JOURNAL OF TRAFFIC AND TRANSPORTATION ENGINEERING (ENGLISH EDITION) 2018; X (X): 1–12

Available online at www.sciencedirect.com

ScienceDirect

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

Original Research Paper

Influence of rejuvenators on bitumen ageing in hot recycled asphalt mixtures

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HIGHLIGHTS

- Evaluation of bitumen service life including its reuse in hot recycling.
- Effect of different rejuvenators on the bituminous blends was analysed.
- Rejuvenated bitumens guarantee lower ageing than virgin bitumen alone.
- At the end of service life rejuvenated bitumen can be less stiff than virgin one.

ARTICLE INFO

Article history:
Received 14 September 2017
Received in revised form
8 January 2018
Accepted 9 January 2018
Available online xxx

Keywords:
Rejuvenator
Reclaimed asphalt pavement
Bitumen
Ageing
Dynamic shear rheometer (DSR)

ABSTRACT

The use of reclaimed asphalt pavement (RAP) in new hot mix asphalt (HMA) by means of hot recycling techniques generates the advantage linked to the exploitation of both lytic and bituminous component, consequently leading to the decrease of both virgin aggregates and bitumen supplying. However, many agencies and public administration authorise RAP percentages ranges from 10% to 30% in hot recycling. The main reason for such a low amount of allowable RAP content is related to the aged bitumen contained in the RAP materials, which is more brittle than a virgin bitumen leading to a final mixture more susceptible to fatigue, thermal and reflection cracking. The use of rejuvenators has the potential to restore rheology and chemical components of aged RAP bitumen, thus allowing a significant increase in the amount of RAP to be properly implemented in HMA.

The experimental investigation is described in this paper and carried out through a dynamic shear rheometer (DSR) which provides the rheological characterisation of a paving grade bitumen during its overall service life including its reuse in hot recycling by adopting different rejuvenators.

Results show that rejuvenators modify bitumen chemistry and consequently rheology by enhancing the viscous response. Moreover, it was observed that oxidation is less harmful, in terms of stiffness increase, on the 50/50 aged bitumen - virgin bitumen blends (rejuvenated or not) than on the virgin bitumen. Moreover, the addition of a rejuvenator in a bituminous blend containing 50% of bitumen reactivated from RAP could lead to a corresponding composite bituminous phase less subjected to ageing phenomena and even less stiff at the end of service life than the associated virgin bitumen alone.

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Peer review under responsibility of Periodical Offices of Chang'an University.
https://doi.org/10.1016/j.jtte.2018.01.001

1. Introduction

Nowadays, the implementation of high reclaimed asphalt pavement (RAP) contents in the production of new hot mix asphalt (HMA) represents a challenging issue for highways agencies and paving companies. The main factors that encourage the use of RAP in HMA are economic and environmental benefits, such as reducing production costs and disposal in landfills as well as preserving natural resources.

Although RAP has its origin from the demolition of damaged asphalt pavements, this material should not be considered as a waste product (Karlsson and Isacsson, 2006), since the important residual properties of bitumen and mineral aggregates contained in RAP could be profitably exploited through hot and cold recycling techniques.

Cold recycling allows reaching the highest amount of RAP to be reused. However, since in cold mix asphalt (CMA) RAP acts as a "black aggregate", the low production temperature does not allow the reactivation of RAP bitumen that hardly interacts in an efficient manner with new bitumen (Grilli et al., 2012).

As regards hot recycling technique, the use of RAP allows a double advantage through the exploitation of both lytic and bituminous component (Al-Qadi et al., 2007), leading to a reduction of virgin aggregates and bitumen supplying in the production of HMA. However, many agencies and public administrations authorise low RAP percentages ranging from 10% to 30% in hot recycling, due to different concerns.

