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A complete laboratory assessment of crumb rubber porous asphalt

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HIGHLIGHTS

- Use of fine crumb rubber by dry process in porous asphalt.
- Drain-down test comparison between fine crumb rubber and fibres in porous asphalt.
- Higher bitumen/aggregate affinity of crumb rubber mixtures comparing to fibres mixtures.
- The use of crumb rubber improved the thermal and water sensitivity behaviour of porous asphalt.
- Higher ravelling resistance by means of Cantabro particle loss results for rubberized porous asphalt.

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ABSTRACT

Besides the many advantages of porous asphalt (PA), the permanent deformation resistance, fatigue strength, stripping and moisture susceptibility are not as good as for dense graded mixtures. In this research, the effectiveness of adding crumb rubber (CR) by dry method to PA mixtures was assessed. Rubberized porous asphalt (RPA) mixtures manufactured incorporating CR into SBS modified asphalt concrete were produced and compared with a control mixture by means of Indirect Tensile Strength (ITS), Indirect Tensile Stiffness Modulus (ITSM), moisture susceptibility, permeability, Cantabro, rolling bottle, draindown and creep tests. Results proved that although the application of CR reduces the vertical permeability and permanent deformation resistance, it improves the bitumen/aggregate affinity and it controls the draindown rate without adding fibres. On the other hand, the use of CR decreased the ITSM value at low temperature, which represents a lower susceptibility to thermal cracking. Other complementary test results in this research support the effectiveness of RPA mixtures.

1. Introduction

Porous asphalt (PA) is an environmentally friendly road material with mostly 15% air voids, which is used effectively in regions with high level of precipitation. The high rate of voids improves the riding quality during the wet weather and improves the safety by reducing the skidding. In addition, porous asphalt prevents hydroplaning and spraying on the road surface and improves the visibility by eliminating the light reflected from the road surface [1]. Alongside with all the PA benefits, some mechanical and performance weak points have been reported after in-situ inspections and previous experimental researches. From the considerable limitations of porous asphalt, those related to lower durability and structural properties in comparison to other typical asphalt mixtures are more relevant [2]. In addition, the higher production and maintenance costs [3,4], due to the needed high quality aggregates and PmBs necessary for governing the susceptibility to moisture damage and permanent deformation control, sometimes prohibit the wide use of PA mixtures.

On the other hand, early oxidation and aging is also reported as common deficiency with PA mixtures. Considering the surface texture and high rate of voids in PA mixture origin, the rate of aging increases by facilitated passage of air and water through the interconnected voids. The result of this aging defects the bitumen/aggregate adhesion and finally will lead to prompted fragmentation, stripping and ravelling [5].

Considering the abovementioned issues, previous researches indicated that substitution of traditional binders by Polymer Modified Binders (PmBs) improves the long-term performance and permanent deformation of PA mixtures.

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Table 1
Gradation limits.

Sieve size (mm)	15	10	5	2	0.4	0.18	0.075
Italian code limits* (%)	100/100	85/100	5/20	0/12	0/10	0/8	0/6
Sieve size (mm)	25	19	12.5	9.5	4.75	2.36	0.075
NAPA limits (%)	100/100	100/100	85/100	55/75	10/25	5/10	2/4

*Province of Bologna specifications.

Test results of laboratory and field evaluation research by Chen et al. proved that using polymer-modified binders instead of unmodified binder reduces rutting and ravelling distresses [6].

Moreover, other researches gave indications of drainage improvement by replacement of traditional binders with PmBs according to extensive field measurements.

From another point of view, as far as the PA is originally considered as open-graded mixture, the remarkable low medium-fine portion made these mixtures prone to high rate of draindown deficiency [6]. For this issue, the application of fibres in PAs is a common solution.

Recycled tyre rubber as an eco-friendly technology has been widely investigated and used in pavements industry to modify asphalt mixtures properties. Previous practical field experiences and long-term case studies provided testimonies on the efficiency of the crumb rubber (CR) in improving the performance properties (resistance to fatigue and rutting) of its mixtures [7].

