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The use of reclaimed polymers to improve the mechanical performance of bituminous mixtures

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Abstract

Nowadays it exists a great environmental concern referring to the consumption of waste plastic materials and their disposal. The reuse of these materials as bitumen modifiers could provide an interesting solution to help to address this problem along with the possibility to obtain the benefits of polymer-modified bitumens at a lower cost (which also could help to extend the service life of road pavements). For this purpose, this study assessed the viability of incorporating reclaimed polymers to produce high performance asphalt mixtures, which were compared to traditional mixtures manufactured with polymer modified and neat binders. To evaluate the mechanical behaviour of these mixtures, binder drainage, moisture susceptibility, stiffness modulus, wheel tracking and UGR-FACT tests were performed. The results show that the use of reclaimed polymers could help to improve some of the properties of bituminous mixtures, which could open their use in roads or asphalt layers were the application of modified materials is advisable but their cost limit their application.

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1. INTRODUCTION

Asphalt mixtures have been dealing with an increase in their deterioration rate in the last decades due to a significant rise of traffic volume and the loads transmitted [1] (in Europe alone the rate of passenger and freight transported by kilometre grows between 1.5-2 % every year [2]). This problem is worse for flexible pavements and in zones with high thermal gradients due to climate conditions [3, 4]. This deterioration can manifest itself through different problems such as rutting or fatigue cracking. In order to overcome these issues it is common to make use of polymer-modified binders [5] and some other additives, like fibers [6] that reduce the susceptibility of asphalt mixtures to these problems and extend its service life. Nonetheless, the use of these materials often implies an increase in production costs, which limit their application to surface layers in high traffic–volume highways leaving out secondary and regional roads, which actually constitute the majority of the transport network in developed countries [2, 7].

On the other hand, the recycling and reuse of materials at the end of their service life is an increasingly widespread practice in construction. Through it, it becomes possible to provide a new function to materials that would otherwise constitute waste whose disposal is not only costly but also environmentally unsustainable. An example is the problem related to the increasing consumption of plastics worldwide (just in Europe, this grew a 7.3% in 2017 in relation to the previous year [8]) and the wastes generated. Although the percentage of recycling increases by the year, there still a high proportion that due to profitability or purely aesthetic reasons does not get a second use. For these reasons, a large number of authors have explored the use of different recycled polymers in asphalt mixtures as a way to obtain, at a lower cost, similar mechanical performance that could be achieved with commercial polymer modified binders [9]. A good example of this is the polyethylene present in the geomembrane used in the waterproofing industry. Each year around 300 million m^2 of this material is produced [10], however, the presence of polyester fibers for reinforcement in some typologies make it impossible to melt the polyethylene resulting from deteriorated geomembranes, excess pieces being generated during its manufacture, or placing (trimmings and cuts) for its reuse.

In this sense, authors have explored the use of reclaimed geomembranes as polymer modifier in previous work [11]. Geomembrane wastes (reclaimed geomembrane (RG)) are composed of a low-density linear polyethylene (LLPDE) in the waterproof layer, and polyester fibers in the layer of reinforcement. When the material is added to the hot bitumen, the LLDPE resin melts and all the components mix together to produce changes in the asphalt binder. In addition, the polyester fibers remain dispersed in the new modified binder, creating an elastic tridimensional net that help to improve the storage stability of the modified bitumen. After the characterization of the material, it was found that the use of recycled geomembrane as binder modifier (Reclaimed Geomembrane – Modified binder, RGMB) leads to a decrease in thermal susceptibility, higher resistance to permanent deformations and a longer fatigue life when compared to the conventional bitumen. Therefore, it was proven that the use of recycled polymers could improve the performance of the bitumen. Then, it is yet to be explored if RGMB could improve the properties of asphalt mixtures and reach similar performance that those high performance mixtures incorporating modified bitumen and fibers. This way, it would be possible to combine the environmental and economic benefits of using geomembranes with the benefits of obtaining an asphalt mixture more resistant and durable with less need of maintenance and repair.

