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Foamed bitumen: an alternative way of producing asphalt mixtures

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Abstract

With the constant need to improve and make the production of asphalt mixtures more sustainable, new production techniques have been developed, the implementation of which implies the correct knowledge of their performance. One of the most promising asphalt production techniques is the use of foamed bitumen. However, it is essential to understand how this binder will behave when subjected to the expansion process. The loss of volume of the foamed bitumen could be translated by a decay curve, which allows to determine the ideal temperature and water content added to the bitumen in order to assure adequate conditions to the mix the bitumen with the aggregates. On the present study, a conventional 160/220 pen grade bitumen was tested by using different temperatures and water contents, and it was concluded that the optimum temperature for the production of foamed bitumen (with the studied bitumen) is 150ºC, which corresponds to a viscosity of 0.1 Pa.s. The water content mostly influence the half-life of the bitumen foam, resulting in quicker volume reductions for higher water contents.

Keywords: Warm mix asphalt; foamed bitumen; asphalt mixtures; bitumen foaming characteristics.

1. Introduction

The asphalt pavement industry has been more concerned with the environment in the last years. The need to mitigate the negative impact of the road construction on the environment has resulted in a high number of new techniques that reduce the adverse effects of the production of asphalt mixtures.

The asphalt mixtures comprise about 95% of mineral aggregates and 5% of bitumen. Due to its viscoelastic nature, bitumen presents a liquid form when heated up to temperatures around 150ºC and a solid form at ambient temperatures. Thus, the production of asphalt mixtures has traditionally been made using high temperatures to be able to work with the bitumen. These temperatures are even higher when the mixtures incorporate reclaimed asphalt materials. The need to mitigate the influence of the production in the ageing of bitumen results in the use of different heating temperatures of the aggregates and reclaimed materials [1,2].

The utilization of high temperatures to the production and application of new asphalt mixtures also cause a high level of GHG emissions. For that reason, the industry has been developing techniques to reduce the production temperatures of the mixtures. This type of mixtures are normally classified as half-warm or warm mix asphalts. The classification of half-warm mixtures is given to mixtures produced between 70 and 100ºC, and the warm mixtures are produced between 100 and 140ºC [3].

A significant number of advantages can be associated to the use of warm mix asphalt (WMA) in a global perspective, i.e., without differentiating between the techniques applied. The reduction of production temperature reduces the gas emissions and the energy

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consumption, while improving the working conditions [4]. Associated to those main advantages, others can be mentioned, namely, the cost reduction associated to the lower energy consumption, the increase on the transport distances due to the lower compaction temperatures [5], and could also extend the paving windows [6], with the mixtures being applied in conditions worse than those of hot mix asphalts (HMA).

WMA mixtures can be produced by different techniques, using organic or chemical additives or foaming processes [7]. The latter can be obtained by water-containing technologies or by water-based technologies [6]. Water-containing technologies are obtained by incorporating additives which include water in their composition, while, in the water-based technologies, the water is injected into the hot bitumen in small quantities and immediately added to the aggregates in the asphalt mixing chamber [4]. This process is normally more technically complex and requires a relatively large financial investment for plant modifications.

To the production of foamed bitumen by direct injection of water, the air and the water are injected in the bitumen as show in Fig. 1.

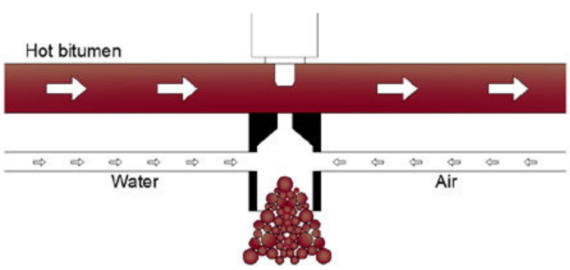

Fig. 1. Schematic procedure of producing foamed bitumen (adapted from [11]).

Jenkins [8] mentioned that the foamed bitumen process is analogous to a baker beating an egg, which is viscous, into foam of low viscosity before mixing it with flour. The beaten egg increases in volume, which is necessary in order to evenly distribute it among the flour and produce a mix of acceptable quality and consistency. Similarly, the foamed bitumen increases in volume, facilitating a good bitumen distribution over the aggregates.

