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Towards 100% recycling of reclaimed asphalt in road surface courses: binder design methodology and case studies

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ABSTRACT

Reclaimed Asphalt (RA) has shown great potential to be reused in new asphalt mixtures, however its incorporation in top asphalt pavement layers is still very limited (10–30%). In fact, despite the advantages that its use implies, RA content in road pavement surface courses is still restricted in most countries due to mainly legislation limitations, but also some technical issues. This paper aims at being a step further to improve the latter by providing a methodology that allows producing fundamental inputs for confidently performing mix design of asphalt mixtures incorporating up to 100% RA. The methodology consists in an advanced preliminary binder's blend design that can be used with any type of RA and also in presence of rejuvenators. This procedure includes in the production of blending charts and laws that considers the uncertainties on accounting the extent of final binder content, Degree of Blending and Replaced Virgin Binder. The description of the methodology is accompanied with results of two extreme case studies consisting in the preliminary design of binders for asphalt mixtures with high content of two types of RA corresponding to extreme cases: the short-term aged RA (STA-RA), having a very soft residual binder (Pen > 20 dmm) and the long-term aged RA, having a much harder residual binder (Pen < 10 dmm). As a result, the proposed methodology allowed assessing the feasibility of using up to 90% of RA and determining whether the use of rejuvenating agents was needed.

1. Introduction

Current concerns about the scarcity of raw materials for the construction and maintenance of roads (and the increase in price that it implies), together with the great potential shown by Reclaimed Asphalt (RA) to be successfully recycled in asphalt mixtures, are encouraging the increase of the use of this material to produce high RA content mixtures (Stimilli et al., 2016). For this purpose, great efforts are being made to understand how to recycle RA directly within surface courses so to avoid its downgrading (Re-Road.fehrl.org, 2013). However, in general, the share of recycling of RA in new asphalt courses remains rather lower than it could be technically, being wearing courses the most challenging ones due to the required high performance such as resisting distresses and skid resistance (West et al., 2016). In fact, despite the advantages that its use implies, RA content in road pavement surface courses is still restricted in most countries due to mainly legislation limitations, but also technical issues such as: variability of RA properties, the often-unknown nature, uncertainties on mixture's performance and the lack of fundamental understanding of some of the mechanisms involved during its mixing with other components of asphalt mixes.

Generally, high RA content mixtures for wearing courses are considered those that have more than 20–30% in weight, depending on the countries and type of RA (Austroads, 2015). Different studies have been carried out to shed lights on whether the increase of RA percentages in wearing courses is actually feasible or not (Sabouri et al., 2015a, 2015b; Doyle and Howard, 2010; Maupin et al., 2008). Beginning with low increases, Maupin et al. (2008) reported the results of testing plant-produced mixes for wearing courses including 21–30% of RA. They showed that there were no significant differences between the higher RA mixes and the control mixes for fatigue, rutting and susceptibility to moisture. Binder testing showed that the addition of RA raised the high temperature grading one to two grades, which should be assumed in mix design, and care has to be taken at low temperatures. In addition, there were no construction problems attributed to the use of the mix with higher RA percentages. The same mixes

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were later studied by Apeagyei et al. (2013) to check the influence of the high RA content in mix stiffness, finding that 30% RA did not produce a considerable effect on it.

Several studies showed that the key to increase the amount of RA in asphalt is a balanced mix design (Canon Falla et al., 2015; Bueche et al., 2016). On this regard, Zhou et al. (2011) developed a balanced RA mix design for high RA content mixtures for surface layers based on changing the binder content of the mix to optimise the maximum density. To validate the design, Zhou et al. (2011) built two field sections with 35% RA content mixes designed with their methodology in different locations. The overall conclusion from the study was that high RA mixes can have better or similar performance to virgin mixes, but they must be well designed following appropriate mix design methods.

Going further in the increase of RA content, Doyle and Howard (2010) studied mixes for wearing courses including 25 and 50% and considering the use of additives to produce warm technologies. Durability, cracking and rut resistance and moisture damage of the mixes were examined and results indicated that the use of high RA in surface mixtures would be feasible without adversely affecting mix performance. Celauro et al. (2010) conducted another investigation of mixtures with 50% RA content for surface layers concluding that, undertaking a tailored design with such a high percentage of RA, mixtures with “high-performance” could be obtained.

NCHRP Report 752 (West et al., 2013) showed that in mixtures with 55% RA content, stiffness could increase up to 25–60% compared to virgin ones, thus leading to cracking problems. On the other hand, rutting and moisture resistance are likely to be better or similar to those of conventional mixtures as the percentage of RA increases (McDaniel et al., 2002; Silva et al., 2012; Tran et al., 2012; Mogawer et al., 2012).

