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The Determination of Rut Susceptibility of Carbon Fiber Modified Asphalt Binders in Hot-Mix Asphalt

R. Christopher Williams
Associate Professor, Michigan Technological University, Houghton, MI, USA

Andrea N. Kvasnak
Research Assistant, Michigan Technological University, Houghton, MI, USA

Bruce Wiljanen
Research Assistant, Michigan Technological University, Houghton, MI, USA

Abstract
Pavement engineers are attempting to reduce the occurrences of rutting utilizing evolving technologies. One of the techniques for preventing rutting is the use of modified binders in hot-mix asphalt (HMA). Recent interest has developed in testing the effects carbon fibers has on HMA related to rutting resistance. The feasibility and successfulness of carbon fibers in HMA was tested using a loaded wheel tester, an Asphalt Pavement Analyzer (APA). The carbon fibers were tested in HMA specimens with varying binder content and carbon fiber percentages. Analysis compared the rutting susceptibility of HMA with carbon fiber and HMA without carbon fibers. Since rutting problems mainly occur at high temperatures, binders intended for areas with significant rutting issues were examined. If the improvement in resistance to rutting are significant with the addition of carbon fibers then the added cost associated with carbon fibers may be justified. The ranking of the pavement's rutting potential is compared to a neat binder and to another polymer modified binder. The effects of carbon fiber on improving the susceptibility of binders were examined to see if it has uniform enhancement properties for all binders or if it is only advantageous for certain asphalt binders.

Keywords
Carbon Fiber, Rutting, Permanent Deformation, Asphalt Pavement Analyzer, Modified Asphalt Binder

1. Introduction

Numerous advancements are being implemented to deter rutting. Modified binders have been used in the past to prevent rutting. Recent interest has developed in testing the effects of using carbon fibers in hot mix asphalt (HMA) to resist rutting to modify the binder. Carbon fibers are appealing for the ability to increase the durability of many materials and being electrically conductive. An additional benefit is carbon fiber production has become more efficient and more reliable in yielding consistent carbon fiber material within the past decade.

The feasibility and successfulness of carbon fibers in HMA was tested using a loaded wheel tester, an Asphalt Pavement Analyzer (APA). The APA has been deemed, in past research, acceptable for ranking pavements susceptible to rutting correctly. HMA samples were tested at varying binder content and carbon fiber percentages. Several performance graded binders were used to determine if carbon fiber modification is beneficial for all binders or only a few. Carbon fiber modified asphalt (CFMA) HMA samples were compared with unmodified HMA samples to determine the change in rutting resistance. Significant increases in rutting resistance could justify an increase in cost for a carbon modified binder.

1.1 Research on Carbon Fibers in HMA

Past research has determined that carbon fibers tend to breakdown during the construction process. The breakdown could be contributed to fiber brittleness, aggregate, fiber imprefections, or the HMA mixing process (Cleven). The use of encapsulated carbon fiber has been studied and results indicate there is some breakdown in the carbon fiber but not as significant as unencapsulated fibers (Fitzgerald). Since the research on encapsulated carbon fibers, the manufacturing process of carbon fibers has improved thus yielding less brittle fibers. The critical length for carbon fibers to mitigate breakdown and ease in mixing has not yet been determined.

2. Experiment Design

Prior research on the effects of CFMA HMA indicated there are at least two main factors to consider; mixture effects and performance effects. The extent of the mixture effects are related to aggregate structure, asphalt content, fiber content, and fiber type. To limit the effects of aggregate type and asphalt content, the same aggregate type and only the optimum asphalt content were used in the test specimens. Controlling the variation introduced by aggregate type and asphalt content ensured that only the effects of fiber length and type would alter damage caused by mixing. The study encompassed both field and laboratory samples.

2.1 Field Experiment

CFMA and unmodified HMA field specimens were mixed in a drum mixer and collected following American Association of State Highway and Transportation Officials (AASHTO) guidelines. The field samples consisted of two neat binders; one with a target asphalt binder content of 5.0% and another of 5.2%. Three CFMA HMAs were tested; 0.25%, 0.50%, and 0.75% carbon fiber. The 3 CFMA targeted binder contents were 5.1%, 5.3%, and 5.5%. The field specimens used a PG 64-22 performance grade (PG) asphalt binder.

1. 2.2 Laboratory Experiment

Aggregates that were sampled from the field stockpiles were used along with unmodified PG 64-22 asphalt and CFMA binder samples. Test specimens were made at the appropriate optimum binder content for each type of HMA used. In addition to testing an unmodified control group, specimens were also made and tested with an increase of one and two high temperature performance grades of asphalt binder (PG 70-22 and PG 76-22) to use in comparison and analysis.

3. Materials

Three performance graded binders were used: PG 64-22, PG 70-22, and PG 76-22. Carbon fibers were mixed in the binder at a plant at 0.25% and 0.75% CFMA for use in laboratory testing. Polypropylene fibers, a common asphalt binder modifier, were used at 0.50% by weight of asphalt binder and added during the laboratory mixing process to compare to carbon fiber modified mixtures. The aggregate blend was designed following Superpave mix design procedures (AASHTO 2000). Table 1 lists the properties of the samples tested.

