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Influence of ageing on the properties of bitumen from asphalt mixtures with recycled concrete aggregates

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ABSTRACT

The reuse of recycled concrete aggregates in new hot-mix asphalt can be a more sustainable method of production, but these mixtures may need a heat treatment before compaction to improve their water sensitivity performance. A direct consequence of this treatment is an increase in the hot-mix asphalt resilient modulus. The aim of this paper is to analyse the effect of ageing on the stiffness of asphalt mixtures with different amounts of recycled concrete aggregates, before and after a heat treatment, which was analysed through the assessment of its bitumen properties. Moreover, this paper also aims to analyse whether the rolling thin-film oven test is able to simulate the ageing effect of the heat treatment. In the laboratory work, a paving grade bitumen B50/70 has been used to produce asphalt mixtures with 0% and 30% recycled concrete aggregates, and the bitumen was later characterised (using penetration, softening point, dynamic viscosity and dynamic shear rheometer tests) in various situations, such as when using virgin bitumen, short-term aged bitumen, aged bitumen after heat treatment (simulated with 4 h of rolling thin-film oven test) and bitumen samples recovered from asphalt mixtures with different production mixes (0% and 30% recycled concrete aggregate) and heat treatment conditions (0 and 4 h of curing time in the oven). Based on the results obtained, it could be concluded that the ageing resulting from the heat treatment is the primary cause of the hot-mix asphalt's increased stiffness, while recycled concrete aggregate content has a small influence. Moreover, it could be concluded that when there is no curing time, the recycled concrete aggregate protects the bitumen against ageing. Additionally, it could be stated that the rolling thin-film test is able to adequately simulate the ageing effect of the heat treatment. Thus, this test is useful for determining the ageing suffered by the bitumen when the recycled concrete aggregate mixture is manufactured using a heat treatment.

1. Introduction

There are some critical issues in sustainable development, such as energy consumption, generation of emissions during production (Gadja and VanGeem, 2001) and waste management (Oliveira et al., 2013). Construction and demolition waste (C&DW) has great potential for recycling within the construction industry (Symonds et al., 1999). In particular, the development of new construction materials that reuse recycled concrete aggregates (RCA) from C&DW has numerous environmental benefits, such as the mitigation of natural resource depletion and the reduction of environmental effects derived from quarry extraction (Blankendaal et al., 2014).

The use of RCA as aggregate for concrete (Rodrigues et al., 2013; Guo et al., 2014; Medina et al., 2014) and unbound pavement layers (Poon and Chan, 2006; Vegas et al., 2011) is widely accepted. Nevertheless, several authors have stated that the use of RCA as aggregate for hot-mix asphalt (HMA) leads to mixtures with a lower moisture damage resistance (Paranavithana and Mohajerani, 2006; Pérez et al., 2012; Zhu et al., 2012), which prevents its generalized use.

However, in recent years, Pasandín and Pérez (2013, 2014) have stated that the heat treatment of HMA mixtures with RCA in the oven for a curing time of at least four hours before compaction

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improves the water sensitivity performance of this type of mixture. The same authors observed a great increase in the stiffness of the mixture (resilient modulus of such mixtures with RCA at 0, 10 and 20 °C) as a consequence of the heat treatment in the oven. Two phenomena, which can occur simultaneously, were hypothesized to be the main causes of the notable increase in stiffness during the heat treatment of the mixtures with RCA: i) bitumen ageing due to oxidation and loss of volatile compounds at high temperatures; and ii) absorption of a great amount of bitumen by the porous mortar attached to the RCA surface.

The heat treatment affects other properties of the mixture, such as permanent deformation and fatigue. In this regard, Pasandín and Pérez (2013, 2014) concluded that mixtures made using a heat treatment with up to 30% RCA exhibit good rutting performance. Nevertheless, they also stated that permanent deformation increases with increasing RCA percentages, so mixtures with higher RCA content should be expected to be more susceptible to rutting. Moreover, Pasandín and Pérez (2014) stated that higher initial densifications of HMA were obtained for greater heat treatment lengths due to their higher air void content. Pasandín and Pérez (2013) also stated that HMA with up to 20% RCA exhibit a fatigue life similar to that of a conventional mixture. However, the fatigue life of an HMA made with 30% RCA was slightly lower than that of a conventional mixture. Thus, again, the maximum RCA percentage to be included in an HMA should be lower than 30%.

