Construction and Building Materials 115 (2016) 527–535

Contents lists available at ScienceDirect

Construction and Building Materials

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

Influence of aging and moisture on laboratory performance of asphalt concrete

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HIGHLIGHTS

- Limited research on laboratory aging and moisture conditioning of asphalt mixtures.
- Cracking, rutting, and compactability of hot mix and warm mix with RAP explored.
- Warm mix had lower temperatures and binder content versus hot mix.
- Warm mix with RAP performed similar to hot mix with RAP.

ARTICLE INFO

Article history:
Received 19 January 2016
Received in revised form 13 April 2016
Accepted 18 April 2016
Available online 26 April 2016

Keywords:
Recycled Asphalt Pavement
Warm Mix Asphalt
Aging
Moisture damage
Cracking
Rutting
Compactability

ABSTRACT

Significant research has been performed in the area of Recycled Asphalt Pavement (RAP) and Warm Mix Asphalt (WMA). This research has often looked at the influence of aging and moisture on cracking and rutting, but there is limited research available that looks at the combination of aging and moisture on both cracking and rutting. This research investigated the effects of RAP and chemical modified WMA on laboratory performance tests including: cracking, rutting, compactability, moisture conditioning, and aging. Based on the test results, WMA with RAP performed similar to Hot Mix Asphalt (HMA) with RAP in cracking and rutting resistance even though the WMA had lower mixing and compacting temperatures and a reduced binder content. In addition, WMA with RAP had similar compaction characteristics as HMA with RAP.

1. Background

Over the past twenty years, asphalt concrete has incorporated two new environmentally friendly and sustainable construction techniques: Recycled Asphalt Pavement (RAP) and Warm Mix Asphalt (WMA). RAP is obtained by milling existing roads, crushing and processing the millings, and incorporating the recycled material back into mix designs. There has been significant research showing the potential performance of RAP [1,2], WMA [3,4], and the combination of RAP and WMA [5,6]. In addition, work has been done looking at the aging gradients through the pavement structure [7]. While these reports, among many others, often looked at either aging or moisture damage, and either rutting or cracking performance, there were no found articles that looked at both aging and moisture damage, and both rutting and cracking performance. This research looks to combine all four of these factors, using both standard Hot Mix Asphalt (HMA) technology and WMA technology, both with and without RAP.

In order to gain a better understanding of the influence of chemical modified WMA and the use of RAP, three mixtures were tested in the laboratory. These three mixtures included a standard HMA mixture, along with HMA with 25% RAP and a chemically modified WMA with 25% RAP. Aggregate and asphalt binder from Hebei province in China was used for this research. Performance testing of the three mixtures included the Semi-Circular Bend [SC (B)] fracture test and dynamic modulus testing in an attempt to better understand the potential cracking and rutting characteristics of the mixtures. These performance tests were run on the three mixtures at three levels of aging and moisture conditioned and unconditioned samples. This allowed for a full understanding of the influence of laboratory aging and moisture conditioning of

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http://dx.doi.org/10.1016/j.conbuildmat.2016.04.063
0950-0618/

the three mixtures. In addition, an analysis of compactability of the three mixtures was executed. Quantification of compactability included the number of gyrations to 92% G_{mm}, the Construction Force Index, the Construction Densification Index, and the Normalized Shear Index.

2. Objective

This paper investigated the effects of chemical modified WMA and the application of RAP on laboratory performance (cracking and rutting) and compactability, considering aging and moisture conditioning.

3. Material

Three types of mixtures were utilized in this study: HMA without RAP (HMA), HMA with 25% RAP (HR), and WMA with 25% RAP (WR). Hebei province provided both the raw materials and an HMA mix design for this research. The RAP came from a series of overlays placed in 2006 on existing highways constructed in 1997. Therefore, it was estimated that RAP was approximately seven years old at the time of milling. In order to include 25% RAP in the HR and WR mixtures, the provided HMA mix design had to be slightly modified. To begin with, the gradation was kept as close as possible to reduce conflicting variables when comparing the three mixtures. The gradation for the HR and WR mixtures was achieved by minimizing the sum of square errors (SSE, errors between HMA and HR/WR blend for each size). Each aggregate size gradation, and final blends, are shown in Table 1. In order to adjust the optimal asphalt binder content to accommodate the 25% RAP, the same air voids at N_{max} in the Superpave Gyratory Compactor was targeted to match the HMA, HR, and WR mixtures. While this is not as accurate as a complete mix design to determine the optimal asphalt binder content, due to limited materials available, this was deemed the best path forward.

