Athens Journal of Sciences - Volume 13, Issue 2, June 2026 – Pages 99-110

Use of Polymer Fiber to Improve Resistance to Rutting and Stripping for HMA with RAP

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A great percentage of highways and roads in California are constructed with Hot Mix Asphalt (HMA) and, as California infrastructure ages, these highways and roads must be maintained and rehabilitated. Reclaimed Asphalt Pavement (RAP) is considered an excellent alternative to virgin (raw, unprocessed) materials because it reduces the use of virgin aggregate and binder. Also, the use of RAP decreases the amount of construction waste placed into landfills. This laboratory study investigated the effect of two different polymer fibers on the mechanical properties of HMA with RAP. Three different HMA with RAP mixes were used in the study. One mix that is commonly utilized on the Central Coast of California contained 15% RAP while the second and third mixes contained 25% and 40% RAP. Three different fiber dosages (0.05%, 0.10% and 0.15% of the total mix) were investigated. Specimens were prepared and tested for rutting and moisture sensitivity using Hamburg Wheel Tracker (HWT). Test results showed that adding fibers improved resistance to rutting for mixes with RAP content higher than 25%. Also, adding fibers improved mixes resistance to moisture damage. In addition, one of the two fibers used in the study outperformed the other. Overall, results indicate that adding polymer fibers to HMA mixes containing RAP has the potential to improve mixes resistance to rutting and moisture damage depending on fiber dosage and type. This study offers information valuable to the maintenance and rehabilitation of roads and highways.

Keywords: *Polymer Fiber, HMA, Rutting Resistance, High RAP, Stripping*

Introduction

Continuous road and highway construction is creating a scarcity on the limited source of natural aggregates. To conserve these non-renewable resources, reclaimed asphalt pavement (RAP) is being used in hot mix asphalt (HMA) at a small percentage all over the United States (Sabahfar et al., 2016). The source of RAP has more impact on the cracking performance of HMA than the quantity of RAP (Sabahfar et al., 2016). One of the methods of performance improvement of HMA

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https://doi.org/10.30958/ajs.13-2-1 doi=10.30958/ajs.13-2-1

is to modify the asphalt binder. Among several modification methods, fiber modification of asphalt binder has gained great attention to researchers. However, the choice of fiber type is not limited.

Corn and cotton straw fibers were used in the study of Wang et al. (2023) and the effect of fiber types on the performance of asphalt binder were investigated. Asghar and Khattak (2022) investigated the impact of different aggregate gradations on the fracture characteristics of Polyvinyl Alcohol (PVA) fiber modified HMA. Carbon Nano-fiber (CNF) modified HMA mixtures show significant improvement in terms of fatigue life and resistance to permanent performance. However, CNF modification does not affect the toughness characteristics and indirect tensile strength (Khattak et al., 2013).

Behnia et al. (2023) investigated the low temperature cracking behavior of aramid fiber (a kind of organic polymer) modified asphalt mixtures. Klinsky et al. (2018) used a mixture of polypropylene and aramid fibers to modify dense graded HMA and compared the mechanical characteristics with a control mix with no fiber. The results showed that fiber modified HMA can perform better in terms of rutting resistance and fatigue cracking resistance, but in terms of moisture resistance fiber modified HMA showed similar result to conventional HMA.

Khan et al. (2023) compared four types of fiber - carbon, fiberglass, basalt, and polyolefin/aramid (PFA) mix using two different binder grades, PG 58–28 unmodified and PG 76–22 polymer modified binder.

The research of Calabi-Floody et al. (2022) indicated polymer fibers processed from End-of-Life Tyres (ELT) can significantly improve mechanical performance of HMA.

Ceramic fiber can be another potential modifier for asphalt binder. Arabani and Shabani (2019) modified binder with 1%, 3%, and 5% of ceramic fibers content and investigated the effect of modification on both binder and mixture level. The tests concluded that ceramic fiber modification has a positive effect on high temperature rutting resistance, but negative impact on low temperature cracking resistance. The study also concluded the optimum ceramic fiber content to be 3%.

Waste paper fiber, which is a cellulose base fiber, can also be used for fiber modification. The study of Hameed et al. (2021) concluded that incorporation of waste paper fiber up to 0.7% can decrease penetration by 45% and increase softening point by 27%.

