Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 3, No. 10, October, 2017

Effect of SBS Polymer and Anti-stripping Agents on the Moisture Susceptibility of Hot and Warm Mix Asphalt Mixtures

Hamed Omrani [a], Ali Reza Ghanizadeh [b*], Amin Tanakizadeh [c]

[a] *PhD Student, Tarrahan Parseh Transportation Research Institute, Tehran, Iran.*

[b] *Assistance Professor ,Department of Civil Engineering, Sirjan University of Technology, Sirjan, Iran.*

[c] *PhD Student, Faculty of Civil Engineering, Semnan University, Semnan, Iran.*

Received 11 September 2017; Accepted 29 October 2017

Abstract

The primary objective of this study is exploring the moisture susceptibility of unmodified and SBS-modified hot and warm mix asphalt mixtures. To this end, two different WMA additives including Aspha-min and Sasobit were employed to fabricate WMA specimens. The moisture susceptibility of warm polymer modified asphalt (WPMA) mixes was evaluated using modified Lottman test at 25°C according to AASHTO standard (T 283). In addition, the effect of different percentages of hydrated lime (from 0% to 2%) and Zycosoil (from 0% to 0.1%) as anti-stripping additives on the moisture susceptibility of the mixtures was explored. Based on the ITS test results, WPMA prepared with Sasobit additive and polymer modified asphalt (PMA) mixes satisfied the desirable tensile strength ratio (TSR) (above 80%) but Aspha-min WPMA mixes had TSR lower than 80%.

Keywords: Warm Mix Asphalt; Polymer Modified Asphalt; Modified Lottman Test; Zycosoil; Hydrated.

1. Introduction

Asphalt concretes are widely used materials that produced for paving of road surfaces. Cold Mix Asphalt (CMA), Half Warm Mix Asphalt (HWMA), Warm Mix Asphalt (WMA), and Hot Mix Asphalt (HMA) are four principal categories of asphalt concretes. The key parameters in this grouping are mixing temperature and energy consumption for production of these materials [1]. WMA is a new product of asphalt materials industry. It collects privileges such as reduced compaction and paving temperatures, increasing workability, lower compaction effort due to reduced viscosity, less fumes and green gas emission, reduced costs for maintenance of asphalt plants, reduced aging and more resistance against cracking, and acceptable performance of the mixtures. Based on additives and production processes, WMA mixtures are divided into four general class including organic or wax additives, chemical additives, water-based and water containing technologies [2]. Some issues impede the widespread usage of WMAs including conditioning and fabrication of samples in laboratory, inadequate coating of aggregates with bitumen, and vulnerability to rutting. Meanwhile, increased moisture damage in WMA mixtures because of improper drying of aggregates at low temperature is a more apparent mistake [3].

The most common way for measuring asphalt concrete moisture susceptibility is modified Lottman test according to AASHTO T 283 standard procedure. In this method, tensile strength of samples under dry and saturated conditions compared with each other and the tensile strength ratio defined as an index for judging about moisture susceptibility.

* Corresponding author: ghanizadeh@sirjantech.ac.ir

http://dx.doi.org/10.28991/cej-030931

The bitumen modification with polymers and application of anti-stripping agents are some methods to mitigate destructive effects of water on HMA mixtures. These solutions can be applied to WMAs to consider if they are effective in delaying moisture susceptibility.

This study investigates the moisture susceptibility of unmodified and SBS-modified warm mix asphalts. In addition, the effect of varying percentages of Zycosoil and hydrated lime as anti-stripping additives is evaluated. To this aim, WMA specimens were prepared with polymer-modified asphalt (PMA) and two WMA additives (Sasobit and Aspha-min). Finally, with application of modified Lottman test, the moisture susceptibility of warm polymer modified asphalt (WPMA) and WMA mixtures was determined.

