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Systematic Evaluation of the Field Constructability and Performance of Asphalt Mixtures Containing High Percentages of Recycled Asphalt †

Logan Cantrell [1] and Haifang Wen [2,*]

[1] Granite Construction, Olympia, WA 98512, USA; logan.cantrell@gcinc.com
[2] Washington Center for Asphalt Technology, Department of Civil and Environmental Engineering, Washington State University, Pullman, WA 99164, USA
* Correspondence: haifang_wen@wsu.edu
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Abstract: This study evaluates the use of high amounts of recycled asphalt pavement (RAP) and recycled asphalt shingle (RAS) in asphalt mixes for sustainable construction. While past research has focused on asphalt binders and laboratory performance testing, this study assesses the effect of high recycle content on constructability and long-term field performance. A total of 72 mix designs placed from 2016 to 2020 were evaluated for compaction characteristics, while the rutting, cracking, and roughness of 16 projects placed from 2011 to 2015 were assessed based on recycled asphalt levels and mix components. Results showed that high recycled mix projects had equivalent compaction characteristics to low RAP mix projects, except that high RAP mixes had lower variability. High RAP/RAS mixes with rejuvenators had a higher density than those without, and high recycled mix projects had comparable field performance to that of low RAP mix projects, except for lower longitudinal cracking in high RAP projects.

Keywords: high RAP; compaction; density; field performance; cracking

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1. Introduction

The constructability characteristics of asphalt mixes, such as compactability and consistency during production and construction, are crucial for the pavement's overall performance. Compaction reduces air voids and provides interlocking of aggregates, affecting the pavement's resistance to rutting, cracking, and moisture. Higher field density leads to better results and extended service life [1]. The compaction of mixes depends on various factors such as aggregate, recycled asphalt pavement (RAP), recycled asphalt shingle (RAS), binder characteristics, and field conditions. Compaction has been identified as the most important construction factor for long-term serviceability [1]. Individual mix properties influence a mixes compaction in different ways [2]. Incorporating high RAP with and without a rejuvenator was reported to produce similar density results to a conventional mix based on test section construction [3]. It has been suggested high RAP mixtures may require more attention due to increased stiffness because of the RAP [4].

After compaction, the pavement's long-term performance is evaluated for rutting and cracking; the main structural distresses of concern. RAP improves rutting resistance, while the aging and stiffening of asphalt increase the cracking potential [5]. Few studies have evaluated the long-term field performance of RAP mixes [4]. Study results varied, with all studies showing similar or decreased rutting and roughness, while some showed increased cracking risk depending on the section [5–7]. Overall, the associated risk of increased cracking with the addition of RAP is concerning.

Superior field performance of asphalt materials is the ultimate goal for which all laboratory testing and pavement design considerations strive. As the use of highly recycled mixes increases, the need to understand its effects on field constructability and performance is imperative. This study compared compaction and performance between high-recycled and low-recycled mixes based on field data.

2. Materials and Methods

Seventy-two mix designs from Washington State Department of Transportation (WSDOT) paving projects performed from the 2016 to 2020 construction seasons were obtained from the WSDOT SAM and analyzed for compaction attributes [8]. These results represent one contractor's mix designs from 13 asphalt plants because only one contractor had been using highly recycled mixes for WSDOT. Three recycle levels were evaluated in this study, including low recycled (LR), high RAP (HR), and super RAP (SR). LR mixes were produced with 0–20% RAP, HR at >20% RAP (maximum 40% binder replacement), and SR used the combination of RAP and RAS (maximum 20% binder replacement from RAS, 40% for the combination). HR and SR mixes analyzed together are referred to as high RAP/RAS (HRR). Overall, 6 SR, 34 HR, and 32 LR mixes were produced from 2016 to 2020, with 48% 1/2″ nominal maximum aggregate size (NMAS) mixes and 52% 3/8″ NMAS mixes.