In general, regardless of the fiber type, use of fibers require higher optimum binder content as the light components of binder are absorbed by the fiber (Slebi-Acevedo et al., 2019). Again, all fibers can have a positive impact on the mechanical properties of asphalt mixtures when used at their optimum content.

Very little information is available in the literature on the effect of fiber modification along with RAP incorporation. Therefore, evaluation of fiber reinforcement in HMA that contains high percentage of RAP is recommended. Should the addition of polymer fiber proves successful in improving the performance of HMA with high RAP contents, it will help in preserving the natural resources for future generations.

Objective

The primary objective of this study is to investigate the effect of two different types of polymer fibers on the resistance to rutting and moisture damage of HMA containing various RAP percentages, specifically 15%, 25%, and 40%. The outcome of this study will help pinpoint the most effective fiber type and dosage for various RAP contents.

Methods

Materials

This study investigated three distinct HMA mixtures, each incorporating a different percentage of RAP. The first mixture contained 15% RAP utilizing a PG 64-10 asphalt binder with an optimum binder content of 5.6% by mix total weight was supplied by CalPortland. The second and third mixtures contained 25% and 40% RAP utilizing a PG 58-22 asphalt binder and were supplied by Granite Construction. As per the provided JMFs, the 25% RAP mix had an optimum binder content of 4.8%, whereas the 40% RAP mix was formulated with a slightly higher optimum binder content of 5.2%.

Detailed aggregate gradations employed in these mixes are summarized and presented in Table 1.

Table 1. *Gradation of combined Aggregate Blend for the Mixtures used in the Study*

Sieve Size	15% RAP (% Passing)	25% RAP (% Passing)	40% RAP (% Passing)
1 in	100	100	100
¾ in	100	98	98
½ in	97	83	82
⅜ in	83	74	73
#4	51	52	51
#8	38	33	32
#16	27	22	22
#30	18	15	16
#50	11	10	11
#100	6	6	8
#200	3.3	4.3	5.5

Two types of polymer fibers, that are commercially available were investigated. As shown in Figure 1**,** Fiber A was a wax-coated para-aramid fiber (maximum 37% by weight) and Fiber B was a para-aramid fiber treated with a liquid emulsion binder (maximum 25% by weight), both of which were manufactured by Surface Tech. These fibers were added to the HMA mixtures at three different dosages: 0.05%, 0.10%, and 0.15% of the total HMA weight. Control mixtures, without any fiber addition, were also prepared for each RAP content to serve as a baseline. It is noted that the 40% RAP mixture was only tested for Fiber Type-B.

Figure 1. *Fibers used for the Study: Aramid fiber Type A (left) and Type B (right)*

The naming for the samples in this study includes the RAP content, fiber type, and fiber dosage. For example, "15-A0.10" indicates a mix with 15% RAP with Fiber A, and 0.10% fiber content. Control samples are labelled with a "C", such as "25-C", representing a mix with 25% RAP and no fiber.

Specimen Preparation

For the HWT test, cylindrical specimens with a diameter of 150 mm and a thickness of 60 mm ± 1 mm were prepared. Samples were molded to have their air void content within 7.0% ± 0.5%. The specimen preparation involved several key steps. First, all aggregates were dried to a constant weight. Then, aggregates were batched according to the JMF. The batched aggregates, including RAP, and asphalt binder were heated to the specified mixing temperature, which varied based on the PG binder grade. Heated aggregates were introduced into a mechanical mixer.

The binder and, for modified mixes, the fiber additives were then added and mixed until all particles were uniformly coated. The loose HMA mixture was subjected to short-term aging(conditioning) for two hours to simulate aging during plant production and hauling. Finally, the conditioned mixture was compacted in the Superpave gyratory compactor to the target air void level in accordance with AASHTO T 312.