Results of the Austroads report (2015), as well as Sabouri et al. (2015a, 2015b) reinforce the previously published general trends that an increase in RA content leads to an increase in stiffness of the asphalt, a reduction in fatigue life, and an increase in permanent deformation resistance. The results do not suggest the RA content has an appreciable impact on moisture sensitivity of the asphalt specimen. Furthermore, It was observed that for mixes with hard RA, here called “long-term aged”, incorporating content below 30%, the performance properties are very similar, but differ significantly from mixes with 60% of RA and those containing only virgin binder (0% RA) (Austroads, 2015). Instead, when RA mixtures were manufactured with even 40% of soft RA, here called “short-term aged”, results of performance-related tests provided evidence of a little impact of the RA. This is justified from the little differences between RA and virgin materials stiffnesses (Sabouri et al., 2015a, 2015b).

In summary, these studies all agree that obtaining good performance of high RA content asphalt concretes strongly depends on RA properties and mixture design. Special attention has to be paid to the mixture design due to the presence of the aged stiff binder. In fact the aged binder could represent an advantage in terms of rut resistance at high service temperature (30–60 °C) but it usually favours cracking phenomenon at lower temperatures (+30 °C to below 0 °C). Furthermore, these studies considered 50–60% RA content as almost a limit for asphalt mixes, especially for surface courses. This is partially related to the final performance of the asphalt concrete that will strongly depend on the properties of the RA, on the RA handling procedures (Bressi et al., 2016) and also to the final grading curve of the targeted mixture that usually needs fixing with additional virgin aggregates. Nevertheless, regardless of the final performance of the asphalt, so far the main technical reason playing against 100% RA asphalt mixtures has been technological and it is due to limitations of the majority of existing asphalt plants that, due to equipment design issues (such as fumes produced by over-heated RA), are not able to incorporate more than 50–60% in new asphalt mixtures (Zaumanis and Mallick, 2015). Current aspirations are to achieve greater RA rates (aiming at 100%) in order to maximise the advantages of RA usage, however technological change of the asphalt plants is needed and it's sporadically happening (Rowe et al., 2015; Zaumanis et al., 2014), but also material characterisation and binder and mixtures design should be adapted to consider RA as the main ingredient, while ensuring the usual desired performance (Canon Falla et al., 2015; Lo Presti et al., 2014).

In this regard, investigating technologies and procedures to take advantage of the binder already contained in the Reclaimed Asphalt binders (RA binders) play a critical role (Hassan et al., 2015; Zaumanis et al., 2014; Zhao et al., 2016). Therefore, developing a proper binder blend's design between RA binders and virgin materials is the first step for designing feasible 100% RA content mixtures. Currently, different approaches are being followed to carry out this task in different countries. In Europe, the standard EN 13108-8:2005 for reclaimed asphalt establishes that if RA content is higher than 10% for surface layers and than 20% for base layers, a logarithmic blending law for penetration and a linear blending law for softening point should be applied to select the proper virgin binder to use. On the other hand, in the United States of America, for high RA contents (>20%), NCHRP Report 452 (2001) described a particular procedure to obtain blending charts assessing high, intermediate and low critical temperatures of the blend of RA and virgin binder. After building blending charts, next step in both specifications is to use the final RA percentage in the mix to obtain the value that the property under assessment (i.e. penetration, softening point, etc.) would have after the manufacture of the mixture. Nevertheless, RA percentage is not the percentage of RA binder that will be blended with the virgin binder. The real percentage of RA binder that will blend is known as Replaced Virgin Binder (RVB) and depends on several factors such as RA binder content, binder content in the final mixture and the degree of blending (DOB) between virgin and aged binders. NCHRP Report 752 (West et al., 2013) already suggested using what they called “RAP binder ratio” but only taking into account binder content in the mixture. Regarding the DOB, recent researches have argued that for high RA contents (>20%) high blending rates take place (Soleymani et al., 2000; Shirodkar et al., 2011; McDaniel et al., 2012).

Other aspect to take into account while developing blend design is that when RA content is wanted to be higher than a certain percentage (limitations depends on RA properties and local specifications), or when RA contains particularly hard aged binder, it could be necessary to introduce another component in the mix (in addition to the virgin binder). This component is commonly known as rejuvenator or rejuvenating/recycling agent and is responsible for restoring some of the properties that the reclaimed material had before its service life (Shen and Ohne, 2002; Karlsson and Isacsson, 2006; Romera et al., 2006; Tran et al., 2012). The effect of rejuvenators on RA mixes has already been studied and applied in full-scale by some authors (Silva et al., 2012; Zaumanis et al., 2013) showing that these materials could allow the use of 100% RA mixes for wearing courses. However, traditional binder blend's design still only considers RA and virgin binders without taking into account the use of rejuvenators.

Within this framework, this paper proposes a methodology that allows predicting the binder's properties of the asphalt mixtures containing up to 100% RA. This methodology consists in the construction of blending charts for conventional and performance-related binder properties, including the use of RVB and DOB concepts, it allows including the use of rejuvenators and it is independent of the RA source. In order to prove the flexibility of the

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