Sixteen mix designs (6 LR and 10 HR) placed on WSDOT projects from 2011 to 2015 were analyzed for field performance attributes and obtained from the WSPMS [9]. These projects were evaluated for rutting, roughness, and cracking characteristics which are used to determine maintenance and rehabilitation decisions [10]. The selected LR and HR projects have at least four years since placement to potentially have cracking issues, with HR data only existing since 2013. Note that SR mixes were not included, as RAS was not allowed by WSDOT until 2016 [11]. Rutting and IRI metrics had continuous data every year, and non-zero starting points were displayed as an increase per year since construction. Cracking results were not continuous and thus were displayed only as the maximum cracking for that section.

3. Results and Discussion

The constructability characteristics of the 72 mixes were evaluated from WSDOT testing results. The field density, standard deviation, and composite pay factor (CPF) results were first compared between LR and HRR projects. Then, a two-sample *t*-test was conducted to determine if the mean difference was statistically significant. For field density, the *t*-test results indicate no statistical difference in the mean density and CPF between LR and HRR mixes, with *p*-values of 0.94 and 0.36, respectively. However, the *t*-test results for the standard deviation of field density indicate that HRR mixes had a statistically lower standard deviation by 0.24 than the LR mixes, with a *p*-value of 0.033. The lower standard deviation of HRR mixes indicates that HRR has better compactability in terms of consistency, contributing to more consistent performance.

The HRR results were then split into HR and SR categories for further evaluation, as shown in Figure 1. SR mixes showed a higher average density (93.9) than that HR (93.1) and LR (93.3) mixes. Analysis of variance analysis (ANOVA) was conducted on the three combinations for density, standard deviation, and CPF returning a *p*-value of 0.13 for density, 0.004 for standard deviation, and 0.62 for CPF. These results indicate no statistical difference in the density and CPF for LR, HR, and SR mixes. The standard deviation showed a statistical difference between the groups, and based on the Tukey post hoc test, the HR mixes had statistically lower standard deviation than both the SR and LR, with *p*-values of 0.035 and 0.014, respectively. HR standard deviation was lower than SR by 0.50 and LR by 0.32, respectively. No statistical difference in standard deviation was found between LR and SR mixes. These results contradict the presumption that a larger variability may be expected when a high percentage of recycled asphalt is included.

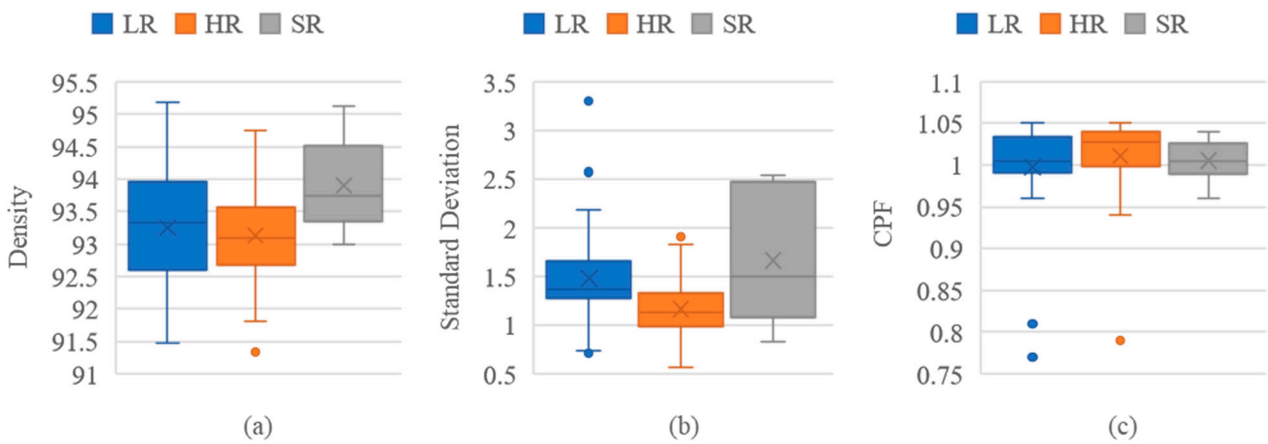

Figure 1. Comparison between LR, HR, and SR for (**a**) Density, (**b**) Standard Deviation, and (**c**) CPF.