Results and Discussion

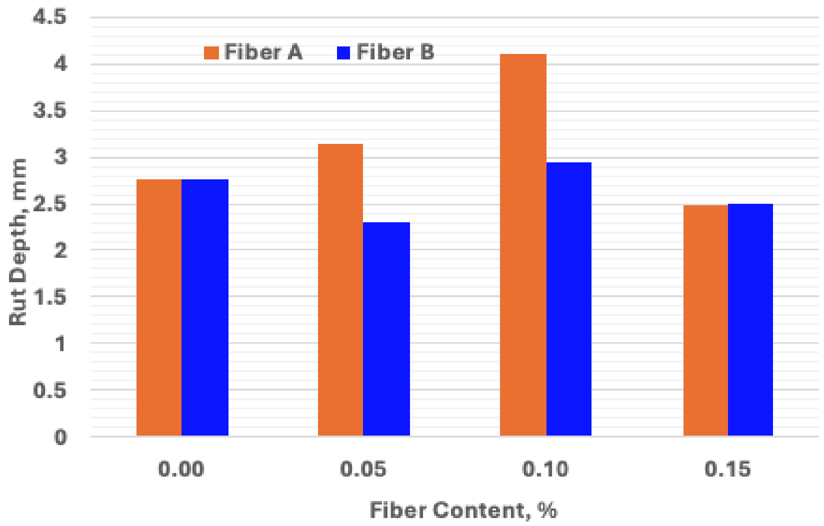
The HWT test was performed on all HMA mixtures to evaluate rutting and stripping resistance and detailed numerical data and analysis for the different mixtures used in the study are presented in the subsequent sections.

Mixtures with 15% RAP

Resistance to Rutting

Two fiber types (A and B) were added in three different percentages to HMA mix containing 15% RAP. Figure 2 presents the average rut depth measured after 15,000 passes. Fiber B at 0.05% and 0.15% slightly improved resistance to rutting compared to the control mix. Also, rut depth for mixes with fiber B performed better than mixes with fiber A at fiber percentages lower than 0.15%. However, fiber A had a negative effect on rutting resistance for HMA with 15% RAP.

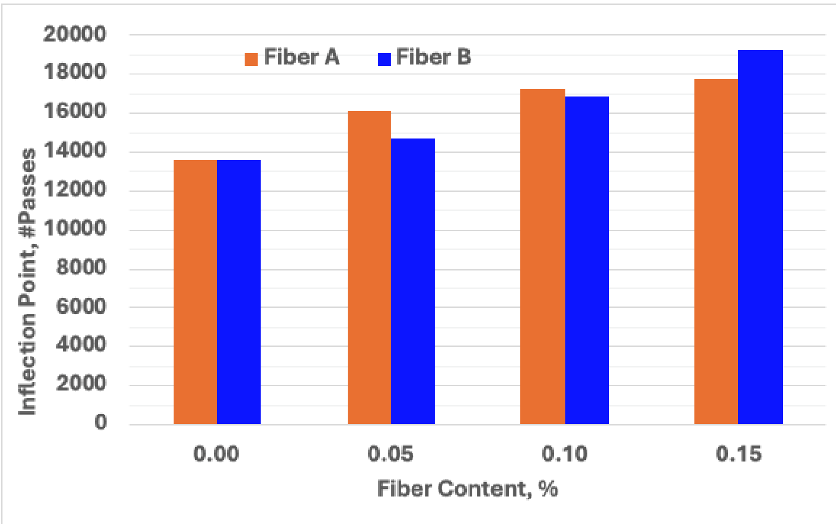
Figure 2. *Effect of Fiber Type and Content on Rut Depth for HMA with 15% RAP*



<u>Resistance to Stripping</u>

Inflection points can be used to evaluate stripping potential. If the stripping inflection point occurs at a low number of load cycles (e.g., less than 10,000), the HMA mixture may be susceptible to stripping. Figure 3 presents the average number of passes at inflection point for HMA mix containing 15% RAP and different fiber types and contents. Results showed that adding both types of fibers resulted in an increase in the number of passes before reaching the inflection, an indication of improved resistance to stripping. All mixes, including the control mix, resulted in number of passes higher than the 10,000-threshold.

Figure 3. *Effect of Fiber Type and Content on Inflection Point for Mixes with 15% RAP*

