissions and to improve paving applications [3]. Besides flow properties, the effect of CW on the rheological properties, softening point and penetration were also investigated. The values of reduction in MT and CT temperatures of the specimens were obtained investigating CDI and TDI parameters and comparing those values with the ones found for conventional HMA.

2. Materials and methods

2.1. Materials

2.1.1. Asphalt cement and CW

Asphalt cement (AC) 50/70 penetration grade was produced at Campo Fazenda Alegre (FA) in the state of Espírito Santo, Brazil.

CW type 4 was used as AC modifier. CW CT4 has a solid form showing hardness and high melting point (approximately 83 °C). The modification of the AC with wax was performed in a high shear mixer at a temperature between 130 °C and 132 °C and mixing speed of 1400–1500 RPM (revolutions per minute).

2.1.2. Aggregates

In this study, 1.27 cm and 0.953 cm coarse aggregates of phonolitic origin and stone dust fine aggregates of granite origin were used. Hydrated lime (HC-I) was used as filler in order to improve the binder/aggregates adhesion. The aggregates characterization was performed according to the Brazilian standard procedures. Bailey methodology was used to choose the granulometric curve shown in Fig. 2. The aggregates percentage used were: (i) coarse aggregate 1.27 cm: 43.5%, (ii) coarse aggregate 0.953 cm: 21.2%, fine aggregate: 34.1%, and filler: 1.2%.

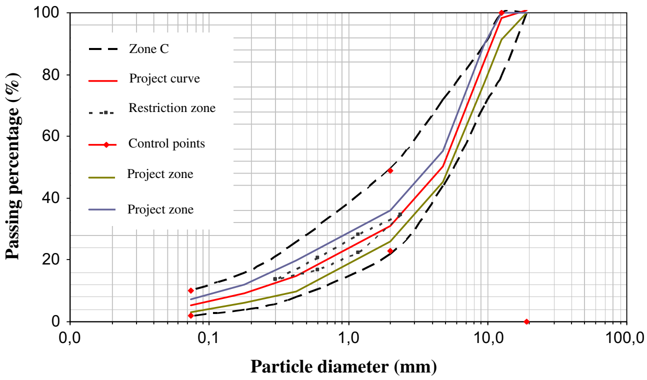

Fig. 2. Granulometric curve prepared using Bailey methodology.

2.2. Experimental procedure

2.2.1. Preparation of binder-CW mix for empirical and rheological studies

The binder-CW mixes were prepared using an IKA RW20 reactor with low shear mixing and processed for 1 h at 120 ± 5 °C and 1000 RPM. The concentrations of CW used for bitumen modification were: (i) CW4T 3% w/w (weight/weight) and (ii) CW4T 5% w/w. Samples were denoted as AC 3CW4T and AC 5CW4T, respectively.

2.2.2. Preparation of asphalt mixtures (binder + aggregate) for CDI and TDI determination

Three different binders were investigated: (I) neat AC 50–70, (II) AC50-70 + CW4T 5%, and (III) AC50-70 + 2% humid fine aggregates. The optimum AC content for the conventional HMA (binder without additive or any type of WMA technique) was 4.8%, found using the Superpave design methodology. Once the gradation curve and the optimum AC content were determined for the conventional HMA, the other investigated asphalt mixtures were replicated with the same gradation and the same AC content. In both cases, the goal was to promote a reduction in the variables to be analyzed and focus more specifically on the issues related to the WMA technique. Compaction was performed using the Superpave Giratory Compactor (SGC) from which CDI and TDI parameters were obtained and used to help on the mixing and on the compaction temperatures selection processes.

2.2.3. Penetration and softening points

The penetration point is measured with a semi automatic penetrometer by means of which a standard needle is applied to the AC sample according to ASTM D5 [11]. The softening point was determined using a Ring and Ball apparatus, according to ASTM D36 [12]. The penetration and softening point results were applied in the Pfeiffer–Van Doormal equation to obtain the Penetration index (PI) (Eq. (1)). The smaller the PI, the greater is the material thermal susceptibility.

$$IP = \frac{500.\log PEN + 20 \cdot PA - 1951}{120 - 50 \cdot \log PEN + PA} \tag{1}$$

2.2.4. Flow viscosity

The viscosity of the investigated binders was measured using a Brookfield DV-II + programmable rotational viscometer with a THERMOSEL control system according to ASTM D4402 [13]. The temperature 120 °C was used in the experiment in order to check the binder low temperatures behavior using a spindle SC4-21. To evaluate the binders shear rate susceptibility, samples were submitted to shear rates of 20, 30, 40, 50 and 60 RPM.

2.2.5. Dynamic rheology

Dynamic shear rheometer (DSR) – TA Instrument AR 2000® was used to measure the complex shear modulus (G^*) and the phase angle (δ) of the binders. Frequency sweep tests (from 0.1 to 10 Hz) were applied under a controlled-stress (120 Pa) mode as a function of loading frequency according to ASTM D 7175 [14]. The tests were conducted in two temperature ranges: from 10 to 40 °C (first stage), and from 45 to 90 °C (second stage). The samples were prepared in a 2 mm thick silicon mold and with 8 mm diameter for the first stage; and 1 mm thick with 25 mm diameter for the second stage. The rheological response was represented by master curves using the well-known time-temperature superposition principle (TTSP) [15]. The reference temperature was chosen to be 25 °C. Additionally, the DSR was used to evaluate permanent deformation (rutting) potential at 70 °C using creep recovery tests at 3200 and 100 Pa stress amplitudes (representing low and medium stress level on a pavement, respectively), according to ASTM D 7405 [16]. To determine the recovery percent (R) and the non-recoverable compliances (J_{nr}), the test was conducted after aging the samples in the rolling thin film oven test (RTFOT) according to ASTM D2872 (2004). Ten cycles of creep and recovery were run at each stress level for a total of 20 cycles. The bending beam rheometer test (BBR – Cannon Instruments Company) was conducted in order to evaluate the stiffness (S) and the rate (m) value for the modified and unmodified binders. The samples were aged on the pressure ageing vessel (PAV) residues.

2.2.6. CDI and TDI

CDI and TDI parameters were obtained based on the number of gyration from the gyratory compactor at varied percent of Gmm (maximum specific gravity) values [5,7]. These compaction indices were calculated using the results from cycle N = 8 to N at 92% Gmm of the compaction curve for the CDI, and from N at 92% Gmm to N at 98% Gmm for the TDI. The correlation between the effort to obtain 98% of the Gmm and the density of 96% of the Gmm presents a new parameter known as TDIm (modified TDI). This modification was suggested by Nascimento [17] to use the samples from the compaction process (with 4% of air voids) to perform its mechanical characterization.