Some mix properties, or construction factors, were analyzed to determine the causes of the difference in the compactability of the above mixes. The statistical analysis results show that the factors having significance are rejuvenator use on HRR densities, as well as gradation and the number of density lots on CPF. HRR mixes using a rejuvenator averaged a 0.6% higher density than non-rejuvenated mixes. This indicates that the rejuvenator may be more effective in softening the aged binder in HRR mixes than using a softer virgin binder alone. The rejuvenator could either physically soften the aged binder via mechanical blending and/or chemically dissolve large oxidized molecules. The fact that rejuvenator is more effective than softer virgin binder alone indicates these aged binders were likely chemically dissolved by the rejuvenator. Additionally, since coarse and fine gradations are defined differently for each NMAS based on the percent passing #8 sieve, 3/8″ and 1/2″ NMAS mixes were analyzed individually. The results showed that while 3/8″ NMAS mixes showed no statistical difference in the standard deviation of density, coarse 1/2″ mixes had, on average, 0.4 lower standard deviations than 1/2″ fine mixes with a *p*-value of 0.003.

The field performance of the 16 projects was evaluated in terms of rutting, IRI, transverse cracking, and longitudinal cracking. The mean values of performance results of HR and LR projects, along with the *p*-values of the two-sample t-tests for each performance metric evaluated, are shown in Table 1. Note that no SR mixes were used in these 16 projects. The average first crack year was 3.5 for LR and 4.0 for HR but showed no statistical difference with a *p*-value of 0.17. The only metric showing significant differences were the percent of longitudinal cracking being lower for HR than LR mixes. One possibility is that the HR mixes are oxidizing slower and therefore are less brittle as they age, possibly due to already having an aged binder included or the softer virgin binder aging at a lower rate. Further study is needed to test these theories to determine why cracking performance varies from LR to HR.

Table 1. Significance of RAP on Field Performance.

Performance Metric	LR	HR	*p*-Value
Rutting/year (in)	0.02	0.02	0.42
IRI/year (in/mi)	1.11	1.20	0.43
Transverse Cracking (count/100ft)	3.00	3.96	0.22
Longitudinal Cracking (% of section)	13.02	4.56	*0.001*

4. Conclusions

As recycled material usage increases, the performance of highly recycled mixes in the field becomes more critical. Most studies on performance involved durability in the laboratory. Few studies addressed the field constructability and field performance of highly recycled mixes. In this study, the constructability of HR, LR, and SR mixes was evaluated, and mix properties were evaluated to explain why differences may exist. The field performance of LR and HR projects was compared. It was found:

1. Overall, the compactability of HRR mixes was similar to or better than typical LR mixes. There was no statistical difference between HRR mixes and LR mixes in density means.
2. HR mixes showed a lower standard deviation than LR and SR mixes. For the 1/2″ NMAS mix, fine-graded mixes showed a higher standard deviation than coarse-graded mixes. Second, HR mixes had lower asphalt contents than LR mixes statistically. In combination, having lower asphalt content (statistically insignificant, though) and coarser mixes appear to be giving these HR mixes lower potential mix tenderness, leading to lower standard deviation.
3. HRR mixes that used a rejuvenator were shown to have increased density results significantly over those HRR mixes that used softer virgin binders only without a rejuvenator. It is believed the rejuvenator may facilitate the compaction by chemically dissolving the highly oxidized asphalt molecules.
4. The use of a rejuvenator significantly increases densities in HRR mixes. The air voids were significantly lower for SR mixes, potentially increasing compactability.
5. There is no statistical difference in rutting, IRI, or transverse cracking performance between LR and HR projects, showing similar rates of change. However, the longitudinal cracking of HR mixes was statistically lower than that of LR mixes, with HR having less than half the cracking of the LR section.

Further studies are needed to verify the findings in this study by incorporating larger populations of data that cover different geographies, climates, material sources, etc.

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