Construction and Building Materials 101 (2015) 628–642

Contents lists available at ScienceDirect

Construction and Building Materials

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

Performance testing of asphalt pavements with recycled asphalt shingles from multiple field trials

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HIGHLIGHTS

- RAS was successfully used in field trials with warm mix asphalt, RAP, and ground tire rubber.
- RAS was successfully used as a replacement for fibers and asphalt in stone matrix asphalt.
- RAS mixes demonstrated acceptable fatigue and fracture properties in laboratory tests.
- The addition of RAP to a RAS mix design decreased its fracture energy at low temperatures.
- Larger RAS particle sizes increased the amount of pavement transverse cracking.

ARTICLE INFO

Article history:
Received 29 December 2014
Received in revised form 1 August 2015
Accepted 19 September 2015

Keywords:
Recycled asphalt shingle
Shingle waste
Hot mix asphalt
Asphalt binder
Recycled asphalt pavement
Performance testing

ABSTRACT

Transportation agencies have become increasingly interested in modifying hot mix asphalt (HMA) pavements with recycled asphalt shingles (RAS), yet they share common questions about the effect of RAS on the performance of HMA. In this study, the field and laboratory performance of RAS mixes produced from seven different transportation agencies are investigated as part of Transportation Pooled Fund TPF-5 (213). Field demonstration projects were conducted that evaluated multiple aspects of RAS that include RAS grind size, RAS percentage, RAS source, RAS in combination with warm mix asphalt technology, RAS as a fiber replacement for stone matrix asphalt, and RAS in combination with ground tire rubber. Field mixes from each demonstration project were sampled and tested for their permanent deformation, fatigue cracking, and low temperature cracking performance. Recovered asphalt binder from each mix was also evaluated. Pavement condition surveys were conducted for each project after completion.

1. Introduction

Waste asphalt shingles have historically been considered a solid waste and placed in landfills. In the United States (US), nine million metric tons (Mt) of asphalt shingle waste are generated each year from the renovation and construction of roofs, and another 1 Mt of waste are produced during the manufacturing process of new shingles [1]. In total, asphalt roofing shingle waste represents up to 3% of all construction and demolition debris in the US [2].

A new sustainable construction technology emerging in the US is the recycling of asphalt roofing shingles for use in asphalt pavements. By diverting waste shingles from landfills and incorporating them into asphalt pavements, what was previously considered a solid waste can now be upcycled into the transportation network for constructing driving surfaces. This innovative technology reduces the environmental impacts resulting from road construction by reducing the amount of virgin materials used in hot mix asphalt (HMA) [3]. Replacing virgin materials with recycled asphalt shingles (RAS) saves resources, reduces the energy burned from using raw materials, eases landfill pressures, and reduces the demand of extraction [4,5]. Using RAS in asphalt pavements can also reduce greenhouse gas emissions produced during road construction by 9–12% [6].

Fluctuations in crude petroleum prices have considerably raised the cost of asphalt binder in the past several years. This increase, coupled with the advancement of shingle processing technology, has created favorable market conditions for RAS to be used in asphalt pavements [7,8]. From 2009 to 2012, the estimated amount of RAS annually used in asphalt pavements in the United States more than doubled, from 0.7 million tons to 1.9 tons [9].

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http://dx.doi.org/10.1016/j.conbuildmat.2015.09.027
0950-0618/

The components of RAS allow it to be a good candidate as a secondary (recycled) material in asphalt mixtures. Recycled roofing shingles contain between 19% and 31% asphalt and include fine angular granules which can improve the resistance to permanent deformation. Shingles also contain fiberglass or cellulose backing, that when crushed during the recycling process, break down into fiber-like particles that may improve the cracking resistance of asphalt [10]. Various fiber modifiers, such as cellulose, polyester, and mineral fibers, have been widely used in asphalt mixtures [11]. Putman and Amirkhanian [12] demonstrated that recycled fibers obtained from waste streams can increase the tensile strength of asphalt mixtures.

With these benefits in mind, more state highway agencies are beginning to see the potential impact RAS could have in lowering the costs of pavements. However, little information about the long-term performance of pavements with RAS is known because it is a new material that agencies are beginning to use. The challenge agencies have when implanting the use of RAS materials, is developing a construction specification for RAS mixtures that ensures a product with similar qualities and performance to non-RAS mixtures. Several aspects about the sourcing and processing of RAS make it important for agencies to understand which factors about RAS affect the material properties essential for good pavement performance. This led to the creation of Transportation Pooled Fund TPF-5(213), a partnership of several state agencies in the United States with the goal of researching the effects of RAS on the performance of varied asphalt applications. As part of the pooled fund research program, multiple state demonstration projects were conducted to provide adequate laboratory and field test results to comprehensively answer design, performance, and environmental questions about asphalt pavements containing RAS.

The demonstration projects focused on evaluating different factors of RAS to determine how they influence the performance of pavements. RAS factors addressed in the different demonstration projects included the evaluation of RAS grind size, percentage of RAS in hot mix asphalt (HMA), RAS source (post-consumer versus post-manufacturer), RAS in combination with warm mix asphalt technology, RAS as a fiber replacement for stone matrix asphalt (SMA) pavements, and RAS in combination with ground tire rubber (GTR). Several of the demonstration projects also included control sections to compare traditional mix designs containing either recycled asphalt pavement (RAP) only or no recycled product to mix designs containing RAS.

2. Experimental plan

To evaluate how different factors of RAS materials effect pavement performance, an experimental plan was developed where each state highway agency in the pooled fund study proposed a unique field demonstration project that investigated a different aspect of RAS mixes. Field demonstration projects were sponsored by the Department of Transportation agencies in Missouri, Iowa, Minnesota, Indiana, Wisconsin, Colorado, and Illinois. The asphalt mixes evaluated from each field demonstration project (Table 1) show the experimental plan of each agency.