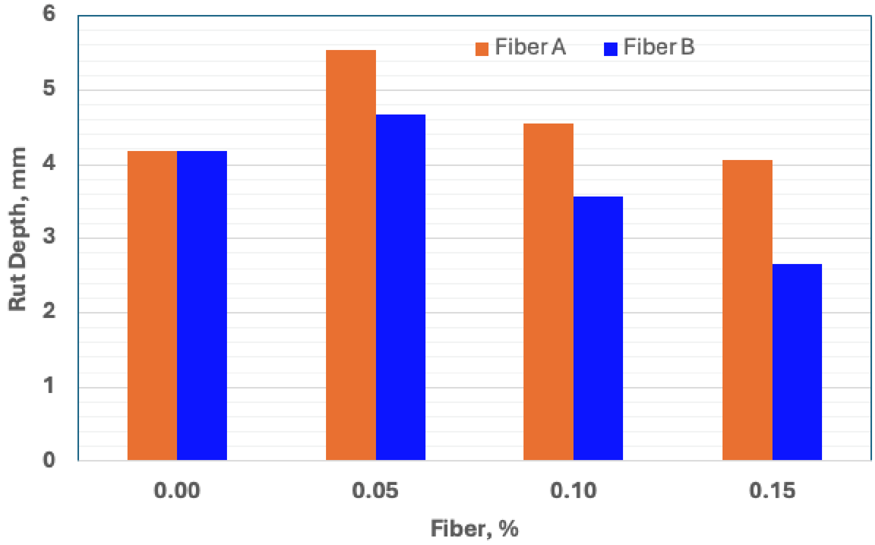


HMA with 25% RAP

Resistance to Rutting

Figure 4 presents the average rut depth measured after 15,000 passes. Fiber B at 0.10% and 0.15% slightly improved resistance to rutting. However, fiber A had a negative effect of rutting resistance for HMA with 25% RAP. Also, as was observed for HMA with 15% RAP, mixes containing fiber B outperformed those containing fiber A.

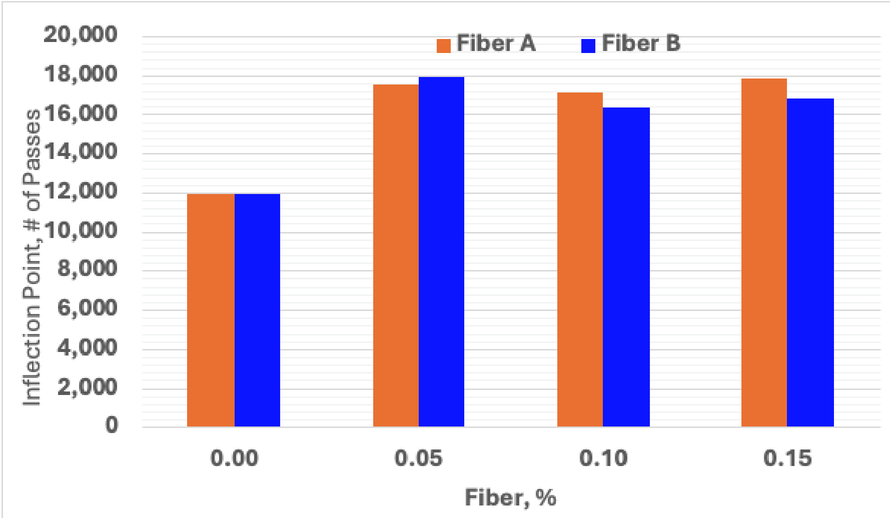
Figure 4. *Effect of Fiber Type and Content on Rut Depth for HMA with 25% RAP*



Resistance to Stripping

Figure 5 resents the average number of passes at the inflection point for HMA mix containing 25% RAP and different fiber types and contents. Results showed that adding both types of fibers resulted in an increase in the number of passes before reaching the inflection point, an indication of improved resistance to stripping. However, both fiber types performed almost equally for HMA with 25% RAP content. All mixes, including the control mix, resulted in number of passed higher than the 10,000-threshold.

Figure 5. *Effect of Fiber Type and Content on Inflection Point for Mixes with 25% RAP*



ANOVA Analysis

An Analysis of Variance (ANOVA) was conducted using statistical analysis software Minitab. The response variables that were investigated were limited to rut depth at 15,000 passes and number of passes at the inflection point.

<u>Rut Depth for Fiber A vs Fiber B</u>

To compare the performance of Fiber A versus Fiber B, the 15% and 25% RAP data were combined and sorted into two groups. Results from ANOVA analysis showed fiber B group had a lower mean rut depth at 15,000 passes than fiber A, as seen in Table 2. The difference between the means is statistically significant at the 95% confidence level (see Table 2).