In terms of the application, CR can be added directly to mixture as for the dry method or primarily added to the bitumen to provide PmB. In many researches it was proven that mixtures produced using both the wet and the dry processes had the potential to improve their properties if compared to conventional asphalt mixtures. In the research by Katman, for instance, it was drawn that the inclusion of rubber (dry process) significantly increased the resistance to water damage, while the resistance to abrasion loss were lower than the ones obtained with the wet process and the traditional asphalt control mix [5]. As the interaction time in the dry process is considerably short, it is generally assumed that the rubber-bitumen reaction is less and, therefore, it has a lower effect on the final material performance than a comparable wet mixture. The term interaction in former related literatures denotes to the diffusion of lighter bitumen fractions (Maltenes) into the CR, which leads to absorbing bitumen by CR particles. [8,9].

Along with the CR application method and amount added to the asphalt mixture, the overall properties, laboratory and field performance greatly depended on other mix design components' characteristics, proportions and temperature of mixture during the production and laying of the material [5].

The objective of this study was to investigate and evaluate the engineering properties of PA mixtures produced with PmB by dry method. In addition, the capability of CR to improve the aggregate/binder affinity in PA without fibres was also investigated.

2. Materials and methods

2.1. Materials

Many previous studies on aggregate quality and characteristics influence on PA mixtures proved the critical role of aggregate quality on satisfactorily behaviour PA layers [3,10].

In this study, aggregate grading for porous asphalt mixtures with and without CR were designed based on Italian local specifications [11]. In addition, the applied grading is close to cover the National Asphalt Pavement Association (NAPA) grading [12]. Table 1 represents the limits considered for the aggregates gradation in this study. Limestone filler, commonly used in Italy, was used up to 6% by weight of dry aggregates.

Table 2
PmB 45/80-70 bitumen properties.

Measured properties	Unit	Value	Standard
Penetration @ 25 °C	0.1 mm	45/80	EN 1426
Softening point (R&B)	°C	⩾70	EN 1427
Cohesion @ 5 °C	J/cm^2	⩾3	EN 13598
Elastic recovery @ 25 °C	cm	⩾80	EN 13398
Fraass breaking point	°C	⩽−20	EN 12593

Table 3
Granulometry of CR.

Sieve size (mm)	Passing (%)
0.59	100.0
0.425	83.0
0.297	34.3
0.18	3.2
0.15	2.4
0.075	1.1

A SBS modified 45/80 pen grade bitumen was used for both control PA (neat mixture without CR) and RPA. Table 2 indicates the properties of the modified binder.

Crumb rubber obtained from waste tires was used at 1% by weight of aggregates with the grain size distributions given in Table 3. As it is demonstrated in Fig. 1 and based on the gradation, it can be considered that it is pulverized rubber. CR additives were blended directly with the heated aggregates by means of the dry processes.

2.2. Samples preparation

For this research, aggregates with the selected grading were heated and preliminarily mixed with CR, before adding the modified binder. After mixing a set of 150 mm diameter cylindrical specimens were compacted by Superpave Gyratory Compactor (SGC) for 80 gyrations. The compaction pressure was fixed at 600 kPa, with an angular velocity of 30 gyrations/min, and external angle of 1.25 degrees. It is worth mentioning that, in this research, no fibres were used in the PA mixtures.

2.3. Prequalification procedure and mix design evaluation

Both RPA and control mixtures were produced with 4.5, 5.0, 5.5, 6.0 and 6.5% modified binder content. Then prequalification tests such as volumetric analysis, ITS and vertical permeability were performed. Based on these assessments the optimized binder content was determined to be 6% (by weight of aggregates) for both PA and RPA mixtures.

Compatibility and workability during compaction and volumetric proportions within the specimens were investigated for both optimized RPA and control PA specimens in terms of maximum densification and air voids content.