The two basic characteristics of foamed bitumen are the maximum expansion ratio (ERmax) and the half-life (HL). The expansion ratio (ER) is the ratio between the volume of the bitumen in a specific time and the initial volume; the ERmax is the maximum value of the ER, immediately after injection. The HL is the time measured between the moment that the foamed bitumen reaches its maximum volume and the moment it reaches half of that value. Jenkins [8] also mentions the foam index (FI) as a characteristic that should be used to choose the ideal conditions for the expansion process. The FI is obtained by applying a theoretical expression to the decay curve, and calculating the area of the graph between the decay curve and a lower limit associated with the adequate viscosity of the bitumen to be mixed with the aggregates. In terms of the decay curve (DC), this is the representation of the evolution of the ER as a function of the elapsed time.

The expansion characteristics of the bitumen is influenced by different parameters. Some studies mention that a softer bitumen, combined with high temperatures, have better results than a harder bitumen [9]. However, other study mentions that the viscosity is one of the most important parameters, i.e., different bitumen foamed at equiviscous temperatures will have identical characteristics [10].

For the present study, only one bitumen was analysed, but with different water contents and temperatures, in order to understand the influence of that type of variables on the bitumen decay curve.

2. Materials and Methods

The material used in this study was essentially a 160/220 pen grade bitumen. This bitumen has been chosen taking into account the literature review that mentions that softer bitumens have generally better foaming results.

To the production of foamed bitumen, a Wirtgen WLB 10 S machine was used. This equipment has been developed to a laboratory scale with the objective of making the analysis of FB characteristics in small scale possible, but it is similar to the equipments used in normal scale [11]. In order to reduce the number of variable under study, the air pressure was maintained with the default value (5.5 bar; 550 kPa), the temperature of all components of the machine were adjusted to the same temperature of the bitumen and a nozzle with 2 mm of diameter (capable of injecting 50 g of bitumen per second) was selected.

2.1. Basic characteristics

Regarding the basic characteristics of the bitumen, penetration (EN 1426) [12], softening point (EN 1427) [13] and dynamic viscosity (EN 13302) [14] tests were carried out. To complete the analysis of the bitumen, its rheological properties have been tested (EN 14770) [15] with the Dynamic Shear Rheometer (DSR), for a temperature range between 19 and 88ºC.

2.2. Expansion characteristics

The expansion characteristics of foamed bitumen are essential to define the optimum combination of parameters that influence the foam stability during the mixing process. For a good characterization of the expansion properties, two parameters have to be determined, namely, the maximum expansion ratio (ERmax) and the half-life (HL).
In this study, the foam index (FI) values have also been calculated, using the equation developed by Jenkins [8], and the decay curves (DC) were presented to understand how the process of expansion decay changes with variations on the temperature (140, 150 and 160ºC) and on the water content (between 2 and 5% of water by mass of bitumen).

3. Results and Discussion

3.1. Basic characteristics

The results obtained for the basic characteristics of the bitumen (Table 1), in terms of penetration and softening point, were in accordance with the reference values for that type of bitumen.

Table 1. Penetration and softening point of the bitumen 160/220.

Binder	Penetration (0.1 mm)	Softening Point (ºC)
Bit. 160/220	173.3	38.4

In terms of rheology, the results for complex modulus and phase angle are presented in Fig. 2. The higher performance grade (PG) limit obtained for this bitumen was 52ºC.

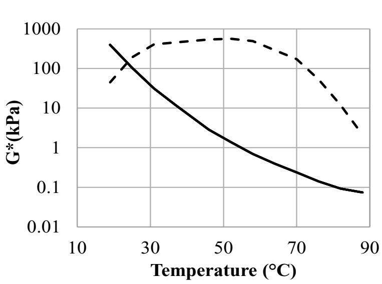

Fig. 2. Complex modulus (continuous line) and Phase Angle (dashed line) of the bitumen 160/220.

The dynamic viscosity of the bitumen (Fig. 3) is important to determine the adequate temperature for testing the expansion characteristics. For that study, it was decided to use the temperature at which the bitumen presents a viscosity of 0.1 Pa.s at the intermediate temperature tested (150ºC).