2. Literature Review

2.1. Polymer Modification

Application of polymer-modified asphalt to achieve better pavement performance has been studied for a long time. The properties of PMA are dependent on the polymer characteristics, content and bitumen nature, as well as the blending process [4]. Elastomeric polymers such as styrene butadiene styrene (SBS) and styrene butadiene rubber (SBR) and plastomeric ones such as Ethyl-vinyl-acetate (EVA) were used in asphalt modification [5]. These polymer-modified mixtures are very effective for paving in some locations such as junctions, intersections, and airports where stress and traffic are high [6-8]. As the most proper polymer, SBS increases the elasticity of bitumen [9]. SBS modified asphalt mixes are more elastic than SBR modified asphalts especially at high temperature while SBR modified asphalts have better ductility at low temperature [10]. In a study by Behnood and Olek (2017) on the rheological properties of modified binders with SBS, styrene-butadiene-styrene (SBS), ground tire rubber (GTR) or poly phosphoric acid (PPA), the results showed that all of the modifiers improve performance of neat binder in high temperatures, while SBS and PPA have no significant effect on binder performance in intermediate temperatures. Also, no modifiers have significant effect on the performance of binder at low temperatures [11]. Comparing SBS and crumb rubber (CR) modified Asphalt concretes showed that the CR modified mixtures are more recoverable and crack initiation resistance are higher in this mixture, while crack propagation resistance decrease in CR modified mixture [12]. Kok and Yilmaz (2009) studied the effect of lime and SBS modifier on various properties of asphalt concrete especially moisture damage resistance. 2, 4 and 6% SBS added to asphalt concrete. The results showed that both of the modifiers improved stiffness, strength and stability of asphalt concrete. Also they reported that addition of only 2% lime have approximately same effect with addition of 6% SBS and mixtures containing both 2% lime and 6% SBS, have higher moisture resistance [13]. In other study by wei et.al (2017) on the effect of Diatomite and SBS on moisture sensitivity resistance of crumb rubber modified SMA, it has been shown that SBS modifier reduces air void and improve sensitivity moisture performance of these mixtures [14].

There are some believes that WMAs are compatible with SBS-modified bitumen, but according to Australian Asphalt Pavement Association (AAPA); probably using of FT-Wax and polymer modified bitumen simultaneously may not be rational. The beneficiary effects of wax on SBS-modified bitumen are less than on neat bitumen. On the other hand, the benefits of production and paving at lower temperatures than HMA make using FT-wax with modified binders worthwhile [15].

In a study on oxidative aging of WPMA with Sasobit and Aspha-min, aging levels were analyzed through large molecular size (LMS). Rolling thin-film oven (RTFO) and short-term oven aging (STOA) procedures were applied in standard form. This study showed that WMA additives reduces the aging level of WPMA mixes [8].

2.2. Moisture Susceptibility of WMAs

Due to less heating of WMA mixtures compared to HMA mixtures, some moisture may be remained in the aggregates. Hence, moisture susceptibility of WMA mixtures can be higher than HMAs and this matter is the biggest concern about WMA mixtures [16].

Solid research on moisture sensitivity of Sasobit, Aspha-min, and Evotherm WMA mixtures was done in Alabama [17]. Indirect tensile strength test (ITS) was performed at different compaction temperatures. The results showed that TSR (Tensile Strength Ratio) value of WMA is lower than HMA mixture in all cases. Only three of the nine samples had TSR value more than 0.8 (According to AASHTO 283). The type of aggregate made some differences in TSR values of mixtures. The results also showed that Aspha-min additives make a cohesive failure in all cases [13].

Xiao et al. in 2009 performed a laboratory study on moisture susceptibility of WMA using Aspha-min and Sasobit as the WMA additives. Experimental design included different aggregate sources with various moisture contents. The test results showed that increasing moisture content decreases moisture damage resistance. Addition of hydrated lime improves moisture susceptibility. The results also showed that moisture sensitivity was affected significantly by the source of used aggregate [18].

Another study by Xiao et al. investigates the effect of compaction temperature on rutting and moisture resistance of foamed warm mix asphalt mixtures. The results showed the aggregate source play key role in the ITS and rutting resistance regardless of other factors. The indirect tensile strengths increased with rising of compaction temperature. Mostly, warm mix asphalt with dried aggregate had TSR values greater than 80% [19].

A research by Kvasnak et al. in 2010 on moisture susceptibility of WMA produced using the Gencor® Ultrafoam GX® showed that dry and wet IDT (Indirect Diametric Tensile) strength values of the WMA mixtures are lower than the HMAs. The TSR value of WMA and HMA mixtures was 0.76 and 0.94, respectively. The WMA have lower TSR value than 0.80 (minimum recommended value by AASHTO T 283). In addition, some stripping was obvious in the broken WMA samples, while the HMAs have not stripping damage [20].

The results of research by Liu et al. on effect of Sasobit-modified warm mixture for Alaskan conditions indicated that Sasobit had no effect on moisture susceptibility of mixtures. They also showed that the tensile strength of warm mix asphalts decreases at low temperatures [21].

2.3. Anti-Stripping Agents

As it was mentioned, warm mix asphalts have low mixing and compaction temperatures and it can be resulted in incomplete drying of the aggregate. Therefore, anti-stripping additives (ASA) are employed to prevent the potential moisture damage. Hydrated lime is one of the most common anti-stripping agents [22]. According to findings of research studies in this field, anti-stripping additives can reduce the destructive impacts of water on asphalt mixes [23]. In mixing procedure of liquid ASAs with bitumen and other modifiers, chemical reactions occur between the ingredients that may be resulted in loss of bond in a mixture [24].

