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Suitability of different foamed bitumens for warm mix asphalts with increasing recycling rates

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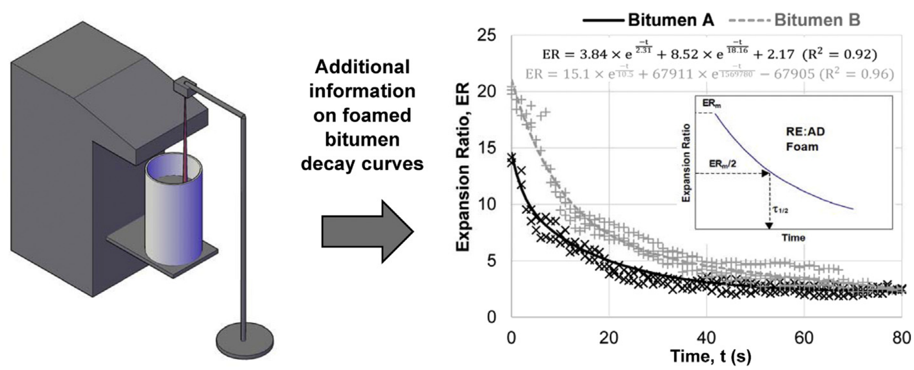
HIGHLIGHTS

- Different foamed bitumens were studied to be used in warm asphalt mixtures.
- Decay curves of foamed bitumen assessed by a laser device were studied in detail.
- Foam index and suitable foam quality space are key tools for foamed bitumen studies.
- Better foamability was found for soft binders, 3% water content and 0.1% additive.
- Foamed bitumen allows production of durable recycled mixtures at lower temperatures.

GRAPHICAL ABSTRACT



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ABSTRACT

Due to the current need for more sustainable production processes and construction materials, foamed bitumen has become one of the most interesting solutions for asphalt paving works, both for new (warm mix) and recycled asphalt mixtures (warm recycled mix). However, significant work still needs to be carried out in order to fully understand the performance of foamed bitumens, and their adequacy for incorporation into asphalt mixtures with different amounts of reclaimed materials, which is the main objective of this work. Three types of bitumen, with increasing penetration grades were selected in order to evaluate their foaming properties, namely their expansion ratio and half-life, as well as the foam index assessed using the foam decay curves obtained through a semi-automated process. After determining the most suitable composition of each foamed bitumen (water content, temperature, foam stabilizing additive content), these were incorporated into asphalt mixtures with 0%, 30% and 50% reclaimed asphalt material. As the amount of reclaimed material increased, the penetration grade of the new bitumen added was also increased, in order to compensate the lost properties of the aged binder. The suitability of these solutions was assessed through water sensitivity tests, and it was concluded that the proposed approach is adequate to obtain long-lasting solutions. Moreover, it became evident that foamed bitumens perform better when incorporated into recycled asphalt mixtures.

1. Introduction

Currently, both researchers and industry, including those working in road construction and rehabilitation of asphalt pavements,

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are paying increasing attention to the sustainability of their activities. Two of the main areas of research in that domain are the reduction of asphalt mixtures production temperatures [1] and the incorporation of reclaimed asphalt paving (RAP) materials [2–4], and this paper presents a new study that focuses in the use of both technologies.

The decrease of asphalt production temperature may be obtained using warm mix asphalt techniques, through the use of bitumen emulsions, organic or chemical additives or foamed bitumen [5–9]. These technologies present several advantages, from which the reduction of gaseous emissions [10], the reduction of fuel consumption and the improvement of working conditions stand out [7,11]. Among these, foamed bitumen is one of the most interesting solutions due to the low quantity of water (which reduces the performance of asphalt mixtures) or additives (which increase the costs and the environmental impact of the mixtures) used. This highlights the importance of better understanding this solution and justifies the work presented in this paper.

According to Bowering and Martin [12], foamed bitumen was originally developed in 1957. It is formed when bitumen interacts with steam, creating a low viscosity foam, which results in a change in the interfacial tension and a substantial increase in the bitumen surface area [13]. The process has now evolved, and foamed bitumen can be obtained either by the use of water bearing additives or by direct injection of water into hot bitumen [14].

Foamed bitumen is normally chosen as a solution to produce cold asphalt mixtures or in-situ stabilization or recycling of asphalt pavements [15,16] with variable materials, namely gravel with some plasticity [17,18]. Moreover, in comparison with bitumen emulsion this technique demands a shorter curing period [19]. However, little work has been presented in the literature regarding the use of foamed bitumen in warm mix asphalt materials [20], which may or not include RAP material, and this paper will try to address this key research topic in more detail, specifically the foam properties of different binders and their suitability for asphalt mixtures with 0 to 50% RAP content.

