RECYCLED ASPHALT MIXTURES WITH FOAMED BITUMEN: AN ALTERNATIVE TO BUILD ECOFRIENDLY ROAD PAVEMENTS

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Abstract

Nowadays, recycling has become a very important objective for the society in the scope of a closed loop product life cycle. In recent years, new recycling techniques have been developed in the area of road pavements that allow the incorporation of high percentages of reclaimed asphalt (RA) materials in recycled asphalt mixtures. The use of foamed bitumen for production of recycled asphalt mixtures is one of those techniques, which also allows the reduction of the mixing temperatures (warm mix technology). However, it is important to evaluate if this solution can maintain or improve the performance of the resulting mixtures. Thus, the main aim of the present study is to assess the performance of warm recycled asphalt mixtures incorporating foamed bitumen as the new binder and 50% RA, in comparison with a control mixture using conventional bitumen. Four mixtures have been produced with 50% RA, one of them at typical high mixing temperatures with a conventional bitumen (control mixture) and the other three with foamed bitumen at different production temperatures. These four mixtures were tested to evaluate their compactability and water sensitivity. The laboratory test results showed that the production of recycled mixtures with foamed bitumen can be reduced by 40ºC without changing the performance of the resulting mixtures.

Keywords: Foamed bitumen, recycling, warm mix asphalt, pavements, environment

1 INTRODUCTION

In order to address the current concerns of the society, namely the prospect of a sustainable future, recycling appears as a priority solution increasingly used in the road paving industry. Thus, the incorporation of reclaimed asphalt (RA) material have been studied by a significant number of authors with the main objective of increasing the percentage of RA used in new mixtures ([1], [2], [3], [4]).
The incorporation of higher percentages of RA can have many advantages, both in an economically and environmentally point of view ([5], [6]). In fact, the conservation of resources and the reduction of energy consumption are clear environmental advantages of using RA in recycled asphalt mixtures, as well as the reduction of greenhouse gas emissions. According to Kerkhof [7], the decrease of energy consumption to produce a recycled mixture with 50% of RA material in comparison with a conventional mixture is 14%, and the corresponding reduction in CO2 emissions is 11%.
However, there are some limitations in the incorporation of RA materials to produce hot mix recycled asphalt in plant. Firstly, the fact that the material is heterogeneous, requiring a more careful treatment previous to production. Moreover, the aged bitumen present in the RA material implies some attention such as the use of lower production temperatures (or selective heating of RA and new aggregates) and the use of a new bitumen with a higher penetration grade or the use of rejuvenating additives to improve the flexibility of the resulting mixture. Another problem is the severe overheating of the virgin aggregates when high percentages of unheated RA material are introduced. In order to solve this problem, recent studies divided the RA material in two fractions (coarse and fines) and the coarse fraction is heated together with the virgin aggregates while the fine fraction is kept at ambient temperature up to the moment it is introduced in the mixer ([4], [8], [9]). Another reason for this procedure is the fact that the fine fraction contains a significantly higher percentage of bitumen, which thus can be preserved from unwanted additional ageing or burning.
Some of the problems associated with the use of RA in recycled asphalt mixtures can be solved by using lower mixing temperatures. In order to reduce the production temperature the road paving industry is increasingly turning to Warm Mix Asphalt (WMA) as an environmentally friendly production process. This technology refers to innovative technologies that involve the use of organic additives, chemical additives and water-based or water foaming technologies. With this technology, asphalt mixtures can

