Structural Performance of Asphalt Mixtures Manufactured with Crumb Rubber

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ABSTRACT

In recent decades, considerable efforts have been made in road engineering in order to establish more sustainable construction techniques that minimise the consumption of natural and energetic resources whilst recycle secondary or marginal materials might otherwise go to landfill. In this respect, the use of crumb rubber in asphalt mixtures could help to improve the mechanical resistance of pavements, offering better performance against fatigue, plastic deformations, or thermal gradients. Due to this fact, and given their potential economical and sustainable advantages, the use of these materials is spreading worldwide. This paper focuses on analysing the structural behaviour of asphalt mixtures manufactured with crumb rubber, considering several layer thicknesses and simulating different climatic conditions and traffic loading. The results indicate that asphalt mixtures manufactured with crumb rubber could minimise the impact of traffic loading and thermal gradients on the structural performance of asphalt pavements, which would contribute to extending their service life.

Keywords: Asphalt, crumb rubber, pavement design, sustainability, fatigue.

1. INTRODUCTION

Traffic loading and thermal gradients induce fatigue processes in asphalt pavements that in the medium-long term lead to their structural failure. In addition, solar radiation, oxygen exposure, and temperature cause an ageing phenomenon, which increases their stiffness and renders the pavement more brittle, affecting its resistance. Thus, one of the main goals of road engineering is to develop new asphalt materials that have the potential to extend the service life of pavements in order to minimize the impact caused by their rehabilitation.

Sustainability has also become one of the main concerns in this field. Thus, the use of more efficient and environmentally friendly construction procedures and technologies (such as the reuse of waste materials, the reduction of contaminant emissions, or the consumption of natural resources), are becoming more and more common.

Taking together both considerations, the use of crumb rubber (CR, produced from end-of-life tyres) as an asphalt modifier has been positioned as an interesting alternative. Many studies have demonstrated that this modifier can improve the mechanical performance of asphalt mixtures (increasing their resistance to fatigue cracking and plastic deformations) and reduce their thermal susceptibility [1, 2]. Furthermore, rubber is not the only component of CR, and the presence of other substances such as black carbon could also help to reduce the impact caused by solar radiation and oxidation in asphalt materials (reducing their sensitivity to ageing).

Nonetheless, in spite of the fact that numerous experiences have demonstrated the considerable potential of CR modified asphalt mixtures, there relatively few research studies that have assessed their impact on the structural response and design of asphalt pavements. Given this, the main objective of the present paper is to evaluate the influence of CR on optimizing the layer thicknesses of asphalt pavements. For this purpose, the mechanical performance of CR modified asphalt layers (of varying thicknesses) have been compared with that offered by other traditional layers under a range of temperature and stress conditions.

2. METHODOLOGY

2.1 Materials

In the present study two different types of AC 22 (EN 13108-1) mixtures were evaluated: one manufactured with a conventional binder (B 50/70) and the other manufactured with a CR modified bitumen (BC 50/70, which uses around 6-8% of CR over the total weight of the binder). In order to reduce the number of variables under analysis, both materials were manufactured with the same mineral skeleton (composed of limestone aggregate, Figure 1) and the same amount of asphalt binder (chosen after the laboratory design of the mixtures). The main characteristics of the mixtures studied are presented in Table 1. As can be observed, both materials present similar resistance to tensile efforts (ITS), as well as to plastic deformations (WTS) and water sensitivity (ITSR).

FIGURE 1 Mineral skeleton of the mixtures studied.