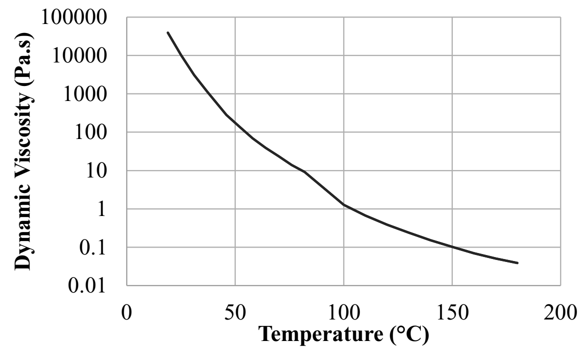

Fig. 3. Dynamic viscosity of the bitumen 160/220.

Taking the results of dynamic viscosity into consideration, the temperatures used to analyse the bitumen expansion characteristics were 140, 150 and 160ºC as previously mentioned.

3.2. Expansion characteristics

Analysing the results of bitumen foaming tests, namely ERmax and HL, with different water contents (Fig. 4), it could be concluded that a higher temperature did not result in better results in terms of the expansion ratio (ER), and the results show that the temperature associated with the reference viscosity value (0.1 Pa.s) conducted to the best combination of expansion characteristics for the studied bitumen.

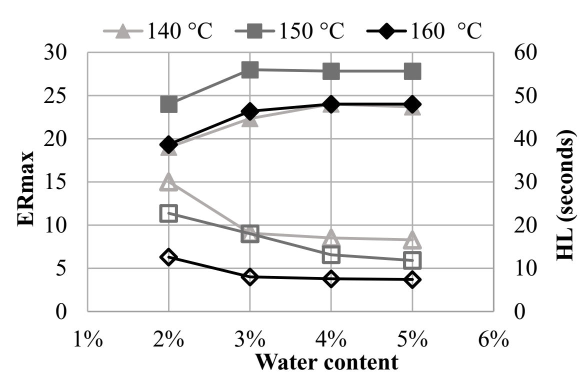

Fig. 4. Essential expansion characteristics of the bitumen (filled markers - maximum expansion ratio, unfilled markers – half-life).

As previously mentioned, a third parameter can be used to analyse the best combination of these two characteristics and their relationship. Thus, the FI has been calculated for all the combinations obtained and the results are presented in Table 2.

Table 2. FI values obtained for different temperatures and water contents using the 160/220 pen bitumen.

Temperature (ºC)	Water content (%)			
	2	3	4	5
140	585.54	553.21	590.20	572.52
150	687.19	739.76	635.55	611.12
160	395.66	444.09	459.30	457.91

With the results presented above it is possible to say that the best results were obtained for the temperature of 150ºC and 3% water content. Whatever the FI values obtained for the studied bitumen, they are much higher than the values mentioned by Jenkins [8] as desirable to be used in mixtures with reclaimed asphalt pavements and in half-warm asphalt mixtures (180 sec). In terms of ERmax, all values obtained also respect the desirable value mentioned by the author, but the same did not happen to the HL, where the desirable value is 13 seconds, which was not respected in any test carried out at 160ºC and in the tests carried out with the water contents of 4 and 5% at 150ºC.

The decay curves (DC) of the bitumen for a given temperature and water content have been obtained for a numerical analyses of three different test repetitions. These have been performed due to the uncertainty of the results obtained in each foamed bitumen injection. Thus, three injections were carried out for each combination of parameters (Fig. 5).

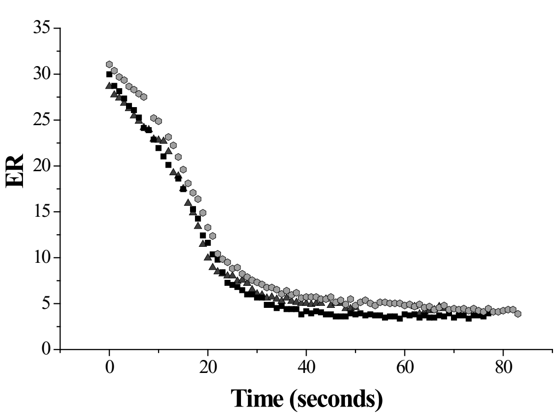

Fig. 5. Decay curves obtained in three repetitions of the expansion tests (150ºC and 3% water content).

The proximity showed in the DCs give the possibility to convert these three curves in a unique curve using a fitting of the three curves (Fig. 6). For that fitting, the *Origin* software was used through the *DoseResp* function for the category *Growth/Sigmoidal.* The selection of that function is based on the good fitting obtained to all the results analysed.

