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Moisture susceptibility evaluation of asphalt mixes based on image analysis

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HIGHLIGHTS

- By applying an image analysis technique, visual rating in boiling water test is converted to a more objective evaluation.
- The stripping results of boiling test show significant linear relationship with TSR and ESR values.
- There is not a significant correlation between RMS values and the boiling test results.

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ABSTRACT

Moisture damage in hot mix asphalt (HMA) is one of the major concerns in durability of flexible pavements. Numerous methods have been developed to evaluate moisture susceptibility of HMA in last decades. Some of these methods are simpler and less costly (qualitative tests) and some of them are more reliable.

In this research, a digital image analysis approach was utilized to convert boiling water test (ASTM D3625) from visual rating to objective evaluation. Some laboratory tests were conducted on specimens to compare the stripping percentages obtained from image analysis of the boiling water test and modified Lottman test (AASHTO T283) results. In AASHTO T283 test, in addition to Indirect tensile test, the dynamic modulus $|E^*|$ test and the Marshall stability test were performed. Therefore, three criteria; tensile strength ratio (TSR), $|E^*|$ stiffness ratio (ESR) and Retained Marshall stability (RMS) were used to compare the results of the two methods. The dynamic modulus test was conducted in indirect tension mode; and a linear viscoelastic solution was used for calculation of $|E^*|$.

Findings showed that the results of boiling water test have significant relationship with TSR and ESR. Good correlation was found between three tests; however, the results of boiling test did not show significant relationship with RMS.

1. Introduction

Moisture susceptibility is an HMA mixture's tendency toward stripping [1]. Stripping is fundamentally the loss of bond between the asphalt and aggregate. Moisture damage continues to be one of the major causes of premature failure of HMA pavements. Moisture damage in HMA occurs due to a loss of adhesion and/or cohesion, resulting in reduced strength or stiffness of the HMA and the development of various forms of pavement distress [2,3].

Numerous laboratory tests have been developed over the years to identify the moisture sensitivity of HMA. The tests for identifying the moisture damage potential of an asphalt/aggregate mixture can be classified into two major categories including those performed on loose mixtures, such as the static immersion test and the boil test, and those performed on compacted mixtures, such as the immersion compression, indirect tensile strength, and modulus tests [4]. Advantages of tests in loose mixtures, is that they are simpler and less costly to run than tests conducted on compacted specimens; and also they require simpler equipment and procedures. But defining a pass/fail criterion is not an easy task for most of these tests. For example, visual evaluation is used in the static immersion test to determine the degree of stripping below or above 95%, a criterion that is not very repeatable between different operators and different laboratories [5]. To eliminate the disadvantage from this test, by using of computer tools, the visual judgment can be converted to a more objective evaluation. Merusi et al. used an image based algorithm to compare stripping resistance of

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asphalt mixtures modified with different synthetic wax [6]. A similar work has been done to evaluate the amount of HMA stripping by Kim et al. [7].

AASHTO T283 is one of the most commonly used procedures for determining HMA moisture susceptibility [5]. In this method Retained indirect tensile strength (ITS) is used as indicator of moisture susceptibility. Nadkarni et al. [8] used the dynamic modulus test instead of ITS test in this field. The analysis indicated that there was no statistical significant difference between the measured TSR and ESR values for the same mixture. The correlation obtained between the two ratios was fair to good. Because the dynamic modulus test is nondestructive and is a major input into mechanistic empirical pavement design guide, they recommended the ESR to potentially replace TSR testing to assess field moisture damage for asphalt mixtures [8]. Kim et al. [9] presented the results from an analytical/experimental study on the dynamic modulus of HMA tested in the indirect tension (IDT) mode using the theory of linear viscoelasticity. Comparison of results from the axial compression and IDT test methods showed that the dynamic modulus mastercurves and shift factors derived from the two methods are in good agreement [9].

2. Objective and scope of the research

Objectives of this research are to:

- Convert the boiling water test from subjective evaluation to a more objective estimation and more reliable test, so that it does not depend on visual rating and operator's judgment.
- Determine if there is a significant relationship between results of image analysis of boiling water test and results of AASHTO T283 Test.

The scope of work included conducting both test methods on specimens prepared from different types of aggregates. Digital images taken from boiling water test were analyzed and compared with TSR, ESR and RMS obtained on dry and moisture conditioned specimens after AASHTO T283.

3. Material and methods

3.1. Materials

Five types of aggregates with different mineralogy were used in two groups to prepare asphalt mixtures with different moisture sensitivity. The first group included limestone and slag–limestone aggregate (substituting the coarse fraction of limestone aggregate with slag) that with high carbonate content has a stronger bond with asphalt binder. The second group comprised of quartzite, granite and andesite aggregates. These aggregates with high silica content have shown potential for stripping. BOF slag was procured from Zob-Ahan steel manufacturing company located in Isfahan city. The gradation of all aggregates is shown in Fig. 1. Two types of anti-stripping additives were used; hydrated lime as filler and a nano-based material namely Zycosoil as liquid anti-stripping produced by Zydex Industries India. It is a water soluble organosilane compound that has been designed to reduce the moisture susceptibility of the compacted asphalt concrete. [10].

