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Bituminous mixtures with low percentage of natural aggregates and rubber modified bitumen with wax

Ángel Vega-Zamanillo[a], Pedro Lastra-González[a], Miguel A. Calzada-Pérez[a], Daniel Castro-Fresno[a], Evelio Teijón-López-Zuazo[b]

[a]*University of Cantabria, Department of Transports, Avda. Los Castros s/n, Santander 39005, Spain*
[b]*University of Salamanca, EPS de Zamora, Department of Construction, Avda. Cardenal Cisneros, 34, Zamora 49022, Spain*

Abstract

The three mixtures included in the Spanish specifications (asphalt concrete, porous asphalt and very thin asphalt concrete) were designed replacing more than 80% of the natural aggregates by black slag of electric arc furnace and recycled asphalt pavement. Besides, a rubber modified bitumen was used as binder, analyzing the performance of a fatty acid amide wax as additive to decrease its viscosity at mixing temperature, and avoid the higher manufacturing temperature of this type of bitumen. Three stages were carried out to design the mixtures: first, the viscosity analysis of the rubber modified bitumen when the wax is added. Second, the experimental design of the mixtures with the alternative aggregates at conventional temperature, using the rubber modified bitumen without wax. Finally, the study of the behaviour of the three mixes with the same dosage of the previous phase, but manufactured at reduced temperature, that is including the fatty acid amide wax to the binder.
The tests of the Spanish specifications have been performed to design the mixtures and compare their performance in both conditions (with and without wax): void characteristics, water sensitivity test, wheel tracking test, and Cantabro loss particle test in dry and wet conditions. The results have shown that it is feasible to design mixtures in which practically the whole mineral skeleton comes from black slag and recycled asphalt, manufacturing them with a rubber modified bitumen but at the same range of temperatures than conventional 50/70 penetration grade binder, and fulfilling the standards for any climatic zone and heavy traffic level.

Keywords: Bituminous mixtures; rubber modified binder; wax; temperature.

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1. Introduction

The construction of roads implies a great environmental impact, especially linked with the consumption of aggregates (Luaces Frades, 2008; Organisation for Economic Co-operation and Development, 1997) and energy (Miller and Bahia, 2009).

The Spanish standard (PG-3) prioritizes the use of rubber modified binder from end-of-life tyres when its use is economically and technically viable. Besides, the concept end-of-waste appears in the European directive 2008/98/EC, which considers as resource some materials that were regarded as waste in the past: ash and slags, materials from construction demolition, scrap and tires (European Parlament, 2008). Therefore, the reuse of these type of materials improving the mechanical performance of bituminous mixtures is one alternative to improve the environmental impact of the roads and to fulfil the increasingly restricted requirements of the European Union.

The reuse of alternative materials, such as construction and demolition waste (Gómez-Meijide and Pérez, 2015), polymeric waste (Moreno et al., 2011; Vila-Cortavitarte et al., 2018; Lastra-González et al., 2016), or different types of slags (Vega-Zamanillo et al., 2017; Skaf et al., 2016) has achieved the replacement of a great percentage of the natural aggregates. Trying to enhance the sustainability of the roads, this paper includes the design of the three bituminous mixtures included in the Spanish standard (PG-3) for surface layer with at least 80% of natural aggregate replaced by alternative materials; besides, a rubber modified binder from end-of-life tyres has been used at reduced temperature with the use of waxes.

Recycled asphalt pavement (RAP) from other roads and black slag of electric arc furnace (EAF) have been used to replace the natural aggregates.

The use of rubber from end-of-life tires to modify conventional asphalt by wet way has many advantages, such as the increase of the elasticity and resilience at high temperatures, or the decrease of the thermal susceptibility (State of California Department of Transportation, 2006). However, rubber also increases the viscosity (Rodríguez et al., 2013) of this bitumen, increasing its manufacturing temperature, which is one of its main disadvantages.

