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Hydrated lime effect on moisture susceptibility of warm mix asphalt

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HIGHLIGHTS

- ▶ Dense graded WMA mixes achieved the desirable TSR criterion with 2% hydrated lime.
- ▶ Gap graded mixes with 1% hydrated lime and Aspha-min passed the 80% criterion.
- ▶ WMA gap graded mixes made with Sasobit satisfied the criterion without any lime.
- ▶ TSR value of control mix decreased when more than 1.5% hydrated lime was added.
- ▶ Adding more than 1.5% lime to WMA gap graded mixes marginally increased the TSR.

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ABSTRACT

Beneficial effects of using hydrated lime to reduce moisture susceptibility of Hot Mix Asphalts are well recognized and widely used in industry. In present study, the effect of varying percentages of hydrated lime (from 0% to 2%) on the moisture susceptibility of warm mix asphalt was evaluated. Based on the obtained results it was shown that increasing hydrated lime content reduces the moisture susceptibility of dense graded warm mix asphalt. However, 80% of tensile strength ratio was reached without utilization of hydrated lime in some prepared samples with gap grading, using polymer modified bitumen.
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1. Introduction

The phenomenon of breaking of the bond between aggregate and bitumen is known as stripping [1]. The physical–chemical mechanisms that cause stripping in bitumen–aggregate mixtures are so complex and not yet fully understood [2]. Detachment, displacement, emulsification, pour water pressure, hydraulic scoring, and bitumen–aggregate interfacial physical–chemical processes have been identified as the cause of moisture susceptibility problems [2]. Stripping will gradually decreases the strength of the material over the years which will manifest itself as rutting, corrugation, shoving, raveling, cracking, etc. [3–6]. Proper mix design is a prerequisite for prevention of moisture damage, however use of anti-stripping agents may also be essential [7]. Researchers found that the mixes containing hydrated lime and liquid anti-stripping agent are stiffer, less susceptible to rutting, moisture damage and cracking [8–10]. The relative effectiveness of liquid anti-stripping agents as well as hydrated lime depends on the aggregate type and the test method used to evaluate the moisture susceptibility [11]. A literature review shows that apart from the sources of aggregate and bitumen, hydrated lime has the most effect on moisture resistance increase [1,5,8,9]. Also it has been reported that the use of lime in warm mix will improve fatigue and rutting resistance [12,13] of the mix, but a study of effects different rates of lime on two types of additives used to make warm mixes and varying aggregate grading including SMA has not been reported.

Recently, the use of warm mix asphalt (WMA) as a substitute for HMA has been widely increased. The use of warm mixture reduces energy consumption, lowers emissions and odors or greenhouse gases from plants, making better working conditions at both the plants and the paving sites [14–16]. Also, addition of WMA additive with crumb rubber not only reduces the mixing and compaction temperatures, but also effectively extends long-term performance of pavement when compared with conventional asphalt pavement [12]. The interim report of NCHRP 9-47 suggested that WMA technology could be divided into four categories (organic additives, chemical additives, water-bearing additives, and water-based processes) [17]. These technologies facilitate the

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decrease in mixing and compaction temperature. Typically mixing temperature used in WMA production is in the range of 100–140 °C [15,16,18]. However, using WMA with lower temperature will result in an increase in stripping potential of the mix. Decreasing production temperature can cause adhesion failure as moisture may remain in the aggregate. In mixing temperatures normally used in WMA, the aggregates are incompletely dried out so, most researchers, have recommended the use of dry sources [1].

A literature review showed that different types of tests have been used to evaluate moisture sensitivity of asphalt mixtures, but it seems that there is no global agreement among researchers on a single method for evaluating this distress. Among numerous conventional test procedures, such as boiling test, Marshall and indirect tensile tests, some researchers and institutions believe that the later is more capable of predicting stripping phenomenon [19].

The objective of this study was to determine the effect of hydrated lime on moisture susceptibility of warm mix asphalt using two different grading (dense and gap grading). Three different percentages of lime was added to two different warm mix manufactured with Sasobit and Asphamin. Indirect tensile strength (ITS) and Tensile strength ratio (TSR, AASHTO T 283), without the freeze–thaw cycle, was used to evaluate the effect of different rates of hydrated lime on moisture susceptibility of warm mix asphalt.

2. Materials and test procedure

2.1. Materials

Experimental runs conducted in the present study included the use of control mixture (without any WMA additives), two commercially available WMA additives (Aspha-min® and Sasobit), two grading (Dense and Gap graded), two bitumen types (60/70 penetrations for conventional dense grading and PMB for SMA mixture as gap grading), hydrated lime as an anti-stripping agent, and a Siliceous aggregate source. The aggregates were brought in from a quarry using alluvial deposits of a local dried river that is commonly used in pavement construction due to lack of limestone crushed rock material in spite of their high stripping potential. This type of material is opting to stripping for its siliceous nature. The Polymer purchased from a firm in Germany was a grained thermoplastic synthetic material consisting of a mixture of premium polyethylene copolymer and a special type of bitumen (ECB). The polymer-modified bitumen was prepared at 160 °C. Polymer was gradually added to bitumen to reach 6.5% of bitumen mass while stirring at 350 rpm for about 15 min. Stabilizing fiber was added by a rate of 3.5 wt.% of mix to the mixture to reduce drain down of bitumen from SMA mixes. The physical properties of neat and modified bitumen are listed in Table 1 and the physical and engineering properties of aggregate are illustrated in Tables 2 and 3 respectively. A total number of 144 specimens were prepared from 24 different combinations of the mix compositions and analyzed by indirect tensile strength test.