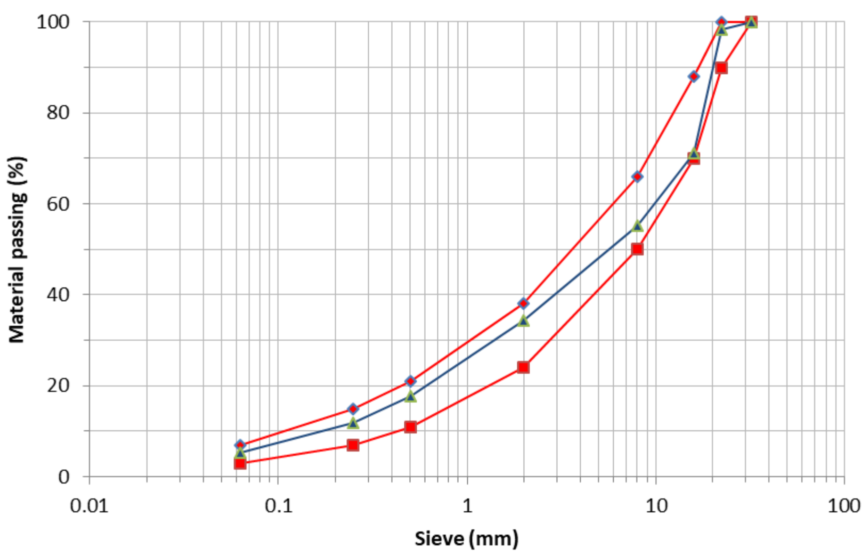
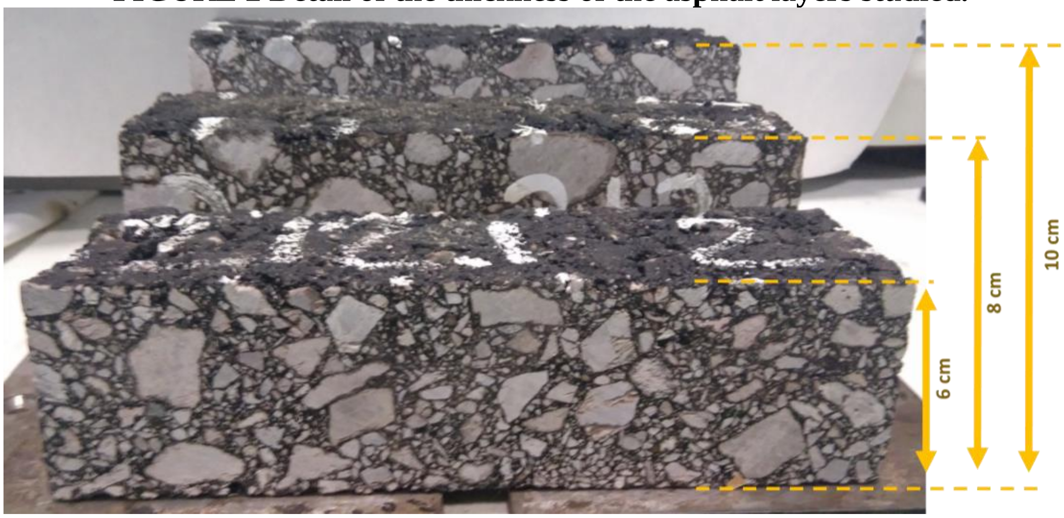


TABLE 1 Characteristics of the mixtures studied

Mixture	AC22 B50/70	AC22 BC50/70
Binder content (% over the total weight of the mixture)	**4.0**	**4.0**
Bulk density (kg/m^3), EN 12697-6 [3]	**2449**	**2435**
Voids (%), EN 12697-8 [4]	**4.1**	**4.3**
ITSd (kPa), EN 12697-23 [5]	**1437.7**	**1374.8**
ITSR (%), EN 12697-12 [6]	**94.8**	**86.6**
WTS (mm/10^3 cycles), EN 12697-22 [7]	**0.105**	**0.101**

These mixtures are commonly used as binder layers in asphalt pavement structures to provide resistance against traffic loading as well as to protect the subjacent layers from water filtration. Therefore, these materials are one of the most widely used in pavement rehabilitation, when milling and replacement is needed. Once a part of the deteriorated asphalt pavement is milled, an AC 22 layer is placed over the remaining structure (whose thickness depends on the level of deterioration and the characteristics of the traffic to be supported), and eventually (when high traffic volumes are supported), a thin surface layer (around 3 cm) is used over the AC 22 layer. Thus, the thickness of the AC22 layer plays a very important role in determining the cost and effectiveness of pavement rehabilitation. Thus, the structural performance of layers of different thicknesses (6, 8 and 10 cm, Figure 2) manufactured with the two mixtures (AC22 B50/70 and AC22 BC50/70) was evaluated during this study.

