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Mechanical performance of dry process fine crumb rubber asphalt mixtures placed on the Portuguese road network

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HIGHLIGHTS

- AR_{dry} with fine granulate rubber is an improved pavement material.
- Stiffness of AR_{dry} is less sensitive to high temperatures than that of a conventional mix.
- Mixing above 175 °C seems to impair the rubber contribution to mechanical performance.
- Permanent deformation resistance confirms the low temperature susceptibility of AR_{dry}.
- Fatigue performance and rut resistance of AR_{dry} and AR_{wet} are at the same level.

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ABSTRACT

This paper evaluates the mechanical response of two gap-graded asphalt rubber mixtures manufactured by the dry process (AR_{dry}). The observed behaviour is compared with that of a similar gap-graded mixture without rubber granulate, used as reference. The laboratory results are also compared with analogous asphalt rubber mixes produced elsewhere by the wet process (AR_{wet}). The blends were produced in a plant and laid in trial sections and on the Portuguese road EN 370, in order to collect representative specimens for laboratory testing. The mechanical evaluation of the mixes was carried out by repetitive four-point bending tests and wheel-tracking tests. The laboratory results and the behaviour observed on the EN 370 allow us to conclude that mechanical performance of the tested AR_{dry} is better than that measured for the reference blend, and is at the same level of performance as $AR_{wet,}$ provided that a proper mixture design and some construction directives are used.

1. Introduction

Recycled tyre crumb rubber (CR) is a material produced from end-of-life tyres (ELTs) suitable to be applied as a bitumen modifier in bituminous mixtures. This granulate is obtained after removal of reinforcing wires and textile fibres from ELTs [1]. Since the use of granulated tyre rubber in the manufacture of bituminous mixtures helps to avoid the inappropriate disposal of tyres, the incorporation of this by-product in asphalt is undeniably beneficial to the environment and the society. The best-known CR production methods are ambient grinding and cryogenic grinding. A detailed description of these and other methods can be found in the review published by Presti [1]. It must be emphasized that rubber granulates ready-to-use, and produced by the aforementioned processes, are available on the market.

Two methods are generally followed to incorporate CR particles into bituminous mixtures, commonly designated as the “wet process” and the “dry process”. The first one generally involves the introduction of fine CR (particles with a size lower than 2.36 mm [1]) into hot bitumen (around 180 °C), allowing interaction between the two materials by permanent agitation within a tank. After that, the resulting improved binder is added to the aggregate blend to produce asphalt rubber (AR_{wet}). Traditionally, the dry process (AR_{dry}) consists in adding CR, as a mixture component, at ambient temperature into a blend of heated aggregates prior to

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introducing bitumen into the process. As mentioned by Rahman et al. [2], in the dry process the rubber particles, which are added, are coarser (0.4–10 mm) and it is normally assumed that the CR is part of the aggregate. Reaction between bitumen and CR is considered negligible because the mixtures are fabricated without any significant interaction time between bitumen and CR. In this process, some fractions of the aggregate blend are generally substituted by CR particles of similar sizes [2,3]. Since performance of AR_{dry} tends to demonstrate some variability and in some situations poor results [2–5], there is a certain lack of confidence in the dry process.

This study concerns the use of a modified dry process, in which the CR used is much finer than usual (0–0.6 mm nominal size as it commonly happens in the wet process in Portugal). The interaction between the bitumen and the rubber occurs during the time that these components come into contact (at least 90 min in this project). As the rubber particles are very fine, the interaction between the rubber and the binder occurs more quickly allowing a certain modification of the heated bitumen. Previous studies carried out in this technique by other authors [6–8] have emphasized laboratorial work. The present study complements the information available. Firstly, by including mechanical properties of specimens taken from a pavement built in a road segment of the Portuguese road 370 (EN 370) 14.5 km in length, between Portalegre and Avis; secondly, by providing information on the observed behaviour of the pavement after five years of service.

The laboratory evaluation of mechanical performance of the studied AR_{dry} is made in terms of stiffness, based on EN 12697-26 [9], resistance to fatigue, according to EN 12697-24 [10], and resistance to permanent deformation by using wheel-tracking equipment operated under the standard NLT-173 [11]. In addition, a pavement inspection was carried out after five years of service.