A fatty acid wax produced in Spain was analysed to reduce the viscosity of this type of binder. In road construction, several processes and products are now available to produce environmentally friendlier bituminous mixes. Silva el al. (2010) studied the use of synthetic paraffin wax additives. These additives facilitate the production of energy efficient asphalt mixtures at reduced manufacturing and construction temperatures. Ranieri, V et al (2017) concluded that warm mix asphalts technology is applicable to porous asphalts in cold climate, adding wax, allowing the lowering of compaction temperatures by about of 20 degrees ºC without any significant decrease in performance. Hofko, B et al. (2017) manufactured mastic asphalt at lower temperatures than usual, using additives of wax and rounded aggregates. This reduction in temperature of 30 °C and 50 °C can decrease costs and energy demand.

The aim is that the designed mixtures, all aimed at surface layer, can be used in any situation. This means they fulfil the requirement for the most demanding situations, including the warmest weather and the highest traffic loads. Besides, the design is based on the idea that their production has to be as simple as possible, and with similar conditions, at least, than the manufacture with a conventional binder.

The design was split into three stages: first, the viscosity analysis of the rubber modified bitumen when the wax is added. Second, the experimental design of the mixtures with the alternative aggregates at conventional temperature, so the performance of the materials is assessed without influence of the wax. Finally, the wax was incorporated to the mixtures to study its impact in each type of mixture. The results are divided regarding these different phases.

Nomenclature

EAF	black slag of electric arc furnace
RAP	recycled asphalt pavement

2. Materials

Black slag of EAF has been used as coarse aggregate (Fig. 1). It presents very good conditions with a Los Angeles coefficient of 18, and polished stone value of 0,59. The main difference with natural aggregates is its high density: 3.821 g/cm3, which requires dosing the mixtures by volume to avoid unbalanced mixtures.

Fig. 1. Black slag.

The RAP has unknown origin (Fig. 2). It presents a density of 2.502 g/cm3 and a percentage residual bitumen of 4% by weight, which is hardened, with a penetration of 13 (dmm) and softening temperature of 76.1°C. The sand equivalent test was carried out to assess whether the RAP was contaminated during the milling or transportation process, reaching a value of 93, so it is in good conditions. The particle size distribution of the recovered aggregates has been used to dose the mixtures considering that the residual bitumen will be softened and partially mixed with the raw materials.

Fig. 2. Reclaimed asphalt.

A fatty acid amide wax has been used as additive, whose provider is UNDESA and it is manufactured in Zaragoza (Spain). It is produced from pig tallow and presents a melting point around 140°C. It is shown in Fig. 3.

Fig. 3. Fatty acid amide wax.

The binder is a commercial PMB 45/80-60 C, with a manufacturing temperature between 165°C and 175°C.

The particle size distribution of the mixture was finished with limestone. It has always been used in the fine fraction to complete the percentage of RAP until the desired grading size.

The final dosage for each type of mixture is shown in the Table 1.

Table 1. Percentage of each material.

Material	AC 16 S		BBTM 11 B		PA 16	
	% Volume	% Weight	% Volume	% Weight	% Volume	% Weight
Black slag	60	69	78	83	88	91
Limestone	19	16	17	13	7,5	5
RAP	18	14	-	-	-	-
Filler	3	1	5	4	4.5	4
New bitumen / Mixture		3.80		3.75		3.85
Total bitumen / Mixture		4.36		3.75		3.85

Initially, the RAP was going to be introduced in the three types of mixture: AC, PA and BBTM; nevertheless, as the fine fraction of the PA and BBTM is small, and previous tests showed that RAP worsened their mechanical performance, it was decided to use only EAF slag in the coarse fraction of these mixtures. In this way, the percentage of recycled material in all mixtures went from 75% to 90% by volume, fulfilling the goal of achieving mixtures with a high percentage of alternative aggregates.

3. Results and discussion

The viscosity analysis of bitumen and the mechanical behaviour of the mixtures, at conventional and reduced manufacturing temperature, are presented (Fig.4).

The percentage of wax added was 3% of bitumen weight, while the mixing process was carried out at 150°C with an IKA homogenizer for 5 minutes at 15000 rpm. The viscosity was studied with a DHR-I rheometer of TA Instruments in a range of temperature from 100°C to 190°C, which covers the manufacture and compaction procedure. The results showed that when the temperature is higher than the wax melting point, this decreases the viscosity of the reference bitumen (Fig.4).