Aspha-min® and Sasobit were utilized as WMA additives in this work. Aspha-min® powder is a sodium–aluminum–silicate crystal, which is hydrothermally crystallized into fine powder. The addition of Aspha-min (containing 21% water by weight) into the warm mix causes the release of all the crystalline water and forming a very fine water spray and a volumetric expansion of bitumen. This volume expansion will increase the workability and the compatibility of the mixture at lower temperatures [20].

Sasobit® is a Sasol Wax company production and is a fine crystalline, long-chain aliphatic polyethylene hydrocarbon extracted from coal gasification using the Fischer–Tropsch (F–T) process [21]. Sasobit forms a homogenous solution with the base bitumen when mixed at a rate of 1.5% by weight of the bitumen, and reduces the bitumen viscosity. Although there is no water in Sasobit structure, its interactions with bitumen, aggregate, and hydrated lime influences the stripping process.

Table 1
Physical properties of Bitumen.

Test	Standard	Result	
		60/70	PMB
Ductility at 25 °C (cm)	ASTM D 113	100	14
Penetration at 25 °C, 100 g (0.1 mm)	ASTM D 5	61	31
Softening point (°C)	ASTM D 36	50.1	57.8
Specific gravity at 25 °C	ASTM D 70	1.016	1.025
Fraass breaking point	EN 1427	–	−10

2.2. Mix design

Twenty-four samples of different combinations of grading, additive type and lime percent were made and tested, 12 were made using dense graded aggregate with 12.5 mm nominal-maximum aggregate size (NMAS) following D5 grading of ASTM D3515, and the other 12 with 12.5 mm NMAS gap grading (following AASHTO M325-08). The aggregate grading for dense graded and SMA mixtures is shown in Fig. 1a and b respectively.

Based on AASHTO R46-06, for effective performance, SMA must consist of a coarse aggregate skeleton with stone-on-stone contact. The condition of stone-on-stone contact within an SMA is defined as the point at which the void in coarse aggregate of the compacted mixture (VCA_{mix}) is less than the voids of coarse aggregate in the dry-rodded (VCA_{dry}) test. The selected grading of SMA mixtures (Fig. 1b) satisfied the requirement of the above-mentioned standard ($VCA_{mix} < VCA_{drc}$).

The design of HMA mixtures (dense graded) was performed according to the Marshall method with 75 blows on each side of cylindrical samples based on the MS-2 specification of Asphalt Institute. In accordance with MS-2, the optimum bitumen content was considered as the amount of bitumen required for maximum stability and with 4% air voids. The bitumen content determined was 5.6% by weight of mix.

As there is no standard specification available for WMA mixing and compaction temperature, the values listed in Table 4, were obtained from other available works [1,5,15,18,20,22–24].

The temperatures used to design SMA mixtures were based on recommendations of polymer manufacturing company and Tehran municipality asphalt plant that have used this polymer. The manufacturer of Aspha-min recommends 30 °C reduction in mixing and compaction temperature and Sasobit allows working temperatures to be decreased by 18–54 °C [18,20]. The applied temperatures are given in Table 4. The optimum bitumen content for SMA was defined as the amount of bitumen required to achieve 4% air void in accordance with AASHTO M325-08. Performing any further strength tests, which are conducted for other asphalt mixtures, was not required in SMA [25]. This requirement resulted in bitumen contents of 6.3% by weight of mix. Drain-down sensitivity of the SMA mixture with optimum bitumen content was performed based on AASHTO T305. The percentage of drain-down by weight of mixture measured was 0.16% which met the AASHTO M325-08 criteria (<0.3%).

2.3. Indirect tensile strength test procedure

Once the optimum bitumen content for two types of grading were determined, ITS specimen's preparation was initiated. The specimens were of 100 mm diameter and 63.5 ± 2.5 mm thickness. Specimens must have achieved 7 ± 0.5% air voids (for dense graded) based on T283, and 6 ± 1% air voids for SMA specimens (gap graded) following AASHTO M325-08. The Marshal Compactor was used to compact the specimens, and desired air voids were achieved with different trials with Marshal Hammer. After the appropriate number of blows was determined, six specimens were prepared for all types of mixtures containing the desired air voids, and then specimens were tested at 25 °C to determine the Indirect Tensile Strength values. Saturated specimens were conditioned using a vacuum saturated procedure in accordance with AASHTO T283.

3. Results and discussions

3.1. Analysis of dense graded mixtures

3.1.1. Dry ITS analysis of dense graded mixtures

Fig. 2 illustrates the dry ITS values of dense graded mixes. Based on the results presented in Fig. 2, Aspha-min samples show the lowest dry ITS values among the other samples regardless of the percentage of added hydrated lime. The minimum dry ITS values of warm mixture for Aspha-min and Sasobit are 637 and 655 kPa, respectively. These results are in agreement with those obtained in other work [26]. The minimum ITS values attained by the mixtures with Aspha-min can be attributed to the water release process in Aspha-min.

The foaming process caused by Aspha-min, leads to a complexity in re-distribution which can affect the mixture moisture susceptibility [1]. It is believed that the bitumen somewhat emulsifies due to the moisture release from the Aspha-min, causing a cohesion failure [20]. As a result, ITS values drop as the cohesion of bitumen decreases. The reduction of mixing and compaction temperatures can also reduce the adhesion between aggregate and bitumen. As shown in Fig. 2, when the amount of hydrated lime increases in the mix, dry ITS values of Aspha-min increases slowly. This

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