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Evaluation of moisture susceptibility tests for warm mix asphalts

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HIGHLIGHTS

- Hamburg wheel tracking test (HWTT) and tensile strength ratio (TSR) were compared.
- Field cores and gyratory samples were compared for moisture susceptibility.
- For the mixes tested more mixes did not pass HWTT criteria compared to TSR.
- Curing time and temperature influenced the HWTT results.

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ABSTRACT

Moisture sensitivity has been identified as an area of concern for warm mix asphalt (WMA) mixtures. To evaluate WMA's influence on moisture damage, three field-produced mixes were selected for evaluation. All WMA mixes studied used the same chemical WMA additive. The objectives are to compare hot-mix and WMA performance in moisture susceptibility tests, compare indirect tensile strength and Hamburg performance of pavement-cores and laboratory compacted samples, investigate reheating effect of WMA compared to hot-mix asphalt for quality-control purposes, and understand the sensitivity of WMA's stripping inflection point to oven-aging time and temperatures. Tests indicate pavement-cores performed better than gyratory samples in the Hamburg. Trends indicate Hamburg results are dependent upon temperature and higher temperatures correlate with better performance.

1. Introduction and background

Moisture damage causes stripping of the asphalt pavement as a result of the loss of bond between the asphalt binder and the aggregate under traffic loading [1,2]. Stripping in hot mix asphalt (HMA) pavements may be induced by as many as five mechanisms including detachment, displacement, spontaneous emulsification, pore pressure, and hydraulic scouring [3]. There are many variables that can impact the susceptibility of a mixture to stripping including: the type of mix, asphalt cement characteristics, aggregate characteristics, environmental conditions, traffic loading, construction practice, the use of anti-strip additives and the common factor is the presence of moisture [1]. There are two major types of moisture damage and they are failure of adhesion and failure of cohesion. The two most common standards used in the United State for evaluating moisture damage is AASHTO T-283 [4] and the Hamburg wheel track test [5,6]. Although the tests are commonly used, studies show the TSR fails to correlate to tested field observations, [7] and HWTT is an empirical test that does not directly measure the stripping "failure mechanism" [8].

Studies have investigated the mechanical properties of plant-produced warm-mix asphalt mixtures and found that the warm mix asphalt (WMA) dosage, production temperature and binder properties all significantly affected the dynamic modulus and the Hamburg wheel tracking test (HWTT) results [9,10]. Stripping inflection points (SIP) for foamed asphalt and Sasobit have shown to be lower than the HMA control mixtures [11].

National Cooperative Highway Research Program (NCHRP) project 9-43 investigated warm mix additives including: waxes, chemical modifiers and foaming additives and foaming processes to understand the mix design methodology of WMA. The moisture susceptibility of WMA using American Association of State Highway and Transportation Officials (AASHTO) T-283 was of particular interest and concluded that moisture susceptibility differences will

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likely exist between WMA and HMA mixes using the same aggregate and binder; however, the WMA mixes with anti-stripping agents had similar or better TSR values. The lower mixing and compaction temperatures may also lead to reduced rutting resistance [12]. A WMA chemical additive, evaluated in NCHRP 9-43, included an anti-strip additive and the reduction in moisture sensitivity was not captured. Anti-stripping dosage rates may vary between HMA mixes and WMA mixes. NCHRP 9-43 also investigated the changes necessary in the WMA mix design process. Very few changes were implemented in the mix design process. The main differences are the mixing and compaction temperatures, the coating and compactability evaluation during the laboratory mix design and the specimen preparation is dependent on the WMA additive used.

Short-term conditioning can factor into the moisture susceptibility of an asphalt mix. NCHRP 9-43 recommended the short-term conditioning continue to be two hours but should be done at the field compaction temperature to simulate the binder absorption and stiffening that occurs during the field production [12]. The NCHRP 9-43 study found plant-produced mixtures have experienced more aging prior to compaction than laboratory mixed samples which may reduce the bonding strength between aggregates and binder. This study also compared HMA and WMA resilient modulus values in an oven-aging study varying time and temperature which concluded that oven-temperature influenced resilient modulus results were more than oven-aging time. Extracted binder from cores was compared with samples that were plant mixed-lab compacted. The binder from the cores was found to have higher stiffness in dynamic shear rheometer testing [13]. Another study found that WMA caused a reduction in the dynamic modulus except for frequencies lower than 0.5 Hz at 40 °C [14]. The WMA also did not perform as well as the HMA in rutting related flow number testing and HWTT. A study by Rushing found WMA mixes also reported reduced rutting performance, reduced TSR values, and poorer performance in the asphalt pavement analyzer (APA) [15]. A similar study by Doyle found that for some mixes, the PUR Wheel test indicated an increased potential for moisture damage but the increased potential was not reflected in the TSR test data. The study indicates that further investigation should be performed [16]. In contrast, a similar study found comparable performance between WMA and HMA in the APA but TSR values showed WMA values to be significantly lower than HMA [7]. Studies using WMA mixes with recycled asphalt materials have shown marginal TSR values but increasing stripping inflection point (SIP) [17]. Other studies also reported observing differences between HMA and WMA mixes for HWTT results [6]. The HWTT are sensitive to the oven-conditioning time and temperatures and continues to be a researched topic [18].