The asphalt binder used in this study was SBS modified PG76-22 binder. The optimal asphalt binder content for the HMA was 4.31%, HR was 4.55%, and WR was 4.09%. The chemical warm mix added was stirred in mechanically at 0.5% by weight of binder. The RAP utilized in this study was unprocessed RAP shipped from Hebei Province. After solvent extraction, the PG grade of the binder in the RAP was determined to be a PG70-22, and the binder content in the RAP was determined to be 4.41% by taking the average of ignition oven and solvent extraction test. The PG grade of the RAP was unexpected, as the RAP binder was in fact softer than the virgin binder, which is unusual. This indicates that the RAP may have come from a project with very soft binder or a pavement that was not exposed to significant aging (i.e. oxidation). Alternatively, the RAP may have come from lower pavement layers that were not exposure to the weathering that is generally encountered at the higher pavement layers. The total binder content for WR and HR incorporated the asphalt binder from the RAP into the optimal asphalt binder content used in the samples fabricated in the laboratory.

Since the RAP received was unprocessed, a laboratory processing procedure needed to be established. At this point, aggregate producers and contractors do not have large stockpiles of existing RAP, and RAP is used on a case-by-case basis. Therefore, a procedure for processing RAP in the laboratory needed to be developed. The raw RAP was processed in the following steps:

1. Dry RAP in a 60 °C forced draft oven,
2. Freeze the RAP in a zip plastic bag to stiffen the aggregate and asphalt binder,
3. Crush the RAP by utilizing a jaw crusher,
4. Freeze the RAP in a zip plastic bag, and
5. Sieve the RAP for batching.

The freezing was critical in both the crushing and sieving stages, as if the RAP was not fully elastic, the asphalt binder would accumulate on the jaws of the crusher and on the sieves, clogging each and preventing proper reduction of size and sieving.

4. Test methods

For evaluation of the HMA, HR, and WR mixtures, two performance tests were used: the Semi-Circular Bend [SC(B)] test and the dynamic modulus. In addition to the performance testing, two factors were considered: moisture conditioning and laboratory aging. Two levels of moisture conditioning (conditioned and unconditioned) and three levels of aging (unaged, short term, and long term) were explored.

The moisture conditioning procedure followed the AASHTO T283 specification [8]. Unconditioned samples were fabricated and tested with no temperature or moisture conditioning. The conditioning procedure can be described briefly in three steps: vacuum saturating, freezing, and thawing.

Both the SC(B) sample and dynamic modulus sample were conditioned after they were cut. While this exposed cut aggregates directly to the moisture conditioning process, it can be very difficult to cut samples after the conditioning procedure, and many samples would potentially be lost due to fabrication issues.

Along with moisture conditioning, aging was the second factor that was considered in the experimental matrix. AASHTO R30 was followed to age the samples for testing [9]. Three levels of this factor were considered: unaged, short term aged, and long term aged. These levels can be described as:

- Unaged: uncompacted samples were exposed to the "standard" aging time of 2 h at compaction temperature before compaction as specified in the Superpave mix design procedure. The samples were stirred at 1 h.
- Short term aged: uncompacted samples were aged for 4 h at compaction temperature and were stirred at 1, 2, and 3 h.
- Long term aged: samples were run through the short term aging protocol first and compacted. After compaction, the sample was placed at room temperature for 16 h, and then aged in an oven at 85 ± 3 °C for 120 h (5 days).

4.1. Semi-Circular Bend test [SC(B)]

The Semi-Circular Bend test, or SC(B), has been successfully applied to investigate the fracture resistance of HMA [10,11]. Although the stress states in a SC(B) test are complicated, it is easy to obtain SC(B) samples from field core and gyratory compacted samples. In addition, this test utilizes a three point bending load configuration, which is easy to execute in a standard laboratory load frame [12]. All testing in this research followed an

Table 1
Aggregate and blend gradations.

	Aggregates							
Size Blend percentage (%)	10–15 mm 21	5–10 mm 23	3–5 mm 5	0–3 mm 22	Fines 4	RAP 25	HR/WR blend	HMA blend
16	100	100	100	100	100	100.0	100.0	100.0
13.2	82.3	100	100	100	100	99.9	96.3	95.9
9.5	8.4	98.2	100	100	100	93.2	78.7	78.4
4.75	0.7	4.4	95.4	100	100	60.9	47.1	47.2
2.36	0.6	0.9	8.3	88.8	100	41.6	34.7	35.3
1.18	0	0.8	0.9	49.4	100	28.6	22.3	21.3
0.6	0	0	0.4	29.2	100	19.4	15.3	14.4
0.3	0	0	0.3	15.8	99.9	11.5	10.4	9.8
0.15	0	0	0	10.2	96.7	4.8	7.3	7.8
0.075	0	0	0	8.8	89.7	2.2	6.1	7