Table 2. *Mean Rut Depth at 15,000 Passes for the Fiber A and B Groups*

Fiber Type	**Mean Rut Depth at 15,000 Passes (mm)**
A	3.98
B	3.10

Table 3. *Differences in Mean Rut Depths at 15,000 Passes and Confidence Intervals for Fiber A and B Groups*

Difference of Means (mm)	**SE of Difference (mm)**	***t***	**Adjusted *p*-value**
0.88	0.39	2.24	0.03

<u>Inflection Point for Fiber A vs Fiber B</u>

Fiber A had a greater mean number of passes at the inflection point than fiber B, as shown in Table 4. However, the results are not statistically significant at the 95% confidence level, as shown in Table 5. However, the results are statistically significant at a 90% confidence level.

Table 4. *Mean Number of Passes at the Inflection Point for Fiber A and B Groups*

Fiber Type	Mean Rut Depth at 15,000 Passes (mm)
A	16,815
B	14,788

Table 5. *Differences in Mean Number of Passes at the Inflection Point and Confidence Intervals for Fiber A and B Groups*

Difference of Means (mm)	SE of Difference (mm)	*t*	Adjusted *p*-value
2,027	1,274	1.59	0.10

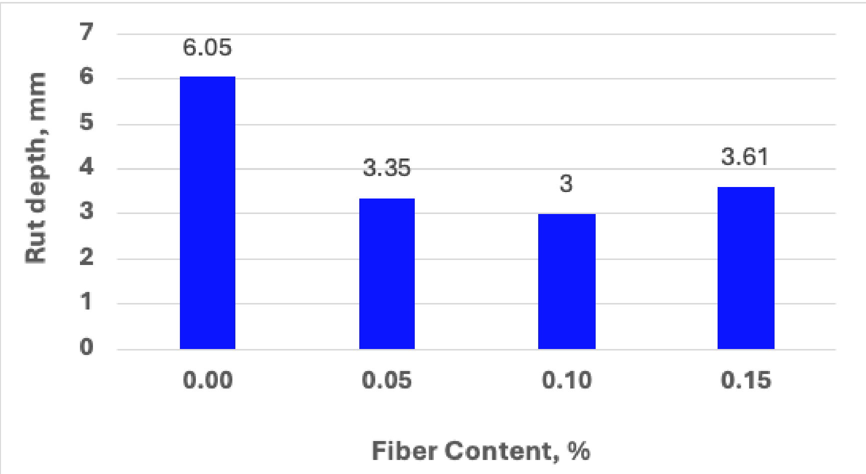
HMA with 40% RAP

Results for mixes with 15% and 25% RAP indicated that fiber type B outperformed mixes with fiber type A. Therefore, only fiber type B was used in HMA with high RAP percentage of 40%.

Resistance to Rutting

Figure 6 presents the rut depth at 15,000 passes for HMA with 40% RAP using fiber type B added at the same dosages previously used in (i) HMA with 15% and (ii) HMA with 25% RAP. As seen in Figure fiber type B significantly improved resistance to rutting in mix that contain high RAP content. The figure also shows that fiber content of 0.1% resulted in the best resistance to rutting.

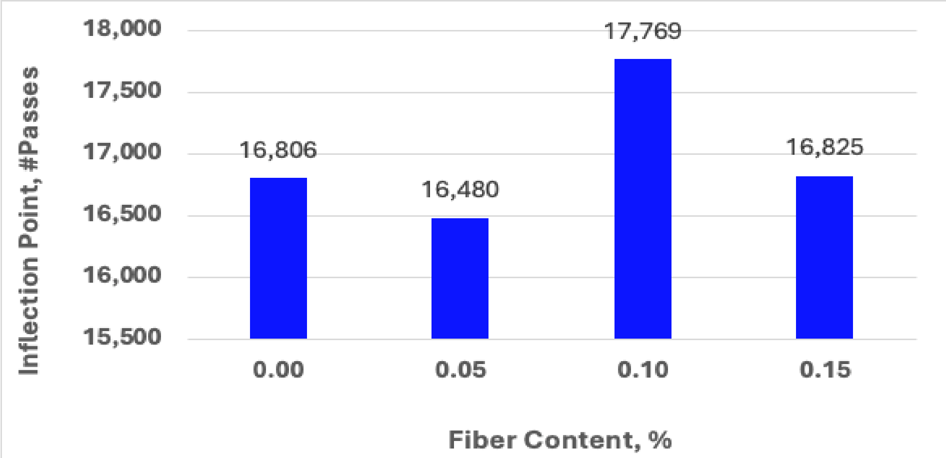
Figure 6. *Effect of Fiber B on Rut Depth for Mixes with 40% RAP*



Resistance to Stripping

Figure 7 presents the average number of passes at the inflection point for HMA mixes containing 40% RAP and different fiber types and contents. Results show that adding fiber B at 0.10% resulted in the highest number of passes at inflection point. However, fiber B contents of 0.05% and 0.15% resulted in approximately the same number of passes as the control mix. It is noteworthy to mention that all mixes resulted in numbers of passes significantly higher than the 10,000 passes threshold and higher than the 15% and 25% RAP mixes.