The aim of this work is to evaluate in more detail the phenomena occurring during the production and heat treatment of asphalt mixtures with RCA, which cause the stiffening of those mixtures. Another objective is to assess whether the bitumen absorption by the RCA could protect the bitumen against ageing. To conduct that analysis, an advanced characterization of the bitumen (penetration grade, softening point, dynamic viscosity and rheological properties) was performed in the following situations:

1. virgin bitumen;
2. bitumen after standard Rolling Thin-Film Oven Test;
3. bitumen after extended Rolling Thin-Film Oven Test of 4 h of ageing time;
4. bitumen recovered from samples of HMA made with 0% RCA manufactured with 4 h of curing time in the oven (recovery 1);
5. bitumen recovered from samples of HMA made with 30% RCA manufactured with 4 h of curing time in the oven (recovery 2);
6. bitumen recovered from samples of HMA made with 0% RCA without curing time (recovery 3);
7. bitumen recovered from samples of HMA made with 30% RCA without curing time (recovery 4).

The comparison between the bitumen properties in the different situations was the main method used to understand the effect of ageing during production (situations 6 and 7 vs. 1) and during the heat treatment (situations 4 and 5 vs. 6 and 7), as well as the effect of using more porous RCA aggregates instead of natural aggregates (situation 5 vs. 4 and 7 vs. 6). The properties obtained in situations 2 and 3, with the rolling thin-film oven test (RTFOT) ageing test, were used to understand if this test is able to adequately simulate the ageing of the studied mixtures after production and after heat treatment.

2. Materials

A commercial paving grade bitumen B50/70 has been used in this investigation, and plays a leading role in the results of this paper. The evolution of the properties of this bitumen was assessed in different phases: before its use, after short-term ageing and after four hours of ageing in the RTFOT (simulating the expected ageing caused by the heat treatment). This bitumen has also been used to produce asphalt mixtures with 0% and 30% of RCA, using two conditioning procedures (0 and 4 h of heat treatment after production). The bitumen used in these mixtures was then recovered and characterized.

Two types of aggregates have been used to produce HMA samples: natural and RCA. A hornfels rock, typically applied in paved road construction in Spain, has been used as natural aggregate. The RCA came from C&DW from residential buildings and was supplied by a Spanish recycling site. The RCA is mainly composed of petrous materials (89.3%) and other materials such as asphalt materials (6.5%), ceramics (3.6%) and impurities (0.6%). It must be noted that RCA aggregates mainly differ from natural ones because they have old mortar attached to their surface. That mortar is a porous material that reduces the RCA aggregates' resistance to fragmentation (Sánchez de Juan and Alaejos Gutiérrez, 2009) and greatly increases their absorption of water (Paranavithana and Mohajerani, 2006; Pérez et al., 2012) and bitumen (Lee et al., 2012; Pasandín and Pérez, 2013). Finally, it should be mentioned that Grey Portland cement (CEM II/B-M (V-L) 32.5 N) was used as filler during the production of asphalt mixtures.

3. Experimental methods

The main tests performed as part of the laboratory investigation are described below.

3.1. Marshall mix design method

The asphalt mixture AC 22 base B50/70 G was designed following the Marshall procedure according to NLT-159/86 (MOPT, 2002). In this test, four series of five cylindrical Marshall samples were analysed to obtain the optimum bitumen content (OBC). The Marshall series were manufactured with bitumen contents ranging from 3.5% to 5.0%. The cylindrical samples were compacted with 75 blows per face using the Marshall hammer. Four series of this mixture were independently studied using this method: with or without RCA and with or without heat treatment (corresponding to the four mixtures used to recover the bitumen for situations 4, 5, 6 and 7 presented previously). The results were obtained by taking the average values of the five samples of each series.

3.2. Bitumen recovery

UNE-EN 12697-1 (AENOR, 2013a) and UNE-EN 12697-3 (AENOR, 2013b) were followed to recover the bitumen from the HMA samples. As shown in Fig. 1, the UNE-EN 12697-1 indicates that the loose (uncompacted) bituminous mixture (Fig. 1a) must first be introduced into an asphalt centrifuge extractor with 1 L of toluene, as shown in Fig. 1b. After five centrifugation cycles, 500 mL of clean toluene must be added and the loose mixture must be subjected to five new centrifugation cycles. As a result of this first step, the bitumen, the fines and the solvent (toluene) were separated from the rest of the aggregates. A Rotofix 32 centrifuge was then used to separate the fines from the bitumen and the solvent (Fig. 1c). In this second step, the cups with bitumen, toluene and fines rotate at 3000 rpm for 10 min and the sediments remained in the bottom of the cups. Finally, in a third step, UNE-EN 12697-3 indicates that a rotary evaporator (Büchi Rotavapor R-205) ensures the evaporation and condensation of the toluene and its separation from the bitumen. The rotating distillation glass balloon of the rotary evaporator device is partially immersed in a heating oil bath while the solution of bitumen and toluene is subjected to a vacuum with controlled pressure (Fig. 1d). As a result, bitumen and toluene are totally separated. Toluene is a highly polluting organic solvent that