be manufactured and spread at temperatures 20 to 55 ºC lower than conventional hot mix asphalt (HMA) ([10]). The use of foamed bitumen was the WMA technology selected to carry out this particular study with recycled mixtures, namely because it is able to avoid the use of additives.
Foamed bitumen is obtained by adding a small amount of cold pulverized water into preheated bitumen. The water vaporizes and the liberated steam is encapsulated within bitumen, resulting in a temporary expansion of its volume together with a reduction of its viscosity ([11]). This process can present many advantages such as improved strength and durability of the mixture, energy savings during production, improved workability, among others ([12]).
The most important characteristics in the production process of foamed bitumen are the expansion ratio (ER) and the half-life (HL) ([11]). The ER is a relation between the volume of the bitumen after expansion and the initial volume of bitumen. Normally the foamed bitumen is characterized by the maximum expansion ratio (ERmax) that represents the maximum volume obtained. The half-life (HL) is the elapsed time between the moment that the foam was at its maximum volume and the time when this volume reduces to a half of that value. Higher ER values mean a higher reduction of bitumen viscosity and consequently better workability of the mixture. At the same time, HL values must be high enough to maintain the bitumen foam stable during the time needed to produce the asphalt mixture.
The present study assessed the possibility to produce recycled mixtures with 50% RA at lower temperatures by using foamed bitumen in comparison with a control mixture produced with a conventional bitumen. The expansion characteristics of the bitumen with and without foaming additive and its basic characteristics have been evaluated and the effect of the production temperature has been assessed by testing different asphalt specimens for compactability and water sensitivity.

2 MATERIALS AND METHODS

2.1 Materials

The new bitumen used in this study was a virgin bitumen with a penetration of 47dmm, both for the control and the foamed bitumen mixtures. The new aggregates are granite igneous rocks and the filler is limestone. The use of those aggregates are justified by the proximity of their sources. The RA material used in this study is the result of milling off the surface layer of a pavement of a highway and it was divided in fine and coarse fractions by using a classifier with a mesh of 8 mm.

2.2 Methods

2.2.1 Foamed bitumen production process

A Wirtgen WLB 10 S lab scale plant was used to produce the foamed bitumen, which injects water and air into hot bitumen in an expansion chamber, promoting the formation of the bitumen foam. This equipment has been developed at a laboratory scale with the objective of making the analysis of the foamed bitumen characteristics in small scale possible (mix design), but it is similar to the equipment used in a normal or in plant scale.
In order to increase the stability (measured by the half-life) of the foamed bitumen, a small amount (between 0.2 and 0.6%) of a specific additive called Iterfoam B® was used. The air pressure used in the foaming equipment was 5.5 bar (default value), while the temperature of bitumen was 160 °C according to previous studies (the same temperature was used in all the components of the machine). The percentage of water used was evaluated in this work, for typical values between 2 and 4%.

2.2.2 Selection of mixing temperatures

The production temperature of bituminous mixtures is a very important factor, especially when dealing with warm mix asphalt technologies. In order to better understand the effect of the foamed bitumen technology used in this study, and its ability to lower the mixing temperature, some workability and performance tests were carried out in the studied mixtures, especially compactability and water sensitivity tests. Thus, three mixtures with 50% RA and foamed bitumen were produced at different temperatures (FB230, FB 210 and FB 190 mixtures in Table 1). For comparison reasons, a similar hot mix asphalt (HMA) mixture (control mixture in Table 1) was also produced with the same 50% RA material but without foaming the 47 pen grade bitumen.
The bitumen of the RA material was totally reused in the new recycled mixture. Taking into account the reuse of the bitumen present in the RA material, and the need to protect it from heating, only the coarse fraction (20%) was heated together with the new aggregates, while the fine fraction (30%) was introduced at ambient temperature (Table 1). To mitigate the ageing effect of heating the coarse RA fraction, the time during which it was submitted to high temperatures was limited two hours.

Table 1 – Reference and real temperatures of the recycled mixtures produced.