Figure 7. *Effect of Fiber B on Inflection Point for Mixes with 40% RAP*



Within the 40% RAP group, there was a significant benefit to adding fiber B to the mix. Adding fiber B at 0.05%, 0.10%, and 0.15% had significantly lower mean rut depths than the control group at 15,000 passes. Table 6 shows the mean rut depths at 15,000 passes for each group, and Table 7 shows the difference in means and confidence intervals between each fiber percentage and the control group within the 40% RAP group.

Table 6. *Mean Rut Depth for the 40% RAP-Fiber B Groups*

Group	Rut depth (mm) @ 15,000 passes
40% RAP Control	6.05
40% RAP with 0.05% Fiber B	3.61
40% RAP with 0.10% Fiber B	3.35
40% RAP with 0.15% Fiber B	3.00

Table 7. *Differences in Mean Rut Depth and Confidence Intervals for 40% RAP-Fiber B Groups*

Group Comparison	Difference in Means (mm)	SE of Difference (passes)	*t*	Adjusted *p*-value	Significance?	95% Confidence Interval
0.05% B – Control	-2.71	0.86	-3.15	0.04	Yes	(-5.26, -0.16)
0.10% B – Control	-3.05	0.86	-3.55	0.02	Yes	(-5.60, -0.50)
0.15% B – Control	-2.44	0.86	-2.84	0.05	Yes	(-5.00, -0.11)

The results were mixed for the effects of fiber on the mean number of passes at the inflection point for the 40% RAP group. The results show that 0.10% fiber B performed slightly better than the control group, while the 0.05% fiber B group performed slightly worse and the 0.15% fiber B group performed significantly worse than the control group. Therefore, there is 95% confidence that adding 0.15% fiber B to the mixture would result in a mean number of passes at the inflection point that is between 8,631 and 17,437 passes lower than the control group. Table 8 shows the mean number of passes at the inflection point for each group, and Table 9 shows the difference in means and confidence intervals between each fiber percentage and the control group within the 40% RAP group.

Table 8. *Mean Number of Passes at the Inflection Point for the 40% RAP-Fiber B Groups*

Group	# of Passes at the Inflection Point
40% RAP Control	16,806
40% RAP with 0.05% Fiber B	16,479
40% RAP with 0.10% Fiber B	17,770
40% RAP with 0.15% Fiber B	3,772

Table 9. *Differences in Mean Number of Passes at the Inflection Point and Confidence Intervals for 40% RAP-Fiber B Groups*

Group Comparison	Difference in Means (passes)	SE of Difference (passes)	*t*	Adjusted *p*-value	Significance?	95% Confidence Interval
0.05% B – Control	-327	1,318	-0.25	0.99	No	(-4446, 3791)
0.10% B – Control	964	1,409	0.68	0.90	No	(-3439, 5366)
0.15% B – Control	-13,034	1,409	-9.25	<0.01	Yes	(-17437, 8631)

Conclusion

This study evaluated the use of two types of commercially available polymer fiber to improve the resistance of HMA that contains RAP at different percentages against rutting deformation and cracking at intermediate temperatures. Using three JMFs that were provided by two pavement construction companies, specimens were prepared for testing in the HWT. Based on the statistical and other analysis of results in this study, the following conclusions can be made:

- In general, fiber type B (treated with liquid emulsion) outperformed fiber type A (wax coated) in enhancing HMA resistance to rutting.