The main objective of this paper was to evaluate the benefits of using reclaimed geomembranes (in the form of the modified bitumen previously mentioned) as part of a high performance asphalt mixture, such as Stone Mastic Asphalt mixture. These mixtures are usually manufactured with polymer modified binders and fibers to offer high resistance to fatigue, cracking and permanent deformations [12, 13, 14]. In order to assess the benefits of using this material, this asphalt mixture was compared with a reference SMA using a conventional binder and with two SMA mixtures using a modified binder, one with fibers (because of the presence of fibers in RGMB) and the other without.

2. METHODOLOGY

2.1. Materials

In order to analyse the performance of RGMB as part of asphalt mixtures, four SMA 11 mixtures (EN 13108-5, [15]) were manufactured changing the typology of bitumen employed. Then, in order to guarantee that no other variables influence the comparative assessment, all the mixture tested share the same bitumen content (5.3% by weight of mixture) and the same mineral skeleton, composed of 6/12 ophite for coarse fraction and 0/6 limestone for the sand. The filler used was cement type CEM II/B-L 32.5 N

This way, four SMA were studied with similar designs (mineral skeleton and binder content), but using four different types of binder: a 50/70 bitumen modified with geomembranes (RGMB, including modification with polymers and fibers) [11]; and three bitumens for reference, a 50/70, a PMB and a PMB with 0.3% of acrylic fibers. In this way, the benefits of RGMB can be analysed against the use of a conventional bitumen used as a basis; in reference to a commonly used modified bitumen (PMB 45/80-65); and the same modified bitumen enhanced with fibers, thus assessing the effect of using fibres included in the RGMB. The main characteristics of the binders used in the study, i.e. penetration (EN-1426, [16]) at 25 °C and softening point temperature (EN-1427, [17]) are included in Table 1. It can be observed how the addition of RGMB decrease penetration and rises softening temperature with respect to the base binder (B 50/70) indicating a more rigid behaviour due to the presence of both polyethylene and fibres.

Figure 1: Reclaimed geomembrane (RG) employed in this study.

Table 1: Characteristics of Binders Studied.

Type of bitumen	Penetration (dmm)	Softening point (°C)
B 50/70	50	52
PMB 45/80-65	56	65
RGMB	23	62

2.2. Testing plan

For the design of the tested mixtures, the Marshall Method was employed. Hence, impact compaction was applied to compact the mixture with 50 blows on each side of the specimens after their fabrication, the basic volumetric properties of the different mixtures were obtained: maximum density (EN 12697-5, [18]), bulk density (EN 12697-6, [19]) and void content (EN 12697-8, [20]).

In order to evaluate the mechanical performance of the different SMA mixtures previously defined, different tests were employed so to determine the binder drainage risk (a frequent problem in this kind of mixtures), their bearing capacity, and their resistance to moisture, permanent deformations and fatigue cracking.

Firstly, it should be considered that SMA mixtures have a gap-graded skeleton and high binder content. Because of that, drainage problems could appear during the mixing, transporting, and laying processes [21]. This is one of the main reasons why the use of fibers is common in this kind of mixture. In this study, the binder drainage test was conducted in accordance with the EN-12697-18 using Schellenberg method [22].

After that, the bearing capacity and the ability of distributing stresses of the different mixtures was evaluated by determining their stiffness modulus. The stiffness modulus test was conducted in accordance with EN-12697-26-Annex C [23] at a temperature of 20°C for three cylindrical specimens. This test determined the extent of the bitumen influence on the stiffness modulus of asphalt mixtures.

Another main conditioning factors affecting the performance of asphalt mixtures is the resistance against the water. Moisture damage is an important cause of failure in asphalt concrete pavements because of loss of adhesion between the asphalt binder and aggregate surface and/or loss of cohesion within the binder. To evaluate this phenomenon, the moisture susceptibility test was carried out in accordance with the EN-12697-12 procedure [24]. Six specimens were compacted using the impact compactor and then divided into two groups: a wet group (in water at 40°C for 72 h) and a dry group at 25°C. Following on, each specimen was subjected to indirect tensile fracture at a temperature of 15°C. Then, in order to evaluate the damage caused by water, the ratio between tensile strength obtained from wet specimens and that obtained from the dry specimens is calculated.