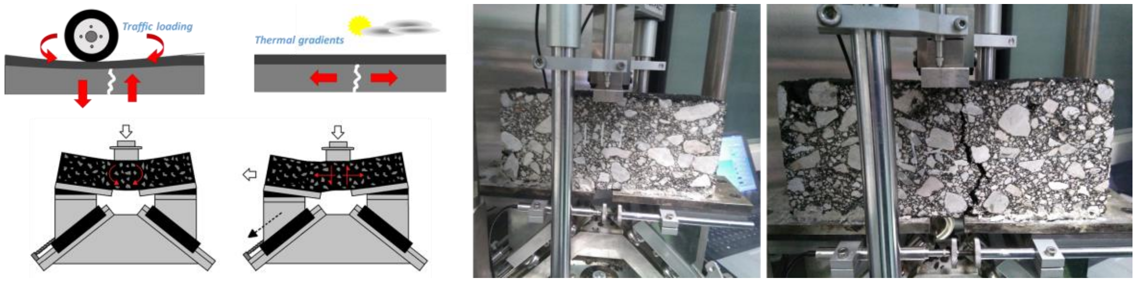
FIGURE 2 Detail of the thickness of the asphalt layers studied.



2.2 Testing plan

To analyse the structural performance of the asphalt layers, the UGR-FACT method was used. This test method is able to reproduce the conditions that lead to the appearance of structural damage in pavements, by simulating the bending and shear stresses caused by traffic loading, as well as the tensile strains produced by thermal gradients [8,] (Figure 3). Four LVDTs (one vertical and one horizontal on each side of the specimen) are used to control the vertical and horizontal displacements produced in each load cycle in the materials evaluated. The information provided during the test can be used to optimize pavement design (where vertical and horizontal strains/stresses define the structural criteria).

FIGURE 3 Detail of the UGR-FACT device.



The test conditions consisted of a stress amplitude of 400 kPa, and temperatures of 10, 20, and 30 °C. The dimensions (length x wide x thickness) of the specimens tested were modified as a function of the thickness of the layer studied: 200 x 60 x 60 mm ±1; 200 x 60 x 80 mm ±1; and 200 x 60 x 100 mm ±1. Three specimens were used for each combination of test conditions (stress amplitude and temperature), type of mixture (AC22 B50/70 and AC22 BC50/70), and thickness of the layer (6, 8 and 10 cm).

3. ANALYSIS OF RESULTS

Figure 4 shows the average results of the initial horizontal deformations (in mm) measured in the bottom of each of the specimens at the beginning of the UGR-FACT tests. These values represent the general flexibility of the different layers of these materials under a given set of service conditions. As can be observed, under similar test conditions the deformations produced are slightly higher in the mixture AC22 BC50/70. Nonetheless, as the thickness of the layer increases and the temperature decreases, the differences between the two materials become lower.

FIGURE 4 Horizontal deformations of the materials studied: (a) AC22 B50/70; (b) AC22 BC50/70.