- For mixes with 15% RAP adding fibers (regardless of the type) did not seem to improve resistance to rutting as compared with control mix. However, when increasing RAP content to 25% and 40%, fiber type B enhanced mixture's resistance to rutting.
- For mixes with high RAP content (40%), fiber type B significantly improved resistance to rutting and stripping. Also, fiber B at 0.1% dosage resulted in the best performance as compared to 0.05% and 0.15% dosages.
- Both types of fibers (A and B) enhanced the mixture's resistance to stripping, yielding higher numbers of passes at the stripping inflection point than the control mix.
- More laboratory investigation for mixes with RAP contents of 50% and above is recommended.
- Development of case studies to evaluate the performance of these additives in the field would further benefit asphalt pavement research.
- It is recommended to conduct a life cycle cost analysis as field performance data for these mixes become available.

Acknowledgment

This research was funded by the Mineta Transportation Institute (MTI). The authors thank Lisa Rose/Editing Press for editorial services, as well as MTI staff Project Assistant Cameron Simon and Graphic Design Assistant Katerina Earnest. The authors also thank Mr. Robert Patterson of CalPortland and Ms. Corina Wong of Granit Construction for providing the research team with the mix design formula, the aggregates and asphalt binder used throughout the experimental program. The research team is very grateful to Caltrans District 5 for allowing the use of their laboratory equipment to saw-cut all specimens used in the Hamburg Wheel Tracker.

References

Arabani M, Shabani A (2019) Evaluation of the ceramic fiber modified asphalt binder. *Construction and Building Materials*, *205*, 377–386. https://doi.org/10.1016/j.conbuildmat.2019.02.037

Asghar MF, Khattak MJ (2022) Evaluation of mixture design and tensile characteristics of polyvinyl alcohol (PVA)–Fiber reinforced HMA mixtures. *International Journal of Pavement Research and Technology*. https://doi.org/10.1007/s42947-022-00233-3

Behnia B, Askarinejad P, LaRussa-Trott N (2023) Investigating Low-Temperature cracking behavior of Fiber-Reinforced asphalt concrete materials. *International Journal of Pavement Research and Technology*. https://doi.org/10.1007/s42947-022-00271-x

Calabi-Floody A, Mignolet-Garrido C, Valdés-Vidal G (2022) Study of the Effect of the Use of Asphalt Binders Modified with Polymer Fibres from End-of-Life Tyres (ELT) on the Mechanical Properties of Hot Mix Asphalt at Different Operating Temperatures. *Materials*, *15*(21), 7578. https://doi.org/10.3390/ma15217578

Hameed A, Al-Busaltan S, Dulaimi A, Kadhim MA, Al-Yasari R (2021) Evaluating modified asphalt binder comprising waste paper fiber and recycled Low-Density polyethylene. *Journal of Physics*, *1973*(1), 012237. https://doi.org/10.1088/1742-6596/1973/1/012237

Khan AR, Ali A, Pandya H, Alfalah A, Mehta Y, Elshaer M, DeCarlo C (2023) Assessment of the impact of binder grade on the laboratory performance of fiber reinforced asphalt mixtures. *Construction and Building Materials*, *401*, 132735. https://doi.org/10.1016/j.conbuildmat.2023.132735

Khattak MJ, Khattab A, Rizvi HR (2013) Characterization of carbon nano-fiber modified hot mix asphalt mixtures. *Construction and Building Materials*, *40*, 738–745. https://doi.org/10.1016/j.conbuildmat.2012.11.034

Klinsky LMG, Kaloush K, De Faria VC, Bardini VS (2018) Performance characteristics of fiber modified hot mix asphalt. *Construction and Building Materials*, *176*, 747–752. https://doi.org/10.1016/j.conbuildmat.2018.04.221

Sabahfar N, Ahmed A, Aziz SR, Hossain M (2017) Cracking Resistance Evaluation of Mixtures with High Percentages of Reclaimed Asphalt Pavement. *Journal of Materials in Civil Engineering*, *29*(4). https://doi.org/10.1061/(asce)mt.1943-5533.0001791

Slebi-Acevedo CJ, Lastra-González P, Pascual-Muñoz P (2019) Mechanical performance of fibers in hot mix asphalt: A review. *Construction and Building Materials*, *200*, 756–769. https://doi.org/10.1016/j.conbuildmat.2018.12.171

Wang K, Wu Q, Hu P, Xu H, Qu L, Li X, Lin Y, Du G, Shi T (2023) Road performance and microscopic mechanism analysis of modified straw fiber asphalt binder. *Advances in Materials Science and Engineering*, *2023*, 1–15. https://doi.org/10.1155/2023/2328556