Mixture	Ref. Temp. (ºC)	Real Temperatures (ºC)				
		New aggregates	Course Fraction	Fine Fraction	Production	Compaction
FB230	230	231.2	233.8	26.6	160.4	144.3
FB210	210	213.0	213.5	23.6	138.2	125.1
FB190	190	192.8	193.9	25.6	134.4	114.7
Control	230	229.0	229.0	24.4	160.1	143.9

In order to maintain the homogeneity of the specimens produced at each studied temperature, all specimens produced at that temperature were manufactured from the same batch (3 specimens for compactability tests and 6 specimens for water sensitivity tests).
The compactability tests (EN 12697-10) were carried out using a Marshall Impact compactor (EN 12697-30) with a measuring device for automatically recording the thickness of the specimen after each compacting blow. According to the standard, the compaction of the specimens comprised the application of a total of 200 blows only in one side of the specimen.
The evaluation of water sensitivity was made using a mechanical test (indirect tensile test) conducted on two groups of three specimens kept in different conditioning environments (wet or dry). The assessment of the water sensitivity is obtained by measuring the mean indirect tensile strength (ITS) of specimens kept dry at 20+/-5ºC, according to EN 12697-23, and specimens kept in water (ITS_w) at 40+/-1ºC over a period of 68 to 72h, according to EN 12697-12. After 68 to 72 hours under the conditions of preparation described, the two groups of specimens are placed at a temperature between 5ºC and 25ºC before the test (15ºC in this specific work). Following the determination of the ITS of each specimen, it is possible to calculate the average value of each group and the indirect tensile strength ratio (ITSR), which corresponds to the ratio between the ITS of the wet group (ITS_w) and of the dry group (ITS_d) of specimens. The air voids content of the specimens was also assessed because it has a significant influence on the water sensitivity performance of the asphalt mixtures.

3 RESULTS AND DISCUSSION

3.1 Foamed bitumen characteristics

As abovementioned, a foam promotion additive was used in this study to improve the half-life results. In order to select the parameters for the process of foamed bitumen expansion, tests were performed with different percentages of the additive Iterfoam B® and different percentages of water. The virgin bitumen without additive was also foamed to evaluate its expansion characteristics. The results of the foaming process are showed in Fig. 1. The additive improved the expansion ratio and the half-time, and the best combination both in terms of higher expansion as higher half-time was 0.4% additive and 3% water.

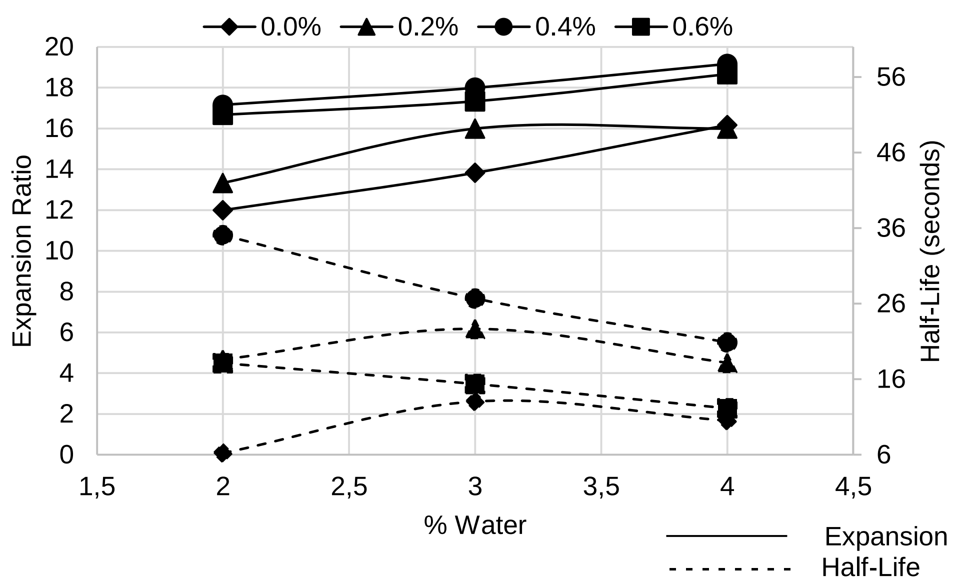

Fig. 1 – Foamed bitumen expansion ratio and half-life results.