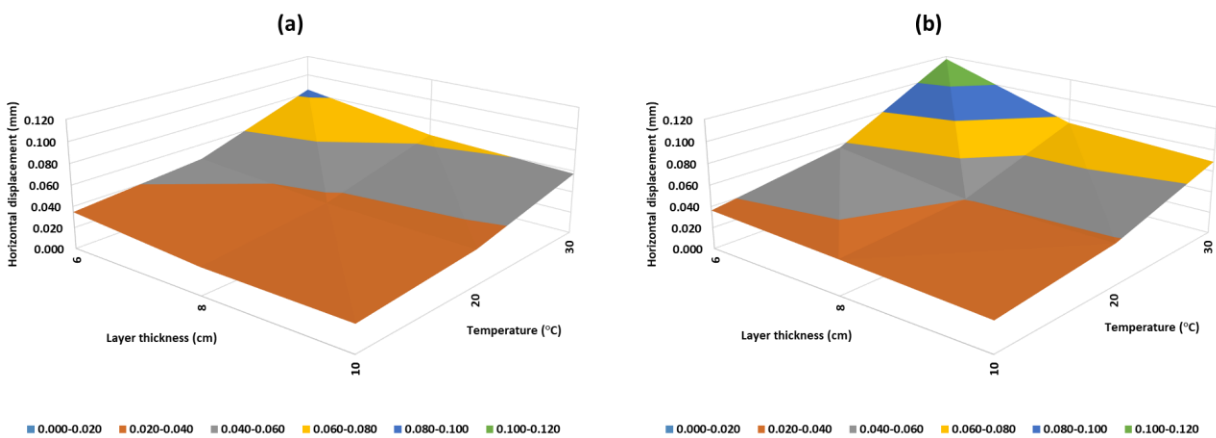
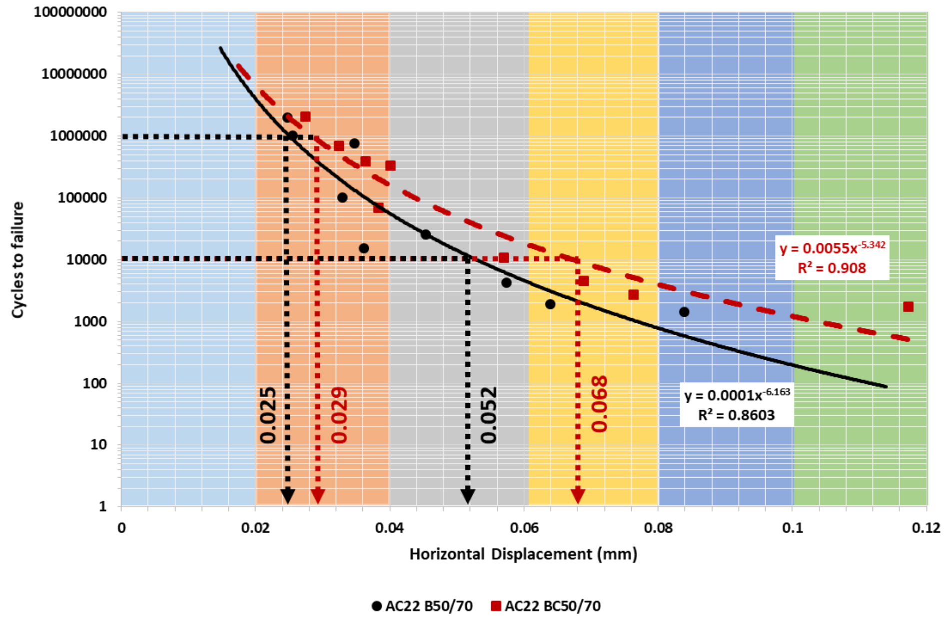


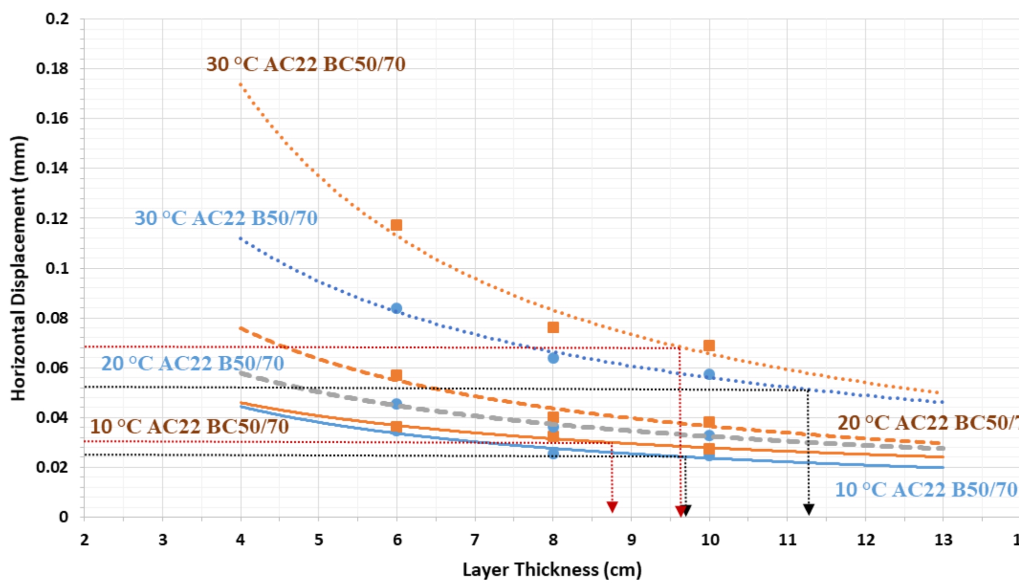
Figure 5 shows the fatigue life as a function of the initial horizontal deformation at the bottom of the layer of the two materials based on the average results of the different specimens tested for each condition (layer thickness and temperature). These values indicate that the fatigue life of the AC22 BC50/70 is longer than that offered by the conventional AC22 B50/70 for any given deformation value.