The manufacturing temperature facilitated by the supplier was used as reference (170°C). When the fatty acid amide wax is incorporated, the same viscosity is reached at approximately 155°C. Therefore, the wax achieves a decrease of the manufacturing temperature around 15°C. So the mixtures were manufactured at both temperatures: to design the mixtures at conventional temperature (170°C) with the rubber modified binder, and to assess the impact of the wax at reduced temperature (155°C). The mechanical behaviour of each mixture at both temperatures is shown below.

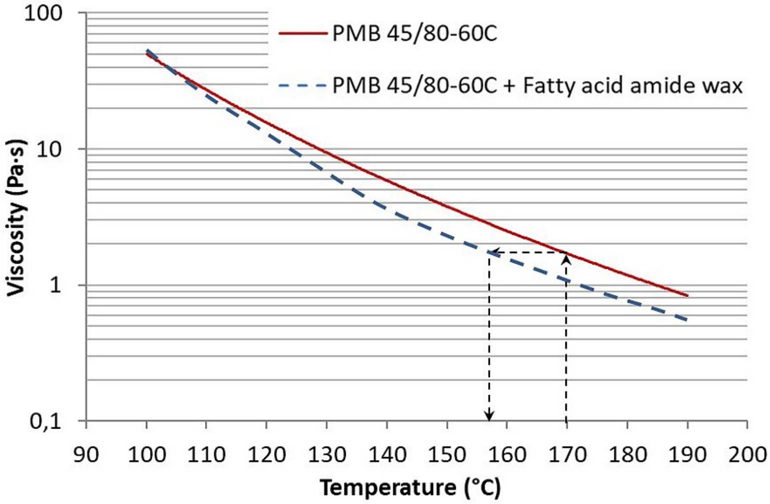

Fig. 4. Viscosity analysis.

3.1. Asphalt concrete (AC16S)

Marshall samples were used for the voids (UNE EN 12697 – 8) and the water sensitivity test (UNE EN 12697 – 12), while for the wheel tracking test (EN 12697 – 22) slabs of 50 mm were manufactured. Fig. 5 presents the results for both asphalt concretes depending on the temperature.

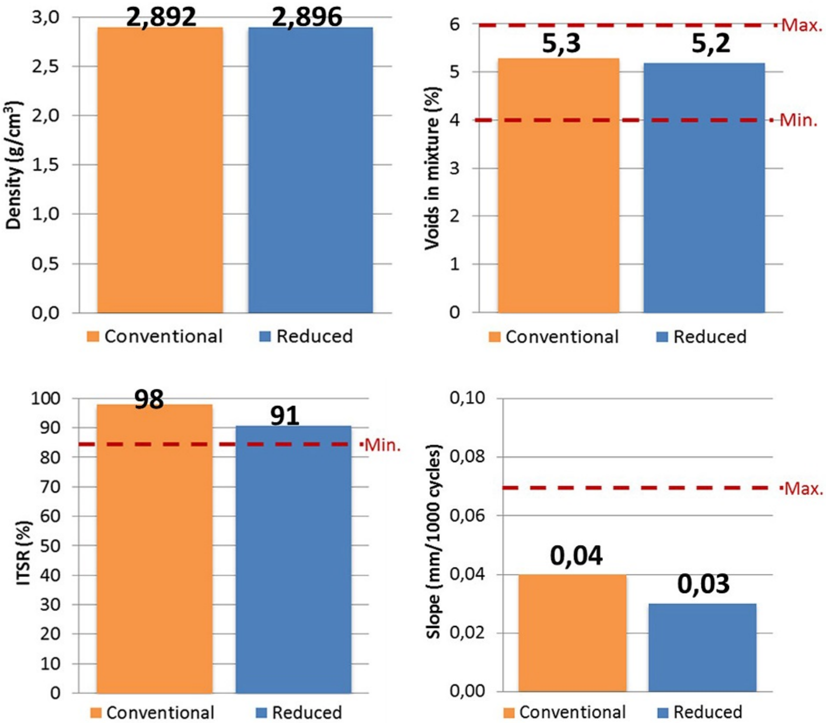

Fig. 5. Mechanical behaviour of asphalt concrete at both temperatures.