2. Experimental methodology

The study only included plant-produced mixtures. This eliminates the concern of laboratory preparation of WMA not matching actual field conditions. The industry has several available tests to evaluate moisture susceptibility. Recently, several agencies have changed moisture susceptibility testing from AASHTO T-283 to the HWTT. In addition, WMA additives for reducing the mixing and production temperature are being integrated into a significant percentage of pavements. The WMA additive evaluated in this research is a chemical additive derived from forest products. The change in the moisture susceptibility specification and coupled with the decrease in WMA production temperatures prompted the need for researching how WMA production influences the performance in the HWTT compared to the tensile strength ratio (TSR). The research plan evaluates the difference between HMA and WMA mixes in HWTT and TSR. The research plan also compares the loose HMA/WMA samples with field cores for HWTT and TSR.

When loose mix samples are collected by an owner/agency for quality control testing, the mix is transported to a laboratory. When it is time to reheat and oven-age the mix for testing, how much influence does the HMA aging temperature and the WMA aging temperature have on the quality control test results? The research plan will investigate this question. It is also valuable to understand how WMA production temperature and oven-aging durations influence the SIP.

Moisture susceptibility was evaluated on three WMA mixtures and one HMA mix using the TSR, AASHTO T-283, and the HWTT. In addition, the influence of time and temperature oven-aging was evaluated for the HWTT. The objective of this research is to do the following:

- compare HMA and a WMA mixtures for differences in TSR and SIP,
- compare mix compacted in a gyratory at the plant (non-reheated, designated "field" or "F") and mixture compacted in the same gyratory at a later date (reheated, designated "lab" or "L"),
- compare the indirect tensile strength of cores to laboratory compacted samples,
- understand the sensitivity of HMA and WMA SIP to oven-aging time and temperatures,
- and compare the SIP with laboratory compacted samples.

Fig. 1 shows the experimental layout and research approach that will address the stated objectives. To evaluate WMA's influence on moisture sensitivity, several plant-produced mixes were selected for evaluation. All projects used the same commercially available chemical modifier WMA additive that also contained an anti-stripping agent. Unless stated otherwise, all HMA samples were conditioned for 2-h and compacted at 150 °C and WMA samples were cured 2-h and compacted at 120 °C. The first mixture, designated FM2, was produced as HMA the first day of production and produced the second day using the WMA additive at reduced plant temperatures. Two additional projects were selected for this study, designated FM5 and FM6, these are WMA-only mixtures to investigate the overall moisture susceptibility of WMA mixtures and evaluate the use of TSR and SIP as moisture sensitivity parameters for WMA. The important mixture parameters are shown in Table 1.

Indirect tensile (IDT) strength testing, Table 2, was performed on dry, non-moisture conditioned (NMC) samples and moisture conditioned (MC) samples. Samples for determining TSR values and comparing reheating effects had a 4-inch [100 mm] diameter and were compacted using a 4-inch [100 mm] diameter mold. The cores collected were 6-inches [150 mm] in diameter. In order to compare laboratory samples with pavement cores, it was necessary to compact 6-inch [150 mm] diameter IDT samples in the laboratory as well. This research will illustrate how HMA and WMA compare in IDT strength and TSR values as well as provide a direct comparison to the difference between moisture susceptibility detected in the HWTT and AASHTO T-283 test for WMA pavements. This study will impact future QC/QA policies and/or procedures for evaluating WMA.

The HWTT testing plan is shown in Table 3. All samples were paired according to their air voids and subsequently tested. This plan will allow comparisons of SIP values and comparison of the pavement cores with gyratory samples. The initial results from this study demonstrated a need for further investigation of the influence of oven aging time and temperature when working with WMA materials. An additional oven aging study was developed in order to better understand how time–temperature combinations influence the SIP.

2.1. Effects of oven aging on warm mix asphalt

The oven aging of WMA samples is often performed at a reduced temperature reflecting the lower production temperatures. This testing studies how HMA and WMA performance in the HWTT change due to different oven aging times and temperatures to evaluate the impact of reduced temperatures. Conditioning times were chosen based on AASHTO R30 which recommends two hours for volumetric mixes and four hours for short-aged mixes. Changing the temperatures will improve the understanding of how temperatures influence HWTT results." The oven-aging durations chosen were two and four hours. Generally, an oven aging time of 6-h and longer is not practical for mix design nor quality control/quality assurance purposes. The oven temperatures included 120, 135 and 150 °C and were tested in the HWTT as shown in Table 4. The intent is to determine how long oven aging should take place and at which temperature in order to have comparable test results in the HWTT between HMA and WMA as well as determining which temperature and time combination best simulate the pavement core HWTT results.

2.2. Indirect tensile strength and tensile strength ratio (TSR) measurements

The tensile strength ratio test follows AASHTO T-283. Samples for measuring TSR values have a 4-inch [100 mm] diameter and are 2.5-inches [63.5 mm] thick. The 6-inch [150 mm] diameter by 3.5-inch [88.8 mm] thick laboratory compacted samples were needed to compare with the 6-inch [150 mm] diameter by 3.5-inch [88.8 mm] thick pavement cores. This is the largest size that could be accommodated in the steel loading head available and cores were cut to the same dimensions for direct comparison. The sample preparation followed the field-mixed, laboratory-compacted protocol and half of the samples were moisture conditioned. Moisture conditioning begins by separating samples into dry and wet subsets. Subsets are determined by pairing the samples according to air voids. Within each pair, one is randomly assigned to be tested dry or moisture conditioned. The samples selected for moisture conditioning are vacuum saturated so that 70–80% of voids are filled with water. Samples are immediately placed in a freezer at −18 °C, wrapped in plastic wrap, in a sealed bag with a tablespoon of water for a minimum