2. Materials

2.1. Aggregates and rubber granulate

Two types of aggregates and limestone filler were used in the study. These constituents allowed the production of three different compositions, whose grading curves were established from three different aggregate fractions of rhyolite (mixtures TB0 and TB3) and granodiorite (mixture TA), as well as a limestone filler. For each different mixture studied, the aggregate blend was determined based on a target grading Portuguese envelope for gap-graded aggregate mixtures for surface layers. Table 1 shows the grading curves of aggregate blends and crumb rubber, Table 2 summarises other aggregate properties determined according to the Portuguese specifications, and Table 3 presents some physical properties of the rubber. The CR producer receives tyres (car and truck tyres) from an organization licensed by the government to manage end-of-life tyres in Portugal.

The filler used was produced from crushed limestone rocks, with 95.5% of particles smaller than 0.125 mm and 78.6% of particles smaller than 0.063 mm. The applied filler met the common Portuguese requirements.

2.2. Binders

The AR mixes were produced with conventional pen 35/50 paving bitumen. After the production and laying of each of the studied blends, the binder was recovered and its properties were determined [13]. Table 4 shows the properties of the original bitumen before and after recovery, as well as the properties of the rubber-binder after recovery. The two-phase procedure consisted in separating the binder from the aggregate by centrifugation with toluene, followed by the separation of the binder from solvent in a rotary evaporator.

It must be emphasized that rubber particles tend to separate from bitumen throughout centrifugation. This suggests that the interaction between both components is predominantly physical. Nevertheless, as proved also by several authors [2,6,7], the final bitumen becomes harder because rubber absorbs some light fractions of it during the time they remain in contact at high temperature conditions. The results show that all the recovered binders were substantially harder than the virgin bitumens.

2.3. Compositions of blends and manufacture temperatures

Table 5 summarises some relevant information about the studied blends. For these types of asphalt rubber gap-graded mixtures the Portuguese specification indicates that the binder content should be adjusted after construction of a trial section, which is used to evaluate the handling and construction conditions in the field. The minimum binder content should be between 8% and 9% (by weight of the total mixture). The gap-graded mixture used as reference has a typical binder content of 5%. Note that this offers the opportunity to discover if incorporating rubber granulate by a modified dry process into the mix, as well as higher binder content, could be significantly beneficial for the mechanical properties of the obtained mixture.

As in the wet process, there was no substitution of fine aggregate fractions by CR particles of similar sizes because the resulting asphalt mixture is practically identical.

The interaction time between virgin bitumen and rubber granulate was 90 and 140 min for blends TB3 and TA, respectively. As demonstrated elsewhere [6], a minimum interaction time of 90 min is recommended for the method of production applied in this project. The interaction occurred during mixing at the plant and throughout haulage time from plant to test site.

The selected mixing temperature of the blends TB0 and TA was in the typical range generally used for hot mix asphalt (around 165 °C). It must be emphasized that temperatures applied in these cases were lower than those typically used for the wet process (around 180 °C or higher), as reported by several authors [1,14]. Therefore, the blend TB3, also produced by the dry process, was mixed at a very high temperature with the goal of evaluating the effect on the mixture performance. In fact, strong hardening of binder and degradation of rubber granulate is expected to occur at these very high temperatures.

The mixing procedure carried out at the batch plant consisted in allowing a period of 15 s pre-mixing of the rubber granulate with the aggregate. Afterwards, the virgin bitumen was added to the mixer.

3. Results of laboratorial performance evaluation and discussion

3.1. Production of specimens for testing

Prismatic beams were cut from the slabs taken from the trial sections constructed at the test site on the Portuguese EN 370. Prismatic specimens of $420 \times 60 \times 60\ mm^3$ were submitted to four-

Table 1
Grading curves of the aggregate blends and rubber granulate (percentage by weight of material passing).

Sieves (mm)	TB0 [reference mix]	TB3 [1.5% of crumb rubber]	TA [1.9% of crumb rubber]	Crumb rubber[a]
20	100	100	100	–
14	88.1	82.4	97	–
10	73.5	66.5	81	–
8	61.2	55.1	69	–
4	30.3	27.5	36	–
2	18.1	17.9	18	100
0.5	9.9	10.1	10	–
1.18	–	–	–	100
0.6	–	–	–	98.1
0.3	–	–	–	26.4
0.125	6.0	6.4	6	–
0.075	–	–	–	0.3
0.063	4.1	4.4	4	–

[a] Ambient grinding CR.