The foamed bitumens with different percentages of additive were also evaluated for their basic characteristics, and the corresponding penetration (EN 1426) and softening point (EN 1427) results are presented in Table 2.

Table 2 – Foamed Bitumen basic characteristics

	Penetration (dmm)	Softening Point (ºC)
Virgin Bitumen (VB)	47.3	50.1
VB + 0.2% Iterfoam B®	40.9	50.6
VB + 0.4% Iterfoam B®	44.0	49.7
VB + 0.6% Iterfoam B®	45.2	49.7

The results of the several combinations are similar, which shows that the additive does not significantly affect the properties of the virgin bitumen.

3.2 Compactibility test results

After selecting the best combination to foam the bitumen, four mixtures were produced both with foamed bitumen at three different temperatures and with virgin bitumen without any foaming process, as previously presented in Table 1. Those mixtures were first tested for compactability, in order to assess the evolution of the air void content of the specimens during the compaction process for each production temperature. In this study, this procedure was repeated for several test temperatures to understand the influence of temperature in the workability of the mixture and, consequently, in the air voids content of the mixture. Based on the results obtained in Fig. *2* it is possible to verify that there are no significant differences for the foamed mixtures produced at 210 and 230ºC, in terms of air voids content, and the results obtained for the control mixture also are very similar to these two mixtures (it is only slightly higher, showing that the foaming process improved the workability of the mixture). An additional, but small increase in the air void content was obtained for the mixture with foam bitumen produced at 190ºC, as a result of a reduced workability after reducing 40 ºC the production temperature. This may mean that the maximum reduction of temperature is being achieved in this situation.

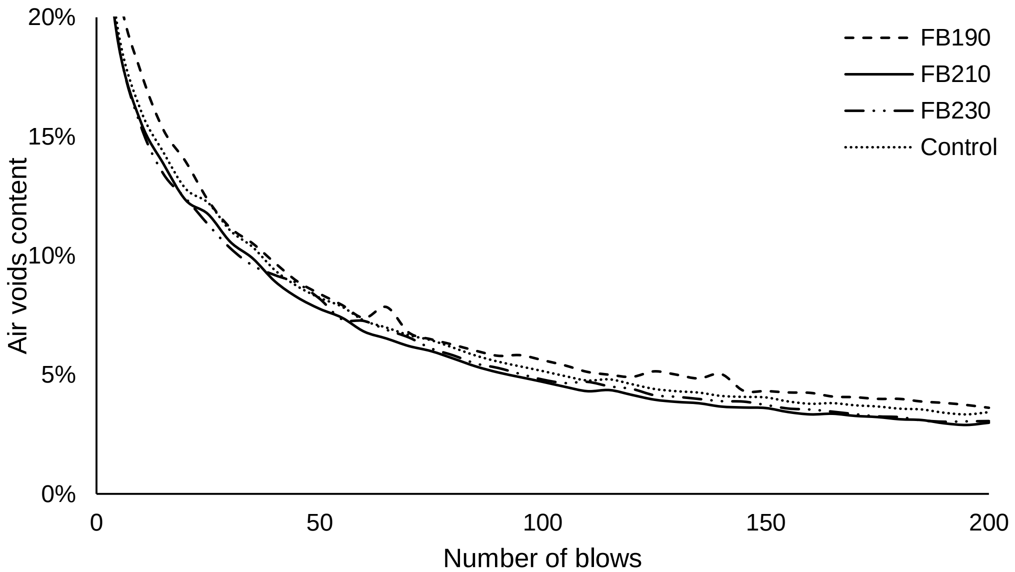

Fig. 2 – Compactability test results of the studied mixtures.

In order to compare the compactability results to those of the specimens prepared for the water sensitivity tests, the air void content should be measured after 150 blows, which is equivalent to the compaction energy used in the Marshall compaction by applying 75 blows in each face of the specimen. Those values are presented in Table 3, and they are clearly within the typical air voids content values expected for this type of asphalt mixtures for surface layers.