Another main concern involving the service life of bituminous mixtures is their resistance to permanent deformations at high temperatures. To evaluate the rutting resistance derived from the use of the different bitumens, the wheel-tracking test (EN-12697-22, [25]) was carried out. This assesses the permanent deformation resistance under conditions that simulate the effects of traffic. Two parallel- piped specimens are manufactured with a roller compactor and then tested at a temperature of 60°C. The test involves 10,000 passes of the loaded wheel and then the final rut depth and the deformation slope (WTS) based on the rut depth between 5,000 and 10,000 cycles are the results obtained.

Finally, and as a way to evaluate both the temperature susceptibility of the mixtures and the fatigue cracking performance of the same, UGR-FACT (University of Granada-Fatigue Asphalt Cracking Test) at three different temperatures: 10 °C, 20 °C and 30 °C was performed for a load of 0.4 kN (corresponding to a traffic pressure of around 330 kPa). Three different samples were tested at 5Hz for the mixture manufactured with base bitumen, the RGMB mixture and the conventional modified asphalt mixture of better performance according to previous tests. The test reproduces the conditions that lead to the appearance of fatigue cracking in pavements (traffic loads and thermal gradients), by using a simple device composed of two sliding supports (with a recovery spring), and two elastic elements placed under these support plates (rubber pads). Using cyclical loads, the device is able to generate and propagate a controlled fatigue cracking process [26].

3. ANALYSIS OF THE RESULTS

In Table 2 the volumetric properties of the different mixtures and some Marshall results are presented. The addition of the reclaimed geomembrane gives way to a slightly higher density and a reduction in the voids content with Marshall results between the mixtures that incorporate the base binder and the modified bitumen of reference.

Table 2: Properties of the Mixtures Studied.

	SMA 11 B50/70	SMA 11 PMB 45/80-65	SMA 11 PMB 45/80-65 0,3% Fibers	SMA 11 RGMB
Bulk density (Mg/m3)	2.697	2.674	2.687	2.717
Void content (%)	3.7	4.8	3.9	2.8
Voids in Mineral Aggregates (%)	17.6	18.6	17.7	16.8
Voids Filled with Bitumen (%)	78.9	74.0	78.0	83.4
Marshall stability (kN)	8.094	11.703	12.727	10.495
Marshall flow (mm)	5.0	5.0	5.7	4.3

Figure 2 shows the binder drainage results for the different mixtures, the red line establishes the upper limit (0.3 %) by the Strategic Highway Research Program (SHRP) that indicates the risk of drain down. This way, is can be seen how the SMA11 B50/70 mixture exceeds this limit while the mixture incorporating the commercial modified binder (PMB 45/80-65) without the employment of fibers is placed just in the limit. Then, the best performance was obtained by this mixture when added fibers to its composition, although the mixture SMA11 RGMB presented also a good drainage resistance (0.2%). These values indicate that the presence of fibers in the reclaimed geomembrane residue makes that the bitumen RGMB does not require the addition of external fibers as additive. As a result, the RGMB bitumen alone is capable of providing stability, and its use can therefore, prevent the appearance of binder drainage in the mix.