The Missouri demonstration project investigates how RAS grind size affects pavement performance and how replacing 5% RAP with RAS affects the properties of the asphalt pavement. The Iowa demonstration project investigates asphalt mixes with an increasing percentage of RAS. The Minnesota demonstration project investigates the difference between using post-consumer (PC) RAS and post-manufacturer (PM) RAS. The Indiana demonstration project investigates replacing RAS with RAP in asphalt mixes and the effect of producing RAS at reduced plant temperatures by using warm mix asphalt (WMA) foaming technology during production. The Wisconsin demonstration project investigates the effect of using Evotherm® 3G chemical WMA additive as a compaction aid at hot mix temperatures in mixes that contain RAS. The Colorado demonstration project investigates using 3% RAS as a replacement for 5% RAP. The Illinois demonstration project investigates using 5% RAS in stone asphalt matrix (SMA) in place of added fibers. While SMA mixes are always designed with fibers to prevent drain-down of the asphalt binder due to its gap-graded aggregate structure, the Illinois mixes did not contain any fibers since RAS has fibers in it. The Illinois project also contained different types of mixes to evaluate mixes produced with 0% RAP versus 11% RAP, mixes produced in the field versus mixes produced in the laboratory, and mixes produced with ground tire rubber (GTR) modified binder versus polymer modified binder.

During each field demonstration project, representative samples of each RAS source and asphalt mixture were collected for binder characterization and mixture laboratory performance testing. The asphalt was recovered from the RAS and asphalt mixtures following AASHTO T164 Method A (Centrifuge Method) by using a blend of toluene and ethanol as the extraction solvent. Solvent was removed from the extract by following the rotovaper recovery process in ASTM D5404. The performance grade (PG) of the extracted asphalt binders was determined by following AASHTO R29 "Standard Practice for Grading or Verifying the performance grade of an Asphalt Binder". Washed gradations of the aggregates after extractions were also conducted by following AASHTO T27. For the RAS samples, a dry gradation was conducted prior to extraction to evaluate the grind size distribution of the RAS product. Laboratory performance testing was conducted on laboratory compacted samples of loose mix collected in the field during the demonstration projects. In the case of the Illinois demonstration project, performance testing was conducted on both field and laboratory produced mixes.

2.1. Dynamic modulus

The dynamic modulus $|E^*|$ test was conducted to determine the stress–strain relationship of the asphalt mixtures under continuous sinusoidal loading for a wide range of temperature and frequency conditions. A higher dynamic modulus indicates that lower strains will result in a pavement structure when the asphalt mixture is stressed from repeated traffic loading. The mechanistic-empirical pavement design guide (MEPDG) uses $|E^*|$ as the stiffness parameter to calculate an asphalt pavement's strains and displacements.

The test was conducted by following AASHTO T342. Replicate test specimens of each asphalt mixture measured 100 mm in diameter and 150 mm in height at 7 ± 0.5% air voids. Specimens were tested by applying a continuous sinusoidal load at nine different frequencies (0.1, 0.3, 0.5, 1, 3, 5, 10, 20, and 25 Hz) and three different temperatures (4, 21, and 37 °C). Sample loading was adjusted to produce strains between 50 and 150 microstrain in the sample. A servo-hydraulic testing machine capable of applying a load up to 25 kN was used to test the asphalt mixture specimens. The testing machine was housed in an environmental chamber capable of controlling the temperature of the test specimens. Three linear variable differential transformers (LVDTs) were mounted between gauge points glued to the test specimens to measure the deformations in the sample. The dynamic modulus test data was used to construct master curves that plot dynamic modulus over a wide frequency range at a 21 °C reference temperature.

2.2. Flow number

The flow number test was conducted to measure the permanent deformation resistance of asphalt mixtures. Specimens of 100 mm in diameter and 150 mm in height with 7 ± 0.5% air voids were placed in a servo-hydraulic testing machine, unconfined, with a testing temperature of 37 °C. An actuator applied a vertical haversine pulse load of 600 kPa for 0.1 s followed by 0.9 s of dwell time. The loading cycles were repeated for a total of 10,000 load cycles or until the specimen reached 5% cumulative strain. Three LVDT's were attached to each sample during the test to measure the cumulative strains. Cumulative permanent deformation in the sample was plotted versus load cycles. The flow number was reached at the onset of tertiary flow, which was determined at the cycle corresponding to the lowest cumulative percent strain rate.

2.3. Four-point bending beam

Four-point bending beam testing was conducted according to AASHTO T321, "Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending". Samples of field produced asphalt were compacted to 7 ± 0.5 air voids in a linear kneading compactor to obtain a compacted slab with dimensions 380 mm in length, 210 mm in width, and 50 mm in height. Each slab was saw-cut into three beams with dimensions 380 mm in length, 63 mm in width, and 50 mm in height. Two slabs were compacted for each asphalt mixture to produce six beams for testing.

The equipment used to conduct the four-point bending beam test included a digitally controlled, servo-pneumatic closed loop bending beam apparatus. The bending beam apparatus was housed in an environmental chamber maintained at the testing temperature of 20 ± 0.5 °C. The mode of loading used for the test was strain controlled. Haversine wave pulses were applied to the specimen during the test at 10 Hz. Testing was conducted at varying strain levels to generate a fatigue curve for each asphalt mixture. For each of the six beam specimens prepared for each asphalt mixture, strain levels of 375, 450, 525, 650, 800, and 1000 micro-strains were applied. Testing at these strain levels were repeated for all the mixtures tested except for the two Indiana mixtures containing 3% RAS. Due to a limited amount of material, only 3 three beams of these mixtures were tested at 400, 700, and 1000 micro-strain levels.