Table 3 – Air voids content of the specimens after 150 compacting blows

	Control	FB190	FB210	FB230
Air Voids content (%)	4.0	4.3	3.6	3.7

3.3 Water sensitivity test results

The water sensitivity tests are used to assess the durability behaviour of asphalt mixtures after long term contact with water. The way the asphalt mixture is affected by the contact with water might cause some problems, including the breaking of the bond between the bitumen and the aggregates (loss of adhesion) and the reduction of the stiffness and resistance of the asphalt mixture (loss of cohesion).
The value of air voids content is closely related to the water sensitivity of asphalt mixtures. Thus, all specimens used for this test were also characterized to assess the air voids content (Table 4). As it can be seen, the results are not significantly different from those of the specimens evaluated in the compactability tests. The main difference was observed for the mixture produced at lower temperature (FB190), which showed the highest increase in the air voids content.

Table 4 – Air voids content of the specimens used in the water sensitivity tests.

	Control	FB190	FB210	FB230
Air Voids content (%)	4.3	4.8	3.5	4.1

The water sensitivity test results are shown in Fig. 3, where it is possible to observe that the mixtures with foamed bitumen have a higher value of ITSR compared to the control mix. Comparing the control mixture produced at 230 °C with the mixture with foamed bitumen produced at the same temperature, it is possible to verify that the ITSR value improves considerably when using the expanded bitumen (probably due to its improved workability). Moreover, the results obtained for the mixture produced at lower temperatures (190°C) showed very interesting ITSR values (above 85%), similar to those of the control mixture.
Although for the mixture produced with foamed bitumen at 230°C presents a lower ITSdry value, the difference to the other ITSdry values is not significant. The relatively high ITSR values obtained for all mixtures may be caused by the use of 50% RA material, which is very stiff and is not affected by water.
Summing up, it can be concluded that it is possible to produce recycled asphalt mixtures with 50% RA with foamed bitumen, reducing the production temperature by 40ºC without significantly affecting the volumetric properties of the mixtures and their water susceptibility.

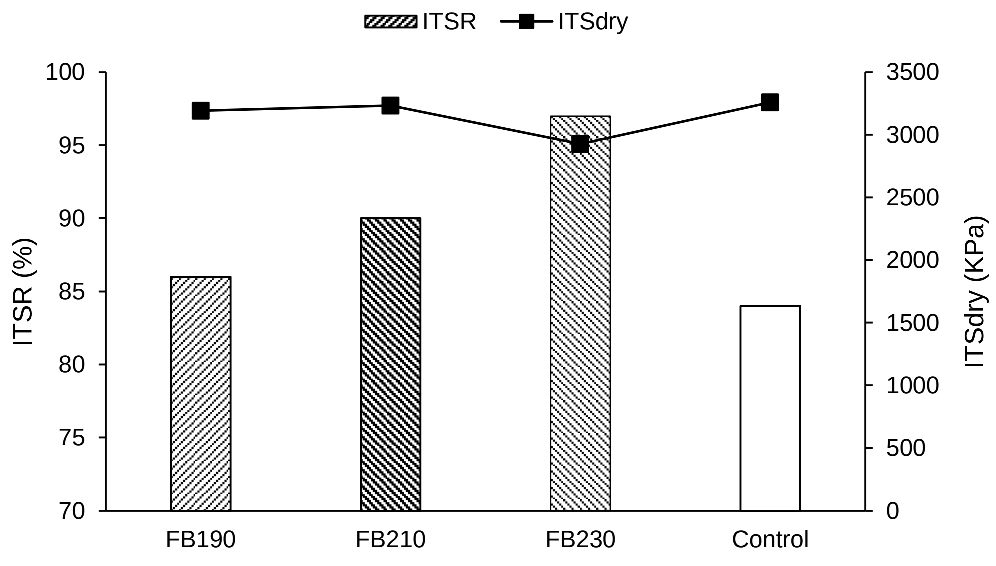

Fig. 3 – Water sensitivity test results.