First, the phenomena of RAP bitumen mobilisation and its blending and interaction with the new virgin bitumen during mix production represent uncertainties which are still under investigation worldwide. Despite the considerable efforts in characterising the interaction between virgin and RAP bitumens (Booshehrian et al., 2013; Navaro et al., 2012; Nguyen, 2009) and their degree of blending (Bressi et al., 2016; Frigio et al., 2015; Shirodkar et al., 2011; Stimilli et al., 2015; Yousefi Rad, 2013), only little fundamental information is available in literature about the physicochemical phenomena and mechanisms during the mixing of a new HMA with RAP. Inaccurate assumptions on the effects of interaction could create problems in both mix design and pavement performance, leading to a final mixture more susceptible to cracking, ravelling, moisture damage and rutting (Dondi et al., 2016; Noferini et al., 2017; Zaumanis and Mallick, 2015).

Moreover, a critical issue is related to the ageing process, which affects physical and chemical characteristics of RAP bitumen entailing a general hardening of the final bituminous blend. As well known, bitumen undergoes two different ageing phases: short- and long-term ageing. The former represents the ageing during plant mixing, transportation and paving and is related to oxidation and lighter components evaporation. Whereas the latter occurs during pavement service life and is mainly linked to oxidation and physical hardening (Lu et al., 2017). Presence of water, local climate, thickness of the bitumen film and, mostly, mix porosity represent the main factors that influence the degree of long-term ageing.

Generally, ageing process causes a progressive change in bitumen rheological and chemical properties, leading to a reduction of the aromatic content and a consequent increase in the amount of resins (which in turn generate asphaltenes), whereas saturates remain essentially unchanged due to their poor reactivity (Lesueur, 2009). Since asphaltenes play a major role in determining bitumen viscosity, it is evident that oxidation causes a stiff behaviour (bitumen hardening) in addition to poor adhesion and reduction of coating properties.

In addition, the maximum amount of RAP to be reused in HMA production depends not only on the ability to correct the physicochemical characteristics of the aged bitumen, but also on the production technology (Mogawer et al., 2012). Considering hot in plant recycling, most conventional drum plants can accommodate 50% RAP, whereas the percentage of reusable RAP in batch plant ranges from 10% to 30% (Kandhal and Mallick, 1997).

When high amounts of RAP (30% or more) are introduced in the production of new HMA, the use of specific additives is strongly recommended to achieve adequate workability and final mechanical performance (Chen et al., 2007; Hajj et al., 2013; Shen et al., 2007; Tran et al., 2017; Xie et al., 2017; Yu et al., 2014). The additives should be non-hazardous and stable over a wide range of temperatures, from production to application. In addition, they must not experience any exudation or evaporation, in order to guarantee a good performance over asphalt pavement lifetime (Bocci et al., 2017; Grilli et al., 2015).

Among recycling additives, a distinction can be made between softening agents and rejuvenators. The softening agents aim at reducing aged bitumen viscosity, whereas rejuvenators attempt to restore the chemical and rheological properties of aged bitumen, thus ensuring long lasting HMA (Grilli et al., 2017, Tabakovi et al., 2017). Rejuvenators can have different nature, which reflects in the molecular structure and polarity (Zaumanis et al., 2014). In the last years, many products including tall oils, organic oils or recycled waste oils have been used worldwide to mobilise the aged bitumen in the RAP with the double benefit of possibly increasing RAP content in the mix and achieving good HMA performance. In particular, it has been observed (Booshehrian et al., 2013; Oldham et al., 2018) that the same target rheological properties, comparable to those of a virgin bitumen, can be obtained by mixing the aged RAP bitumen with a rejuvenator. However, the chemical composition (e.g. the ratio of asphaltenes to maltenes) of the rejuvenated

Please cite this article in press as: Mazzoni, G., et al., Influence of rejuvenators on bitumen ageing in hot recycled asphalt mixtures, Journal of Traffic and Transportation Engineering (English Edition) (2018), https://doi.org/10.1016/j.jtte.2018.01.001