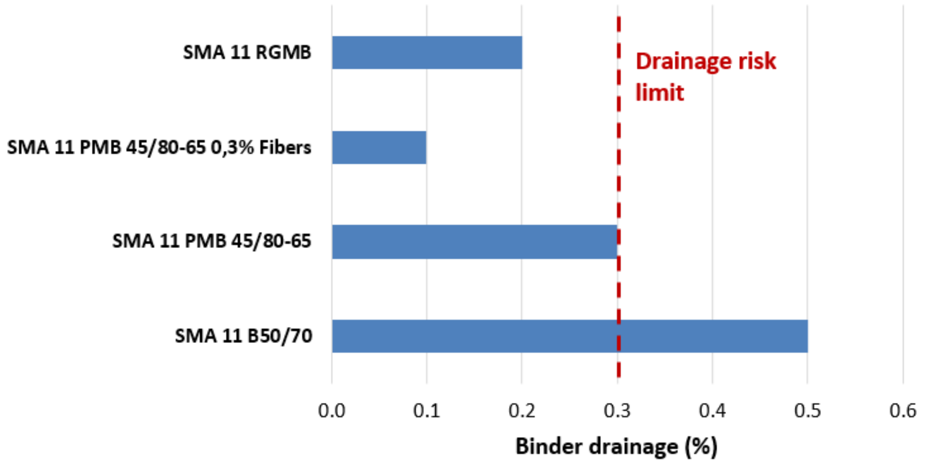

Figure 2: Binder drainage test results.

In relation with the moisture susceptibility of the mixtures, Table 3 shows the results of indirect tensile strength for both dry and wet group. It can be observed how the addition of reclaimed geomembrane (SMA 11 RGMB) increases the tensile strength resistance of both dry and wet groups when comparing with the other mixtures. This is in accordance with other studies involving the use of fibers in asphalt mixtures [27, 28]. With respect to the strength retained after the water conditioning, the mixture that makes use of the RGMB proved to be less susceptible to water damage than the other mixtures reaching a high value of retained ITS (99.6%) although it is true than it also reduce the void content of the mixture. Consequently, the addition of reclaimed geomembrane to the bitumen improves the moisture susceptibility behaviour of the asphalt mixture.

Table 3: Indirect tensile strength and ITSR results.

Asphalt Mixture	Indirect tensile strength (kPa)		ITSR (%)
	Dry Group	Wet group	
SMA 11 B50/70	1922.9	1574.9	81.9
SMA 11 PMB 45/80-65	1537.2	1415.3	92.1
SMA 11 PMB 45/80-65 0,3% Fibers	1914.2	1785.3	93.3
SMA 11 RGMB	2481.7	2471.5	99.6

Figure 3 displays the results of the stiffness modulus test at 20 °C for the different mixtures studied. It can be observed how, in general terms, the use of SBS polymers reduce the stiffness of the mixture (PMB 45/80-65) although the presence of fibers tends to increase it. Nevertheless, the mixture that employed RGMB as bitumen was the one with the highest stiffness modulus. The presence of plastomers and fibers in the bitumen could explain the higher stiffness of the RGMB (as the lower penetration and higher softening point temperature values of the bitumen indicated) and, therefore, the higher stiffness of the asphalt mixture. A higher value of stiffness modulus makes the mixture more resistant to plastic deformations, however, when that is excessive could lead to fatigue and thermal cracking at low temperatures. For this reason, the fatigue cracking resistance of the mixtures at different temperatures was evaluated forward in this study.

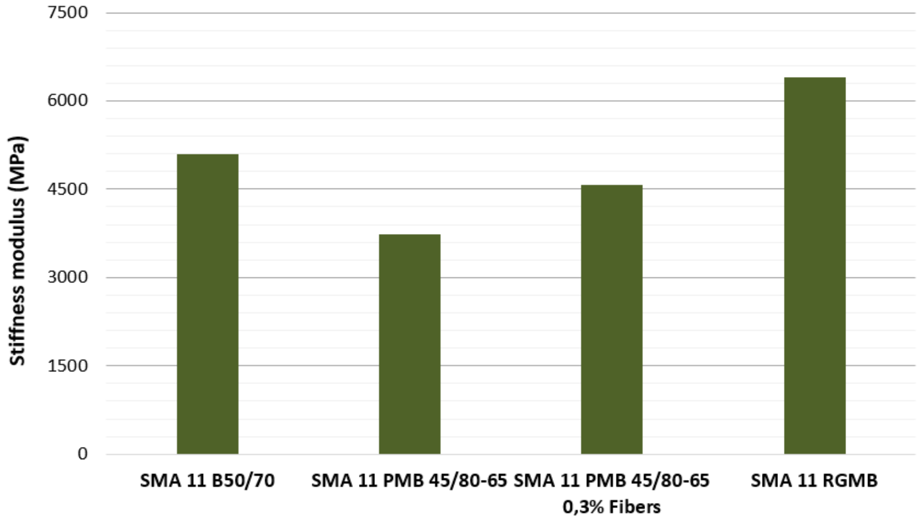

Figure 3: Stiffness modulus test results.