Table 1 HMA Material Properties

	Unmodified			Modified			
Site	**No. of Samples**	**Asphalt Content (%)**	**Performance Grade**	**No. of Samples**	**Fiber Content**	**Asphalt Content (%)**	**Fiber Type**
Field	3	5.0	PG 64-22	3	0.5	5.1	Carbon
	3	5.2	PG 64-22	3	0.5	5.3	Carbon
				3	0.5	5.5	Carbon
Laboratory	3	5.2	PG 64-22	3	0.25	5.4	Carbon
	3	5.2	PG 70-22	3	0.75	5.4	Carbon
	3	5.2	PG 76-22	3	0.50	6.0	Polypropylene

4. Asphalt Pavement Analyzer

The asphalt pavement analyzer (APA) is a loaded wheel tester, similar to a Hamburg Wheel Tracking Device, used to assess an HMA's susceptibility to permanent deformation. Cylindrical specimens of 150 mm diameter and a height of 75 mm ± 0.5 mm were tested in an APA for rut susceptibility. All specimens for this study were tested dry at 60ºC (140°F). APA testing consisted of 8,000 and 20,000 wheel cycles with 100 conditioning cycles. The applied wheel load is 45.36 kg with a hose pressure of 7.03 $\frac{kg}{cm^2}$.
APA testing was performed at a constant 60°C for all mixture types tested. Testing each mix at the asphalt binders high temperature grading may provide more information in carbon fiber affects. Carbon fiber would have to be added to each performance grade used, i.e. testing a neat PG 70-22 and a carbon modified PG 70-22 at 70°C. This may realize the carbon fiber impacts to different performance grade binders in permanent deformation analysis.

The rutting potential of the samples was examined with the APA. Some samples were only tested to 8,000 cycles, which is the standard number of cycles used in research. The remaining samples were tested for 20,000 cycles with the rut depth at 8,000 cycles also noted. It was hoped that with 20,000 cycles a comparison of the number of cycles versus a common rut depth could be achieved. A rut depth of 7 mm in the APA was chosen for this study based on past research with APA performance data(Hill). The additional cycles were used since failure of a pavement in the field is based upon rut depth instead of the number of passes. A more appropriate method of analysis is to determine the number of cycles to achieve a certain "failure" rut depth. This approach is considered more realistic as pavements fail as a result of a rut depth threshold being exceeded. A depth of 7 mm was chosen as the failure depth criteria.

Preliminary analysis of APA rut depth data involved determining percent improvements between mixes tested and the control mix. Percent improvement is determined by comparing the percentage of rut depth more than the control mix at a certain number of cycles, mainly 8,000 but 20,000 cycles were also used.

Deformation depths increase at a faster rate in early stages of rutting compared to slower changes typically experienced in the later stages. Investigating two different cylces allows for the effect of carbon fiber on rut depth to be analyzed for initial stages of rutting and long term rutting.

4.1 Statistical Analysis of APA Results

The data collected from the APA was evaluated to determine statistical significances. Only samples tested at the same number of cycles and mix locations were compared to one another. Neat field sample data indicated the coefficient of variation decreases with increasing cycles while the CFMA field samples exhibit an increasing covariance with increasing cycles. Interestingly, the benefits for carbon fiber do not increase with the amount of fiber. The 0.5% CFMA samples performed better than both the 0.25% and 0.75% CFMA samples as well as the neat samples. Less than 0.5% carbon fiber appears to be less beneficial to the samples while the 0.75% of carbon has no significant benefits over a neat binder in the field. Further research should investigate the results and identify the exact range at which carbon fiber is beneficial.
The samples mixed in the laboratory exhibited slightly less favorable results for CFMA samples than the field data. The average rut depths were lower for neat samples than for CFMA samples, however the coefficient of variation for the neat samples was higher than for CFMA samples. The 0.25% CFMA yielded the lowest coefficient of variation. This lower coefficient of variations for CFMA in the laboratory than in the field could be related to fiber breakdown. The fibers may break down less in the laboratory due to less handling. A lower coefficient of variation for CFMA laboratory samples than the neat samples could indicate better blending in an attempt to disperse the fibers throughout the mix.

The final analysis of the project based on the APA results was the comparison of the laboratory CFMA samples to the polypropylene modified asphalt binder samples. The polypropylene modified asphalt binder samples exhibited a rut depth between those yielded for the 0.25% CFMA and the 0.75% CFMA, with 0.75% displaying the lowest rut depth. The variation in the rut depth results was lower however for the polypropylene samples than both types of CFMA tested in the laboratory.

5. Life Cycle Cost Analysis

The life-cycle cost analysis (LCCA) for permanent deformation initiated with correlating equivalent single axle loads (ESALs) to cycles in the APA that would achieve a set failure level of rut depth, 7 mm. From previous studies at WesTrack, an APA cycle is approximately equal to 129.9 80-kN ESALs (Hill). A rutting season, time which temperature facilitates rutting, was established to be 3 months. Since some of the samples did not reach the failure criteria of 7 mm, regression was used to extrapolate the number of cycles to reach failure.

The best economic value using the given criteria in analysis (in terms of equivalent uniform annual cost) for the field material tested to 8,000 cycles was the 0.50% CFMA HMA with 5.3% asphalt content. For the field samples tested to 20,000 cycles the best value was the unmodified HMA with 5.0% asphalt content. The PG 76-22 laboratory mixture appeared to be the best value.

6. Conclusions

The study evaluated the significance of carbon fiber in resisting rutting by evaluating HMA samples, mixed in the field and in the laboratory, via the APA. The results indicated that during the initial rutting process the 0.50% CFMA HMA is the most economical choice while for long term rutting the unmodified HMAs performed better. The difference in the results between the three levels of CFMA suggests that a carbon fiber content range exists over a small interval at which beneficial properties are acquired. In this study, the field 0.50% CFMA appeared to be beneficial while the 0.25% CFMA HMA was detrimental and the 0.75% had no significant contribution. Further testing should be conducted to establish this interval.

7. References

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