Both asphalt concretes fulfil the requirements for the highest heavy traffic level and the warmest area, independently from the manufacturing temperature. Although the density and the percentage of voids are practically the same, the water damage is slightly higher in the case of the AC with wax. Besides, it seems also that the wax increases the resistance against plastic deformation.

3.2. Very thin asphalt concrete (BBTM 11B)

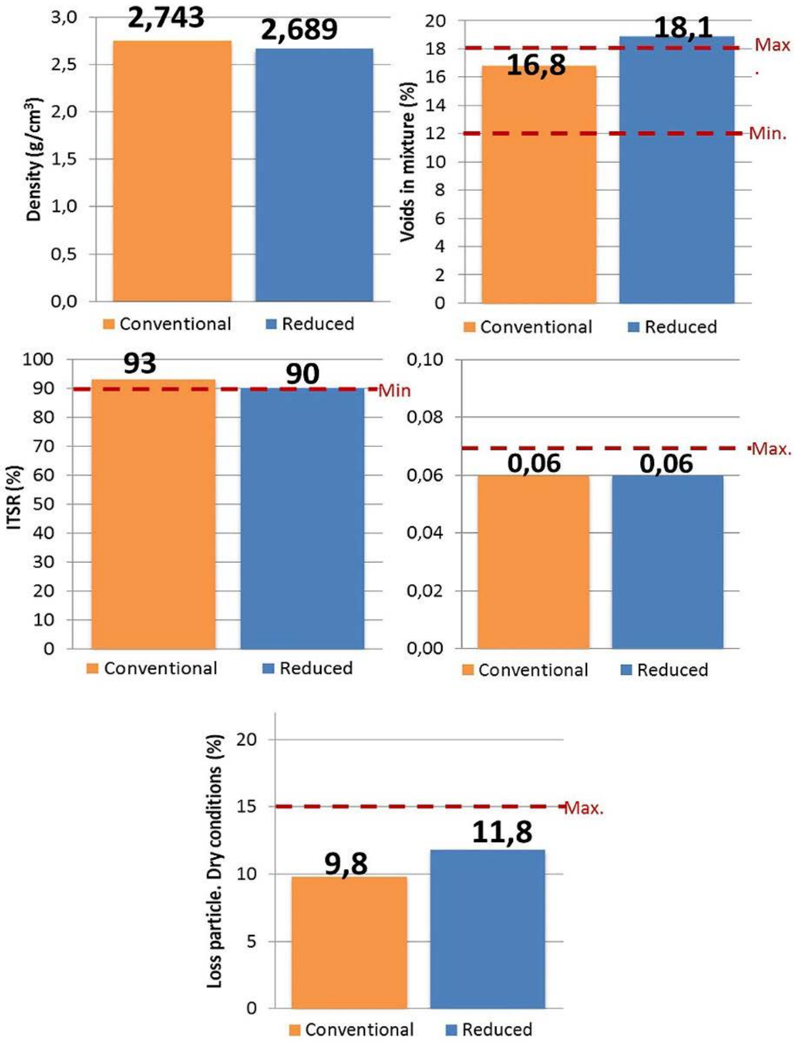

Fig. 6. Mechanical behaviour of very thin asphalt concrete at both temperatures.

The voids test (UNE EN 12697 – 8), the water sensitivity test (UNE EN 12697 – 12) and the resistance against plastic deformation test (UNE EN 12697 – 22) with slabs of 40 mm height were carried out. Besides, the Cantabro particle loss test (UNE EN 12697 – 17) was also performed, required by the Spanish standards until the update of 2008. The results are included in Fig. 6. The mixture with wax showed a higher percentage of voids. Although the difference is slight, this point can be related with the lower indirect tensile strength ratio and the higher percentage of particle loss, in the water sensitivity test and cantabro test respectively. Despite the higher percentage of voids, the mixtures at both temperatures had the same resistance against plastic deformation.