The effect of the different binders on the rutting resistance of SMA mixtures are displayed in Figure 4 in which both the rut depth values after 10,000 load cycles and the deformation slope (WTS) are represented. It can be observed how the lowest values of rutting and deformation slope are obtained for the mixture manufactured with the commercial polymer modified binder and fibers (SMA 11 PMB 45/80-65). The SMA mixture with reclaimed geomembrane as modifier obtain, for its part, similar results being able to significantly increase the permanent deformation resistance at high temperatures when comparing to the base binder (B 50/70). These results are in line with the findings of other studies [27, 29] where the use of fibers as a modifier produced an improvement in the mechanical response of the asphalt mixture against plastic deformations. These results proved that mixtures using the modified bitumen are less susceptible to rutting and meet with the requirement of WTS < 0.07 mm/103 load cycles fixed for wheel-tracking test in some normatives such as the Spanish one.

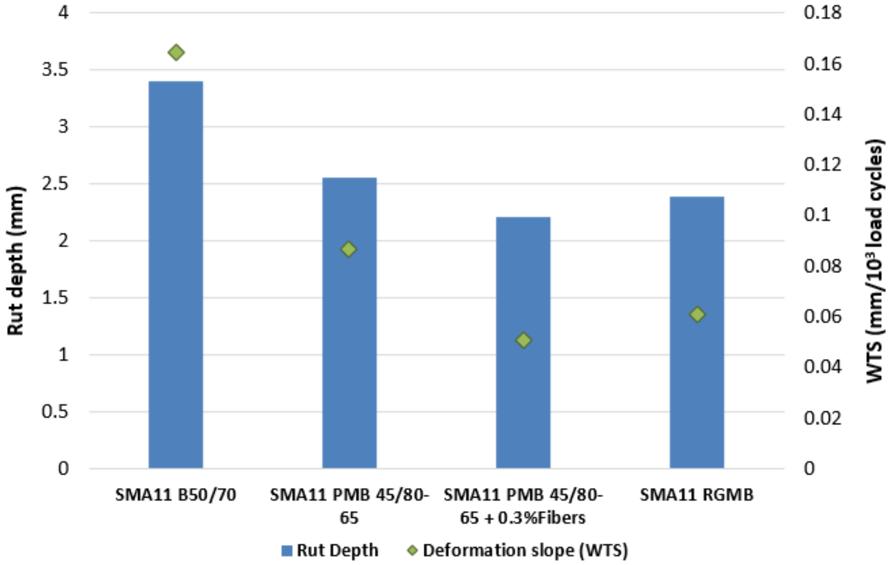

Figure 4: Wheel-tracking test results of the different mixtures.

Figure 5 shows the average UGR-FACT test results of the mixtures with better performance according to the previous compared to the one manufactured with base binder one. This way, it can be seen how the fatigue cracking resistance is higher for the SMA manufactured with the polymer-modified binder of reference and fibers regardless the temperature. Nonetheless, although the asphalt mixtures that uses RGMB, as bitumen does not reach the resistance of the previous one, it is able to improve significantly the resistance of the mixture manufactured with the base binder (SMA B 50/70). In addition, this increase in the number of cycles until failure also happens when the test temperature is low (10°C) proving that the higher stiffness of this reclaimed geomembrane modified binder (RGMB) does not lead to an excessively fragile behaviour at low temperatures that could compromise its performance. This improvement relating to the fatigue life was previously proved at bitumen level in the study of García-Travé et al. [11] and it is related to both the addition of polymers [30] and the presence of fibers, which are known to extend the fatigue life of mixtures [6, 29].

