Construction and Building Materials 107 (2016) 165–171

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Performance evaluation of rubberized and SBS modified porous asphalt mixtures

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HIGHLIGHTS

- Impact of crumb rubber (CR) and SBS on porous asphalt performance was investigated.
- CR and SBS enhance M_R, skid resistance, moisture susceptibility, and rut resistance.
- Crumb rubber and SBS has negative effect on permeability of porous asphalt.
- CR-10% is the most effective dosage with respect to overall performance.

ARTICLE INFO

Article history:
Received 5 September 2015
Received in revised form 4 January 2016
Accepted 5 January 2016
Available online 11 January 2016

Keywords:
Porous asphalt
Permeability
Resilient modulus
Moisture susceptibility
Rutting resistance

ABSTRACT

Porous asphalt (PA) has high drainage and noise-abrasion properties, however, its performance regarding rutting resistance, fatigue life, and moisture susceptibility is not as efficient as dens-graded mixes. This paper evaluates the influence of crumb rubber (CR) on performance enhancement of porous asphalt. PAs fabricated by asphalt cement incorporating 10%, 15%, and 20% of CR were compared with control and 5% SBS modified ones regarding rutting resistance, resistant to draindown, skid resistance, moisture susceptibility and permeability. Results indicate that, on one hand, CR and SBS reduce permeability of PA and, on the other hand, they improve rutting resistance significantly. In addition, despite initial improvement of resilient modulus, skid resistance, and moisture damage resistance, adding more CR has negative effect on these properties.

1. Introduction

Porous asphalt is a hot bituminous mixture normally used as a special-purpose wearing course. It is produced using open-graded aggregates mixed with essentially polymer modified binder. PA is characterized by the use, predominantly, of narrowly graded crushed coarse aggregate without a significant proportion of fines. This results in sufficient interconnected voids to provide high permeability after laying and compaction [27]. As this non-structural bituminous layer is designed in such a way that any surface water entering into it is rapidly drained to the road shoulders, it is laid on a structurally sound and impermeable pavement surface with adequate cross fall [14].

Advantages of PA mixtures include reduction of splash and spray as well as risk of hydroplaning and wet skidding, and improvement of pavement markings visibility in wet weather [10]. In addition, PA mixtures provide improved riding quality and noise reduction effectiveness as compared to dense-graded HMA. Cleaner runoff was also reported as an advantage of PA mixtures. For example, Barret reported smaller concentrations of pollutants related to particulate material and total suspended soils in the runoff obtained from Permeable Friction Course (PFC), another name for PA, as compared to that of dense-graded HMA. Some disadvantages reported for PFC or PA mixtures are reduced structural durability (resistance to disintegration) and functional durability (premature voids clogging), relatively high construction cost, use of limited high-quality aggregate, reduced structural contribution, and winter maintenance issues (e.g., black ice formation) [4].

Crumb rubber has been long under study and its effectiveness for improving rheological properties of bitumen and performance of asphalt mixtures has been proved [17,22,32,2]. A crumb tire rubber modified bitumen displays enhanced mechanical properties, which improves its resistance to both rutting and fatigue cracking [22,2]. In both dry and wet process, addition of CR improves resistance of dense-graded mix to plastic deformations. Therefore, lower permanent deformation values are expected in the mixes

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http://dx.doi.org/10.1016/j.conbuildmat.2016.01.006
0950-0618/

with higher percentage of crumb rubber [21]. Results of dynamic creep test demonstrates that a crumb rubber content twice that of the SBS content in the dense-graded hot mixtures provides the same performance, and a high affinity between 3% SBS and 6% CR modified mixtures can be observed with respect to the accumulated strain values [17]. Moreover, CR modified dense-graded mixes were found to have greater resistance to moisture damage compared to normal mixes [23].

Application of CR in gap-graded mixtures result in larger air void and greater optimal binder content [18]. Lower abrasion loss, fatigue life increase, moisture damage and rutting resistance improvement are advantages of using CR in PA [26]. However, skid resistance is not affected by bitumen modification and permeability is reduced due to CR addition into PA [26]. It was found that the water-accessible air void content can be used as a surrogate of the total air void content to indirectly assess permeability [3]. Analysis of mixture internal structure based on X-ray CT and image analysis techniques indicated that PFC containing CR have higher mean total air void content and mean air void size values, along the entire height, as compared to the Performance Grade PFC mixtures. However, the smaller ratios of water-accessible air void content to total air void content of rubberized PFC mixtures, compared to Performance Grade PFC mixtures, led to lower drainability values for the rubberized PFC mixtures [5]. It appears that not all percentages of CR lead to the same results and evaluation is required for different rubber contents. Moreover, a comparison with a widely-used polymer can help to a better cognition of performance efficiency of CR in PA.