3.3. Porous asphalt (PA16)

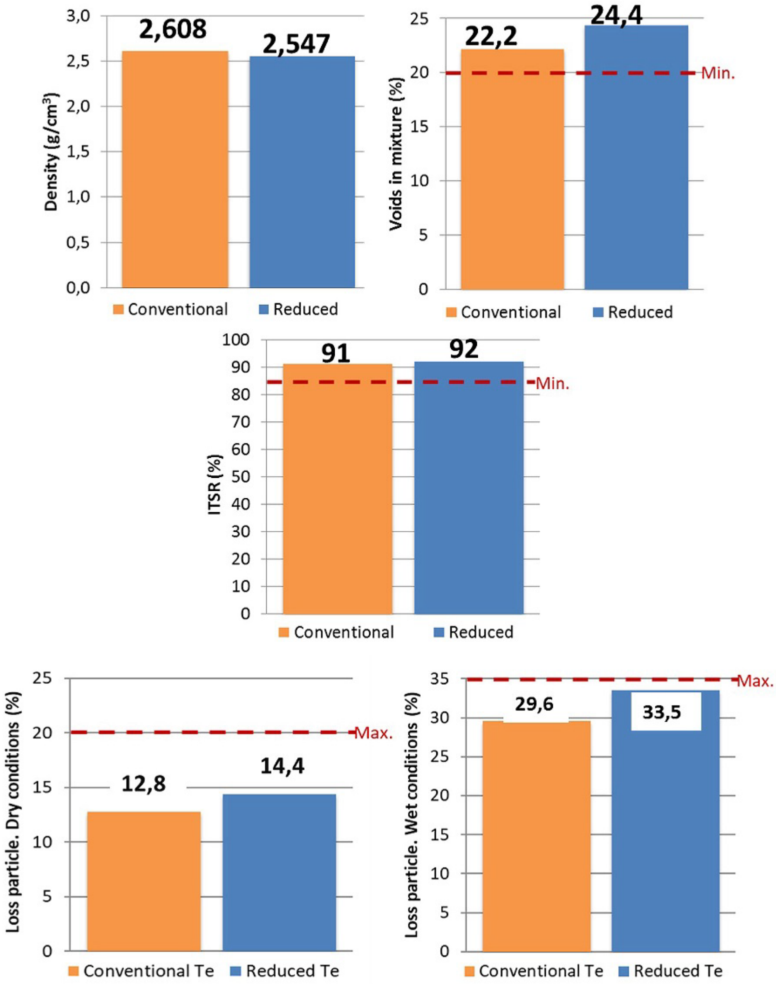

Fig. 7. Mechanical behaviour of porous asphalt mixture at both temperatures.

The tests required by Spanish standard for this type of mixture were performed to design the porous asphalt: the voids test (UNE EN 12697 – 8), water sensitivity test (UNE EN 12697 – 12) and Cantabro loss particle test (UNE EN 12697 – 17). Fig. 7 shows the mechanical tests performed on the mixtures at both temperatures.

The voids of the porous asphalt are also increased when the wax is incorporated, and as in the case of the BBTM mixtures, mixtures show a lower cohesion with higher particle loss when the wax is incorporated. Although the water damage seems similar, with practically the same indirect tensile strength ratio in the water sensitivity test, and a particle loss in wet conditions proportionally higher to dry conditions.

4. Conclusions

The three mixtures included in the Spanish standard have been designed with alternative aggregates and rubber modified binder. Besides, a fatty acid amide wax has been added with the aim of reducing the production temperature to the conventional ranges used by a 50/70 penetration grade bitumen.

Based on the results of this study, the following conclusions are drawn:

- The mixtures at reduced temperature have not had important differences with the mixtures at conventional temperature in the mechanical tests All of them, at both temperatures, fulfil the specifications required by the Spanish standards for the highest heavy traffic level and the warmest areas.
- The mixtures designed with more than 80% by weight of alternative aggregates fulfilled the technical requirements established by the Spanish regulations for their use in the most demanding roads. The EAF Slag and RAP are suitable materials to be used in any type of mixture, although the RAP is more appropriate for asphalt concrete mixtures.
- Above the melting point of the fatty acid amide wax (130°C / 140°C) a decrease of the viscosity of the rubber modified binder is observed that allows to decrease the manufacturing temperature of the asphalt mixture by 15°C.
- The three designed mixtures have a similar performance independently from the changes in their manufacturing process, although when the wax is incorporated, the results show a trend to increase the percentage of voids. The particle loss in the Cantabro test are also increased, which could be related with the increased voids. Despite this increment, the resistance against plastic deformations and the indirect tensile strength ratio are similar.

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