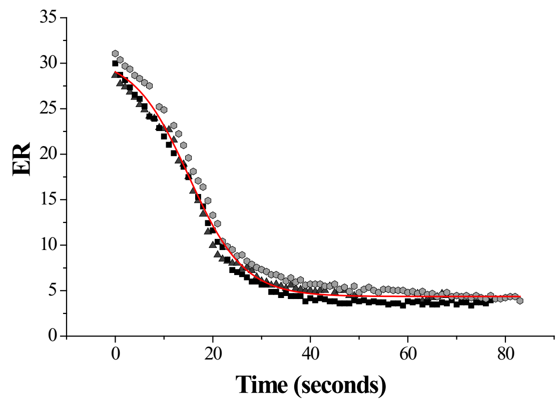

Fig. 6. Fitting made with the *Origin* software.

After this first analysis, where the function that describes the DC to all the parameters were obtained, and in order to understand how the temperature and the water content change the foaming characteristics of the bitumen, the DC of the foamed bitumen produced at 150ºC with 3 % water was compared with that of the foamed bitumen produced at the same temperature but with 5% of water (Fig. 7) and with the foamed bitumen produced at 140ºC and with the same water content (Fig. 8).

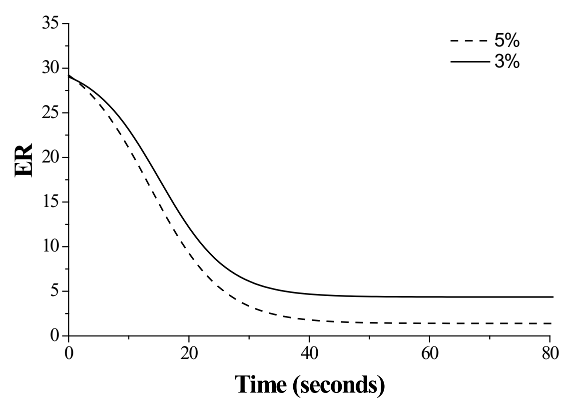

Fig. 7. Decay curves of the foamed bitumen produced at 150ºC with different water contents.

The results obtained for different water contents show that the higher the percentage of water the quicker the FB volume decreases, which originates worse results in terms of HL. In terms of the ERmax, the results were very similar, as previously presented in Fig. 4.

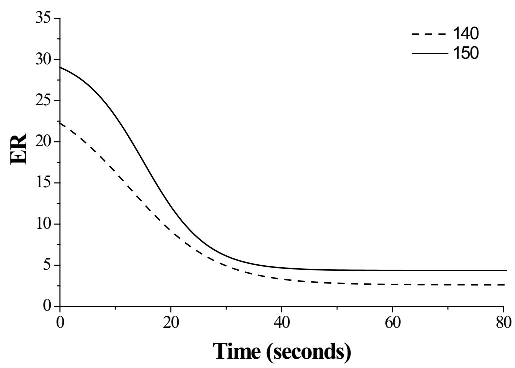

Fig. 8. Decay curves of the foamed bitumen produced with 3% water using different temperatures.

In terms of temperature used in the production of foamed bitumen, it is clear that a small variation on the temperature can change the behaviour of the DC in a significant way. According to the results presented in Fig. 8, it can be concluded that even though the volume decrease with time is slower for the temperature of 140ºC than that observed for the temperature of 150ºC, the maximum expansion was significantly lower for the temperature of 140ºC. This may compromise the operation of adequately mixing the foamed bitumen with the aggregates.

4. Conclusions

The use of foamed bitumen to produce new asphalt mixtures imply a complex analysis of the behaviour of the bitumen when subjected to the expansion process.

With this study, which took into consideration only the results of one bitumen type (160/220 pen grade), it was possible to conclude that there is an ideal temperature (or viscosity) to produce foamed bitumen. The temperature corresponding to a viscosity of 0.1 Pa.s conducted to the best results, regarding the foaming characteristics of the studied bitumen, which contradicts the idea that higher temperatures always lead to better foaming results, as mentioned in part of the literature on this subject.

Regarding the influence of the water content on the foaming characteristics, it was concluded that it affects mostly the HL. For the tests carried out at the same temperature, the DC showed quicker reductions in the ER for the tests carried out with higher water contents.

The present study highlights the importance of adequately understanding the foamed bitumen expansion process, prior to the mix design stage, in order to assure the production of quality asphalt mixtures when foamed bitumen is used. However, this study shall also be carried out for other bitumens.

Acknowledgements

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