In fact, although the most relevant characteristics of binders for the production of hot mix asphalt mixtures in Europe are considered to be the penetration, the softening point and the viscosity, for foamed bitumen these characteristics are not sufficient. In addition, the maximum expansion ratio (ER_{max}) and the half-life (HL) are typically used to characterize this type of binder, and Jenkins [21] has discussed the combined use of those properties to evaluate the foamability of a given binder.

The expansion ratio (ER) is the ratio between the bitumen volume after the foaming process and its initial volume, and the maximum expansion ratio (ER_{max}) value is obtained immediately after spraying into a vessel of known capacity. This value is a measure of foamed bitumen's viscosity and is related to the wettability of the foamed bitumen and the workability of the resulting mixture. The half-life (HL) is the time elapsing between the moments when the foamed bitumen reaches its maximum volume and half of that value. This value is a measure of a foamed bitumen's stability and it is proportional to the time available for mixture production [21]. In order to obtain the best foamed bitumen quality for mixture production it is necessary to optimize of these values, by selecting the parameters (mainly the water content) which result in sufficiently high ER_{max} and sufficiently long HL [22].

In order to increase the confidence in the characterization of foamed bitumen, Jenkins [21] developed a new property defined as Foam Index (FI), which combines both the expansion ratio and the half-life values, because he considered that these values cannot be evaluated independently. After producing foamed bitumen, the foam often undergoes an asymptotic expansion reduction with time, i.e., a decay curve. The foam index is the area under that curve, and above a minimum expansion ratio of 4. The shape of the decay curves (and the corresponding equations) can also give valuable information to be used in the characterization of foamed bitumens, as mentioned by Jenkins [21] and Lesueur et al. [23].

The quality of foamed bitumen depends on a significant number of parameters, which have been addressed by different authors, namely the type and origin of bitumen [24,25], the temperature of the bitumen in the foaming process [21,26], the foamed bitumen spray rate [21] and the use of foam stabilizing additives [21,24,27]. However, the rate of foamant water used in the process is the most influential parameter in the quality of the foamed bitumen, increasing the expansion ratio and reducing the half-life value [21,26]. The temperature of the water and the quantity of air used together with water are also important in the process [21].

When using foamed bitumen technology in the production of asphalt mixtures, some authors have discussed the increase in the susceptibility of the mixtures to moisture damage [14,28], on mixtures produced with 100% virgin materials. Other authors [29] have mentioned that the incorporation of RAP may have a beneficial effect on the performance of the asphalt mixtures.

Based on these observations, in the present work, a comprehensive study of foamed bitumen technology was carried out, in order to understand how the properties of different binders can be used to produce warm mix asphalts incorporating increasing percentages of reclaimed asphalt material. Furthermore, a recent noncontact measurement method using a laser sensor has been adopted to assess the evolution of the expansion ratio with time and particular attention has been given to the use of the Foam Index (FI) concept to assess the suitability of a particular binder to a specific application, as discussed in the following sections.

2. Materials and experimental methods

2.1. Materials

In the present study, three straight run bitumens of different penetration grades were used to produce asphalt mixtures with foamed bitumen technology, named respectively Bitumen A (50 pen), Bitumen B (75 pen) and Bitumen C (170 pen), where A is the hardest and C is the softest bitumen. The selection of such binders was made based on the objective of producing foamed bitumens adequate for asphalt mixtures with different recycling rates.

Furthermore, a specific additive (TEGO® Addibit FS 725 A) was used as a foam stabilizer in the production of foamed bitumens; it is an organo-modified siloxane based additive [30]. This additive has already been used by Hailesilassie et al. [31] with the same objective. The additive suppliers recommend an additive percentage of 0.25 % by mass of bitumen. However different amounts were tested in the present work, as presented later in the paper.

For production of the asphalt mixtures evaluated in the present work, new aggregate and reclaimed asphalt material were necessary. The new aggregate was granite and the filler was limestone; they were selected based on local availability. The reclaimed asphalt material was obtained from a local contractor, and was previously subjected to a separation/classification process in order to assure a higher homogeneity of the RAP material, according to a previously discussed procedure [32]. In this publication, details regarding the two fractions in which RAP was divided (in an 8 mm sieve) are given, namely a coarse fraction with 4.2% binder content and a fine fraction with 5.9% binder content. The RAP binder was also characterized for penetration and softening point, presenting 9×0.1 mm of penetration and 67 °C ring and ball temperature, respectively.