Asphalt binder with 60/70 penetration grade was procured from Isfahan petroleum refinery company and its basic properties are presented in Table 1.

3.2. Mix design and specimens preparation

The superpave mix design was utilized to determine the optimum binder content of HMA mixtures. The target air void was selected 4% for all mixtures. The optimum asphalt content was obtained 4.6% for limestone, 5% for slag–limestone, 4.9% for quartzite, 4.4% for granite and 5.1% for andesite aggregate. All mixtures were mixed in laboratory and then compacted on the IPC Servopack Gyratory Compactor. The specimens were compacted into a 100 mm (4 in.) diameter gyratory mold and approximately a height of 65 mm. In TSR testing, limited additional specimens were compacted by a standard Marshall hammer to assess the effect of compaction method.

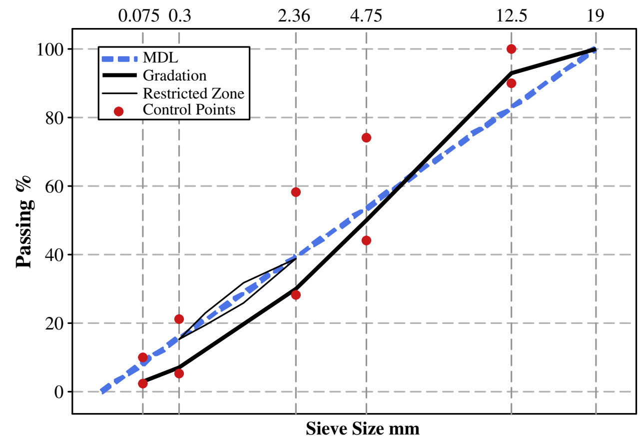

Fig. 1. Gradation of aggregates used in this study.

Table 1
Properties of asphalt binder.

Properties	Standard	Measured values	Requirements
Density (g/cm^3)	ASTM D70	1.021	–
Penetration at 25 °C (0.1 mm)	ASTM D5	66	60–70
Softening point (°C)	ASTM D36	49.5	49–56
Ductility at 25 °C (cm)	ASTM D113	>100	>100
Viscosity at 135 °C, cSt	ASTM D2170	295.5	–

Hydrated lime slurry was used as anti-stripping, which 2% hydrated lime by dry weight of aggregates mixed into water (ratio of 1–3 by weight). The precoated aggregate was then stockpiled for a marination period of 48–72 h to take place chemical reactions on the surface of aggregates. Zycosoil was added in the molten asphalt with the amount of 0.5% by weight of asphalt binder and mixed thoroughly [10].

3.3. Boiling water test

The boiling water test is a simple test to assess the effect of water on the adhesion between aggregate and asphalt binder. This test involves immersion of bituminous-coated aggregate in boiling water for 10 min and the retained coated area is evaluated by visual rating. According to ASTM D3625, 250 g of the loose mixture samples with temperature of 85–95 °C were placed in approximately 800 mL distilled boiling water for 10 min.

As mentioned before, the boiling test is qualitative which depends on judgment of the operator. In order to eliminate this disadvantage, a digital image analysis approach was employed to convert the test from subjective rating to a more objective evaluation. After cooling the boiling mixture to room temperature, the water was decanted and the wet mixture emptied onto an absorbent towel and allowed to dry for an hour and then some digital color photographs were taken from the mixture. Two image processing software were employed; in the first step, the images in JPEG format were imported into Image-Pro Plus software in order to segment, detect and separate the background and sparkles of the mixture's image. The modified images were saved in TIFF format to avoid decrease of quality and size and then transferred into Image Toll software. In this step, the color images were transformed to 8-bit grayscale images and thresholding was used to create binary images. In digital images, each pixel has a luminance value, regardless of its color. Luminance can also be described as brightness or intensity, which can be measured on a scale from black (zero intensity) to white (full intensity). Most image file formats support a minimum of 8-bit grayscale, which provides 256 levels of luminance per pixel and range from 0 (perfect black) to 255 (perfect white). According to ASTM D3625, any thin, brownish, translucent areas should be considered fully coated. Therefore different threshold levels were applied to images and then a threshold value of 65 was selected to distinguish the white and black pixels (stripping and bituminous-coated aggregate respectively). This threshold level seems to be a more realistic value to recognize the stripping areas of samples. However, applying different threshold levels indicated that the threshold values between 62 and 68 did not significantly affect in stripping percentage results; but for a consistent comparison, it is important to use the same