4 CONCLUSIONS

The use of foamed bitumen in the production of asphalt mixtures incorporating 50% RA material have been tested and the results show that this technique could be a good option to reduce the production temperatures of this type of mixtures.

Assessing the water sensitivity and compactability results obtained in this study, it was observed that is possible to reduce the mixing temperature by 40 ºC, at least in the production process used in laboratory. Taking into account these results, this solution should now be applied "*in situ*" in the near future, after additional validation with rutting and fatigue performance tests.

5 ACKNOWLEDGMENT

The authors would like to acknowledge the contribution of the companies Galp and Elevo Group for providing the binders and the RAP material used in this study. This work was funded by ERDF funds through the Operational Competitiveness Program – COMPETE in the scope of Project "Energy Efficiency and Environmental Design of Bituminous Mixtures and Reducing Emissions of Greenhouse Gases" (SI Innovation Project 7603).

REFERENCES

[1] Celauro, C., C. Bernardo, and B. Gabriele (2010). Production of innovative, recycled and high-performance asphalt for road pavements. Resources, Conservation and Recycling (54), pp. 337-347.

[2] Shu, X., B. Huang, E.D. Shrum, and X. Jia (2012). Laboratory evaluation of moisture susceptibility of foamed warm mix asphalt containing high percentages of RAP. Construction and Building Materials (35), pp. 125-130.

[3] Su, K., Y. Hachiya, and R. Maekawa (2009). Study on recycled asphalt concrete for use in surface course in airport pavement. Resources, Conservation and Recycling (54), pp. 37-44.

[4] Abreu, L.P.F., J.R.M. Oliveira, H.M.R.D. Silva, and P.V. Fonseca (2015). Recycled asphalt mixtures produced with high percentage of different waste materials. Construction and Building Materials (84), pp. 230-238.

[5] Silva, H.M.R.D., J.R.M. Oliveira, and C.M.G. Jesus (2012). Are totally recycled hot mix asphalts a sustainable alternative for road paving? Resources, Conservation and Recycling (60), pp. 38-48.

[6] Oliveira, J.R.M., H.M.R.D. Silva, L.P.F. Abreu, and J.A. Gonzalez-Leon (2012). The role of a surfactant based additive on the production of recycled warm mix asphalts – Less is more. Construction and Building Materials (35), pp. 693-700.

[7] Kerkhof, E.V.D. (2012). Warm waste asphalt recycling in belgium – 30 years of experience and full confidence in the future. 5th Eurasphalt & Eurobitume Congress.

[8] Oliveira, J.R.M., H.M.R.D. Silva, L.P.F. Abreu, and P.A.A. Pereira (2012). Effect of Different Production Conditions on the Quality of Hot Recycled Asphalt Mixtures. Procedia - Social and Behavioral Sciences (53), pp. 266-275.

[9] Palha, D., P. Fonseca, L.P.F. Abreu, J.R.M. Oliveira, and H.M.R.D. Silva (2013). Solutions to improve the recycling rate and quality of plant produced hot mix asphalt. 2nd International Conference - WASTES: solutions, treatments, opportunities.

[10] Choudary, D.R. and M.N.G. Sorum (2012). Warm Mix Technology: Need of Today. Third International Conference on Construction In Developing Countries (ICCIDC–III).

[11] Jenkins, K.J.,(2000). Mix Design Considerations for Cold and Half-warm Bitumen Mixes with Emphasis on Foamed Bitumen University of Stellenbosch: Faculty of Engineering.

[12] Namutebi, M., B. Birgisson, and U. Bagampadde (2011). Foaming Effects on Binder Chemistry and Aggregate Coatability using Foamed Bitumen. Road Materials and Pavement Design (12), pp. 821-847.