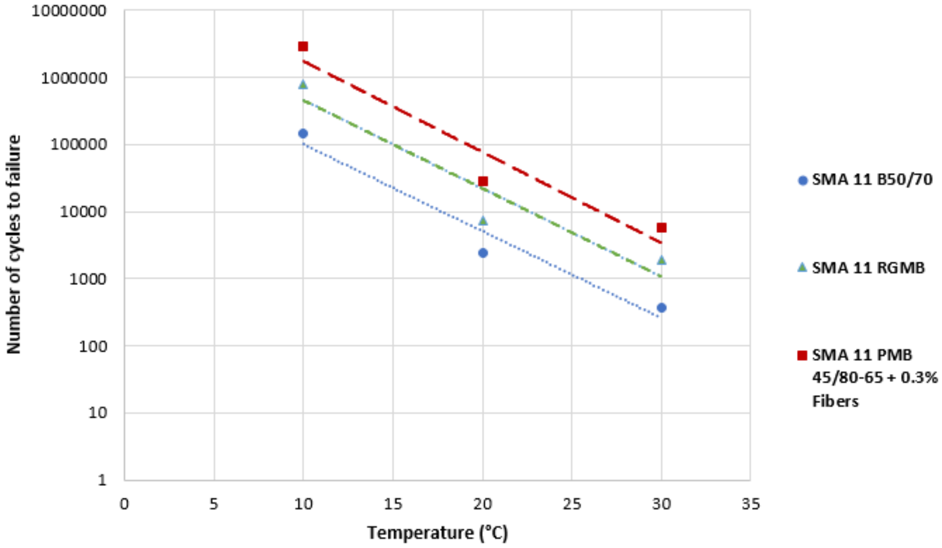

Figure 5: UGR-FACT test results at different temperatures.

4. CONCLUSIONS

The aim of this paper was to evaluate the mechanical performance of SMA mixtures manufactured with reclaimed geomembranes used as a bitumen modifier. The performance of these mixtures was compared to the ones obtained through the use of a neat bitumen and two reference asphalt mixtures manufactured with a commercial polymer modified bitumen with and without the use of fibers. Based on the results obtained in this study, the following conclusions can be drawn:

- The inner presence of fibers in the reclaimed geomembrane residue is able to reduce the binder drainage risk in SMA mixtures reaching similar value to the SMA11 PMB 45/80-65 0.3% fibers.
- The incorporation of reclaimed geomembranes in the asphalt mixture increase the tensile strength of both dry and wet specimens as well as the retained strength after conditioning which proves a better water resistance of this mixture.
- Use of RGMB in the manufacture of the SMA mixtures leads to higher stiffness related to the use of fiber present in the material, which, along with the polyethylene, could enhance the bearing capacity of the mixture and its resistance to permanent deformations.
- The mixture manufactured with RGMB show an adequate rutting resistance at high temperatures confirming the stiffness test results. SMA11 RGMB is less susceptible permanent deformations when compared with conventional asphalt mixtures reaching a similar performance than high-performance mixtures manufactured with commercial modified bitumen and fibers.
- The RGMB mixture is also able to enhance the fatigue cracking resistance of the mixture when comparing with the conventional mixture (SMA 11 B50/70) in all the range of temperatures tested. The improvement al low temperatures (10 °C) proved that the addition of reclaimed geomembrane does not lead to an excessively fragile behaviour of the asphalt mixture despite the increase in the stiffness when comparing to the base bitumen mixture.

Taken together, the present study proved that the use of reclaimed geomembranes as part of the bitumen of SMA mixture offers sound mechanical performance in terms of binder drainage, moisture susceptibility, bearing capacity and both rutting and fatigue cracking resistance at different temperatures. For all these reasons, the use of RGMB constitutes an interesting alternative to commercial modified bitumens since it allows for reaching similar performance with lower cost and environmental benefits. Further research will be conducted in the future so to deepen on the environmental benefits of this kind of mixture and its recyclability after the end of its life service.

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