FIGURE 5 Fatigue life of the materials studied.



Taking these results together, it is possible to determine the optimal thickness for a specific set of service life conditions (Figure 6). For instance, to ensure a minimum service life of 10,000 cycles at a temperature of 30 °C, a thickness of 11.3 cm is needed in the case of the AC22 B50/70 or a thickness of 9.6 cm in the case of the AC22 BC50/70 (Figures 5 and 6). Similarly, if the service temperature is 10 °C and the load cycles to be supported must be 1,000,000, the thickness of an AC22 B50/70 layer should be at least 9.7 cm, while the thickness of an AC22 BC50/70 layer should be 8.8 (Figures 5 and 6).

FIGURE 6 Relationship between thickness and horizontal deformation at different temperatures.



4. CONCLUSIONS

The present paper set out to analyse the structural performance of asphalt mixtures manufactured with crumb rubber. On the basis of the results obtained, the following conclusions can be drawn:

- Asphalt mixtures manufactured with crumb rubber could offer more flexibility than traditional asphalt mixtures under any given thickness and temperature conditions.
- For a given level of deformation, the asphalt mixture manufactured with crumb rubber has been shown to have a longer fatigue life than the traditional mixture.
- It is possible to reduce the thickness of the asphalt layer using asphalt mixtures manufactured with crumb rubber, which demonstrates their better structural performance. The percentage of thickness reduction would depend on the service temperature and number of load cycles to be supported. The results obtained in the present study have found a reduction that ranges between around 5 and 20 %.
- It would be of interest to extend this study in order to verify these findings with other types of mixtures and binders, along with the using other procedures such as the dry process for crumb rubber addition.

REFERENCES

[1] Moreno, F.; Sol, M.; Pérez, M; Martín, J.; Rubio, M. C. “The effect of crumb rubber modifier on the resistance of asphalt mixes to plastic deformation.” Materials and Design, 47, pp. 274-280, 2013.

[2] Moreno-Navarro, F.; Rubio-Gámez, M. C.; Jiménez del Barco, A. “Tire crumb rubber effect on hot bituminous mixtures fatigue cracking behavior.” Journal of Civil Engineering and Management, 22, 65-72, 2016.

[3] EN 12697-6: Bituminous mixtures. Test methods for hot mix asphalt - Part 6: Determination of bulk density of bituminous specimens. AENOR, Asociación Española de Normalización y Certificación, Madrid, 2012.

[4] EN 12697-8: Bituminous mixtures. Test methods for hot mix asphalt - Part 8: Determination of void characteristics of bituminous specimens. AENOR, Asociación Española de Normalización y Certificación, Madrid, 2003.

[5] EN 12697-23: Bituminous mixtures. Test methods for hot mix asphalt – Part 23: Determination of the indirect tensile strength of bituminous specimens. AENOR, Asociación Española de Normalización y Certificación, Madrid, 2004.

[6] EN 12697-12: Bituminous mixtures. Test methods for hot mix asphalt – Part 12: Determination of the water sensitivity of bituminous specimens. AENOR, Asociación Española de Normalización y Certificación, Madrid, 2009.

[7] EN 12697-22: Bituminous mixtures. Test methods for hot mix asphalt – Part 22: Wheel tracking. AENOR, Asociación Española de Normalización y Certificación, Madrid, 2008.

[8] Moreno-Navarro, F., Rubio-Gámez, M.C. UGR-FACT Test for the Study of Fatigue Cracking in Bituminous Mixes. Construction and Building Materials, vol. 43, pp. 184-190, 2013.

[9] F. Moreno-Navarro, M. C. Rubio-Gámez, A review of fatigue damage in bituminous mixtures: Understanding the phenomenon from a new perspective, Construction and Building Materials. Vol. 113, pp. 927-938, 2016.

[10] F. Moreno-Navarro, Sol-Sánchez, M., M. C. Rubio-Gámez, “Structural analysis of polymer modified bituminous materials in the rehabilitation of light-medium traffic volume roads.” Construction and Building Materials, 156, pp. 621–631, 2017.