In this study, various tests evaluated design and performance of rubberized asphalt at concentrations of 10%, 15%, and 20%. Conventional and SBS modified PA were then used for comparison purposes.

2. Materials

Table 1 presents physical properties of used limestone aggregates. As shown in Fig. 1, particle size distribution falls within the upper and lower limits of the proposed gradation of Iran Highway asphalt paving code [9]. Properties of used PG58-22 bitumen are also presented in Table 2. Table 3 indicates that penetration decreases and softening point increases with crumb rubber content increase. In addition, in this study, the rubber was produced from automobile tires by ambient shredding.

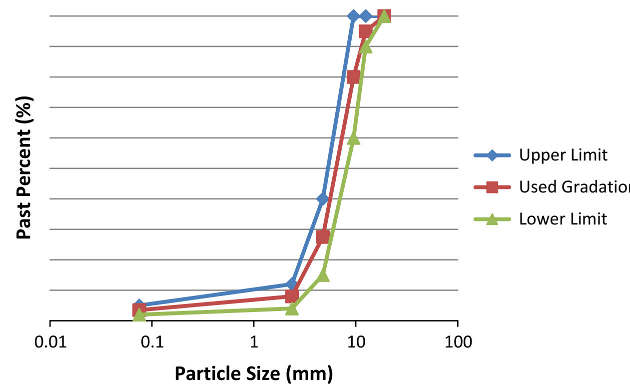

Fig. 1. Particle size distribution.

Table 2
Binder properties.

Measured properties	Standard (ASTM)	Value
Penetration at 25 °C (0.1 mm)	D5-73	64
Softening point (R&B °C)	C36-76	53
Ductility at 25 °C (cm)	D113-79	>100 cm
Density at 25 °C (gr/cm^3)	D70-76	1.05
Flash point (°C)	D92-78	308

Table 3
Penetration and softening point at different concentrations of crumb rubber.

Properties	CR-10%	CR-15%	CR-20%
Penetration at 25 °C (0.1 mm)	40	32	30
Softening point (R&B °C)	58	67	71

** CR-10%, CR-15%, and CR-20% are asphalt cement samples containing 10%, 15%, and 20% crumb rubber, respectively.

Table 4
Crumb rubber gradation.

Sieve size (mm)	Past percent
0.6	100
0.425	91
0.3	78
0.18	43
0.15	8
0.075	0

3. Experimental setup and procedure

3.1. Rubberized binder preparation

In wet process, high-speed stirrer apparatus is used to blend rubberized binder. In this research, –40 mesh rubber with gradation presented in Table 4 at concentration of 10%, 15%, and 20% were added to the virgin binder at reaction temperature of 180 °C and a reaction speed of 3500 rmp for 30 min [24]. It was shown that more than 30 min is not influential on blended binder properties [33]. SBS was also blended as crumb rubber.

Table 1
Aggregate physical properties.

Measured properties	Standard (ASTM)	Value
Bulk specific gravity of coarse aggregate (gr/cm^3)	C127	2.59
Bulk specific gravity of fine aggregate (gr/cm^3)	C127	2.32
Water absorption of coarse aggregate (%)	C127	2.2
Water absorption of fine aggregate (%)	C127	2.4
Los Angeles abrasion value (%)	C131	22.3
percentage of fractured particles in one side	D5821	97
percentage of fractured particles in two sides	D5821	94

3.2. Sample fabrication

Superpave Gyratory Compactor (SGC) was used to fabricate cylindrical samples with a diameter 100 mm and approximate height 67 mm, which weight 1000 gr. Table 5 presents setup parameters of SGC [8]. It is equivalent to 50 blows of Marshal hammer with respect to level of compaction. Samples at binder contents of 4.5%, 5%, 5.5%, and 6% were used to determine optimal binder content of control, 5% SBS modified, 10%, 15%, and 20% rubberized mixtures. Three identical samples were prepared for each percentage and the average was calculated as the measured value of different tests.

3.3. Cantabro test

This test was performed with accordance to standard ASTM C131 to determine optimal binder content of porous asphalt mix. Its procedure measures the breakdown of compacted specimens utilizing the Los Angeles Abrasion machine. It rotates at a speed of 30–33 rpm for 300 revolutions without steel spheres at 25 °C. After that, the loose material broken off the test specimen must be discarded. The percent of weight loss (Cantabro loss) is an indication of PFC durability and relates to the quantity and quality of the asphalt binder. The percentage of weight loss is measured and reported [31]. The result is the weight loss calculated by following equation: