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Executive Summary Report

**Mechanical Properties of Warm Mix Asphalt
 Prepared Using Foamed Asphalt Binders**

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Problem Statement

Hot mix asphalt (HMA) is a mixture containing aggregates and asphalt binders prepared at specified proportions. The aggregates and asphalt binder proportions are determined through a mix design procedure such as the Marshall Mix Design or the Superpave Mix Design methods. Overall, the goal of determining such proportions is to establish an HMA mixture that will meet specific performance criteria. In addition, it is imperative to ensure that the asphalt binder will fully coat the aggregates and that the resulting mixture is workable and compactable.

In order to ensure sufficient aggregate drying and coating, both the asphalt binder and the aggregates are heated to elevated temperatures ranging between 300°F and 325°F. The use of such high temperatures would result in lowering the viscosity of the asphalt binder which is the main factor affecting the coating and workability of asphalt mixtures.

In recent years, a new group of technologies have been introduced to the United States that allow producing asphalt mixtures at temperatures 30 to 100°F lower than what is used in HMA. This group of technologies is commonly referred to as Warm Mix Asphalt (WMA). They are promoted as environmentally friendly green alternatives to HMA mixtures as they produce lower greenhouse gas emissions. This new group of technologies aims at reducing the viscosity of the asphalt binder through the addition of organic or chemical additives or by introducing cool water into the heated molten asphalt under controlled temperature and pressure conditions, resulting in so-called foamed asphalt binder. As a consequence, lower temperatures are needed during production for the asphalt binder to be absorbed by the aggregates.



Over the last few years, WMA mixes prepared using foamed asphalt binders (WMA-FA) have received increased attention and use in Ohio. This technology is believed to be the most cost effective from among the WMA technologies since it does not require any costly additives to be added to the mixtures and more importantly it does not require very expensive plant modifications since the foaming component can be attached to old systems for a reasonable price, without the need for any additional changes. Other potential advantages include reducing energy consumption since lower temperatures are used, increasing haul distances since warm mix asphalts retain their temperatures for a longer period of time, improving working conditions due to lower odor, fume, and emission levels produced from heating the asphalt binder; and more importantly improving compactability and the ability to reach the desired density with fewer number of roller passes.

In spite of the above-mentioned advantages for WMA-FA mixtures, many concerns have been raised regarding the use of lower mixing and compaction temperatures during the production of this material. Among these concerns are the increased susceptibility to permanent deformation due to less binder aging and the increased propensity to moisture-induced damage due to use of water in producing foamed asphalt binders. Therefore, research is needed to evaluate the performance of this material with regard to these concerns.

Study Objectives

The main objectives of this study are:

1. Develop a procedure by which WMA-FA mixtures can be produced in the laboratory;
2. Evaluate the performance of WMA-FA mixtures with regard to moisture susceptibility and permanent deformation;
3. Evaluate the performance of control HMA mixtures prepared using the same aggregates and asphalt binders;
4. Compare the performance of WMA-FA and HMA mixtures; and
5. Recommend changes to current ODOT practices and specifications to address the research findings.

Description of Work

To achieve the objectives of this study, an experimental plan was designed and executed to evaluate and compare the performance of WMA-FA and HMA mixtures with regard to moisture susceptibility and permanent deformation. Two aggregates (gravel and limestone) and two asphalt binders (PG 64-22 and PG70-22M) were used in this study, resulting in four material combinations. These materials were obtained from ODOT approved asphalt and aggregate suppliers. The aggregate gradation met ODOT Construction and Material Specifications (C&MS) Item 441 Type 1 surface course subjected to medium traffic. The optimum asphalt binder content for the HMA mixtures was determined using the Marshall mix design method. The same optimum asphalt binder content was used for the WMA-FA mixtures, which is consistent with the current state of the practice in Ohio and across the US.

A laboratory scale asphalt binder foaming device called WLB10 was used to foam the asphalt binders. This device utilizes the same process in producing foamed asphalt binders to that used in field foaming systems such as the Astec Double Barrel Green system, Terex WMA system, and Gencor Green Machine. The asphalt binder was foamed using a foaming water content of 1.8%, which is the maximum water content permitted by ODOT. Furthermore, as specified by ODOT, the WMA-FA mixtures were produced using mixing and compaction temperatures 30°F lower than those used in the preparation of the HMA mixtures.



The testing plan involved utilizing the AASHTO T 283 test to evaluate the resistance of the WMA-FA and HMA mixtures to moisture-induced damage, and the Asphalt Pavement Analyzer (APA) and Dynamic Modulus (E^*) tests to evaluate the resistance of both mixtures to permanent deformation. Comprehensive statistical analyses were performed on the experimental test results to evaluate the significance of the different variables affecting the mix performance, and to determine their effect on the test results.

Research Findings & Conclusions

Based on the performance test results and the subsequent statistical analysis findings the following conclusions were made:

- The unmodified and modified asphalt binders (PG 64-22 and PG 70-22M, respectively) were successfully foamed using a laboratory scale asphalt binder foaming device called WLB10, produced by Wirtgen, Inc.
- As expected, the unmodified PG 64-22 asphalt binder had a slightly higher expansion ratio and thus was easier to foam than the modified PG 70-22M asphalt binder.
- Aggregates in WMA-FA mixtures were fully coated after mixing in a mechanical mixer for 3 minutes even though the mixing temperature was 30°F lower than that for HMA mixtures.
- WMA-FA mixtures had slightly lower Rice specific gravities than HMA mixtures. This might have been caused by two factors. First, the presence of entrapped air bubbles within the foamed asphalt binder even after mixing. Second, a slight reduction in asphalt absorption in the case of WMA-FA mixtures.
- WMA-FA mixtures were found to be more workable and easily compacted in comparison to HMA mixtures even though the mixing and compaction temperatures were 30°F lower than that for HMA mixtures. This is mainly attributed to the use of foamed asphalt binder.
- Generally, the WMA-FA mixtures had slightly lower tensile strength ratio (TSR) values than the HMA mixtures. However, the difference was found to be statistically insignificant. In addition, the TSR values of both the WMA-FA and HMA mixtures satisfied ODOT's minimum TSR requirement for medium traffic (TSR \geq 70%).
- Mixtures prepared using natural gravel had higher TSR values than those prepared using crushed limestone. This is probably due to using higher asphalt binder content and finer aggregate gradation in the case of mixtures containing crushed limestone.
- The HMA mixtures exhibited slightly higher indirect tensile strength (ITS) values than the WMA-FA mixtures. Softening of the asphalt binder due to foaming and lower asphalt binder absorption might be the causes of such result.
- Mixtures prepared using crushed limestone exhibited higher ITS values than those containing natural gravel. This is probably due to the greater interlock within the crushed limestone aggregate structure.
- The WMA-FA mixtures had higher rut depths in the APA test than the HMA mixtures. This may be attributed to the softening of the asphalt binders due to foaming, lower asphalt binder absorption, and reduced binder aging due to the use of lower production temperatures in the case of the WMA-FA mixtures.
- Mixtures prepared using crushed limestone had lower rut depths in the APA test than those prepared using natural gravel. The greater interlock within the crushed limestone aggregates structure might be the cause of such result.
- HMA and WMA-FA mixtures prepared using PG 70-22M were more resistant to rutting than those prepared using PG 64-22, which is expected since the former is a polymer modified asphalt binder with a higher PG grade.
- All rut depth values obtained from the APA test were lower than 0.35 inch except for the WMA-FA mixtures prepared using natural gravel and PG 64-22, which had an average rut depth of 0.6 inch. Therefore, ODOT is encouraged to examine the performance of recently constructed projects in Ohio using foamed asphalt binder and this material combination with respect to permanent deformation in order to determine whether this observation is consistent with field performance data or not.



- The dynamic modulus of the WMA-FA mixtures was very close to that of the HMA mixtures. This suggests that the performance of the WMA-FA mixtures is similar to that of the HMA mixtures with respect to permanent deformation. However, the APA test results have shown an increased rutting potential for the WMA-FA mixtures than the HMA mixtures. Therefore, it is believed that the dynamic modulus test is not capable of predicting the rutting performance of the considered mixtures.
- As expected, mixtures containing crushed limestone had higher dynamic moduli than those containing natural gravel. The greater interlock within the limestone aggregate structure might be the cause of such result.
- Mixed results were obtained for the effect of the asphalt binder type on the dynamic modulus. Slightly higher dynamic moduli were obtained for PG 70-22M than PG 64-22 in the case of natural gravel, whereas slightly higher dynamic moduli were obtained for PG 64-22 than PG 70-22M in the case of crushed limestone.

Study Limitations

- Only two types of aggregates and two types of asphalt binders were used in this study.
- Only one aggregate gradation was used for mixtures containing gravel and one gradation was used for mixtures containing limestone.
- The study was limited to mixtures prepared using an optimum asphalt binder content obtained through the Marshall mix design procedures.
- The mixtures were prepared to withstand medium traffic only.
- WMA-FA mixtures were prepared using the same optimum asphalt content obtained for the HMA.
- The foaming parameters (i.e. foaming water content, air pressure, water pressure, and foaming temperature) were not varied and their effects were not evaluated.
- This study was limited to using fully dried aggregates.
- This study was limited to reducing the mixing and compaction temperatures by 30°F only without any consideration to potential further reductions in these temperatures.

Recommendations for Further Study

It is recommended that future work expands the current study to include a wide range of aggregates obtained from different sources in Ohio and different asphalt binders. This study can also be expanded to evaluate the effect of the foaming parameters on the performance of WMA-FA mixtures. Furthermore, the study can be expanded to account for the effect of aggregate drying on the performance of WMA-FA mixtures.

It is also recommended that future work would take into consideration the effect of heavy traffic conditions as well as the Superpave mix design procedures. Moreover, it is recommended that future work takes into consideration the effect of asphalt binder aging as well as quantifying the amount of entrapped air bubbles within the foamed asphalt binder in order to ensure accurate assessment of the volumetrics used in the preparation of WMA-FA mixtures.

Recommendations for Implementation

Based on the research findings, WMA-FA seems to be a viable alternative to HMA as a paving material for roadways subjected to traffic levels ranging from low to medium. However, the performance of such material has to be evaluated in terms of permanent deformation. Therefore, it is recommended to modify ODOT C&MS Item 441 to include a permanent deformation test as part of the mix design procedure to ensure satisfactory field performance.