Hurley evaluated WMA moisture susceptibility using three different additives (Sasobit®, Aspha-min®, and Evotherm®). Investigating the useful effects of ASAs on moisture susceptibility of WMA mixtures, hydrated lime showed improved resistance to moisture damage of the Aspha-min® and Sasobit samples [25, 26].

Xiao et al. measured the moisture susceptibility of the mixtures containing anti-stripping and WMA additives. The anti-stripping agents were lime and two liquid ASAs added to WMA mixtures prepared with Aspha-min and Sasobit. The liquid ASAs have more moisture susceptibility than hydrated lime regardless of WMA additives and aggregate types [27].

Khodaii et al. evaluated the effect of preparation of asphalt mixtures with Zycosoil as an anti-stripping agent on moisture sensitivity of them. Moisture susceptibility was explored using the surface free energy method and laboratory dynamic modulus test. The method explores effective mechanisms of adhesive bond between the aggregate and the asphalt binder. With application of Zycosoil ASA, the required free energies of adhering asphalt bitumen to aggregate in dry and saturated conditions become more close to each other. Consequently, this leads to more moisture damage resistance of the mixture [28].

Hesami et al. studied the effect of using hydrated lime as anti-stripping additive on moisture susceptibility of WMA mixtures prepared with Sasobit and Aspha-min in a similar way. The results of the surface free energy method suggest that hydrated lime improves the adhesion between the asphalt binder and aggregate and decreases the moisture susceptibility of the mixtures [29].

Arabani et al. used surface free energy method for predicting moisture resistance of warm mix asphalt (with Sasobit and Aspha-min) modified with Zycosoil. With application of surface free energy and dynamic modulus results, an index was defined for comparing the moisture damage level of mixes. The result showed that WMA decreases free energy base components of bitumen which leads to increase of mixture moisture susceptibility. In addition, an increase in wet to dry dynamic modulus ratio was obvious for Zycosoil-contained samples in comparison with WMA mixes [30].

Xiao et al. studied the effect of long-term aging on WMA mixtures prepared with moist aggregates, 1 and 2% lime by weight of dry aggregates as anti-stripping, one liquid ASA, and five WMA additives (Aspha-min, Cecabase, Evotherm, Rediset, and Sasobit). They indicated that the resistance of WMA mixtures against moisture damage was improved with long-term aging. The aggregate type had a key role in controlling ITS values [31].

Kavussi et al. investigated the effect of aggregate gradation, hydrated lime, and Sasobit additive on moisture damage using indirect tensile tests and response surface method. The results indicated that dry samples had better mixing with binder than wet samples. The TSR value of samples with lime content ranging from 1.1% to 2.5%, Sasobit content from 0.5% to 2.5%, and fine aggregates from 66% to 74% was greater than 80% [32].

Based on the reviewed literatures, it seems that no comprehensive study has been conducted on the effect of simultaneous application of anti-stripping agents and polymer additives on the moisture susceptibility of WMA mixtures. This study aims to explore the effect of selected ASAs on the moisture damage resistance of WMA and WPMA.

3. Materials and Method

3.1. Materials

In this study, the AC 60-70 was used for fabricating of HMA and WMA mixtures and also for preparation of SBS-modified bitumen for PMA and WPMA mixtures. Based on previous researches, modification of bitumen with 5% SBS (by weight percent of bitumen) showed satisfactory results regarding performance of asphalt mixtures [31, 32]. Therefore, this SBS percentage (5%) was added to bitumen using a high shear mixer at speed of 3500 rotation per minute for about 15 minutes. The physical properties of neat and polymer-modified bitumen are given in Table 1.

Table 1. Properties of Asphalt bitumen (60/70 and PMB)

Test	Standard	Result	
		AC 60/70	PMB
Ductility at 25 °C (cm)	ASTM D113	100<	66
Penetration at 25 °C (0.1 mm)	ASTM D5	69	45
Softening point (°C)	ASTM D36	47	84
Specific gravity at 25 °C	ASTM D70	1.013	-
Flash point (°C)	ASTM D92	313	302
Thin-Film Oven Test	ASTM D1754	0.01	0.01

The crushed granite type aggregates were used for preparation of all mixes. The nominal maximum aggregate size of asphalt mixes was 19 mm. Figure 1 represents the gradation curve of the aggregates including lower and upper limits of MS-2 specifications of the Asphalt Institute [35]. Tables 2 and 3 summarize the physical and engineering properties of the aggregates, respectively.

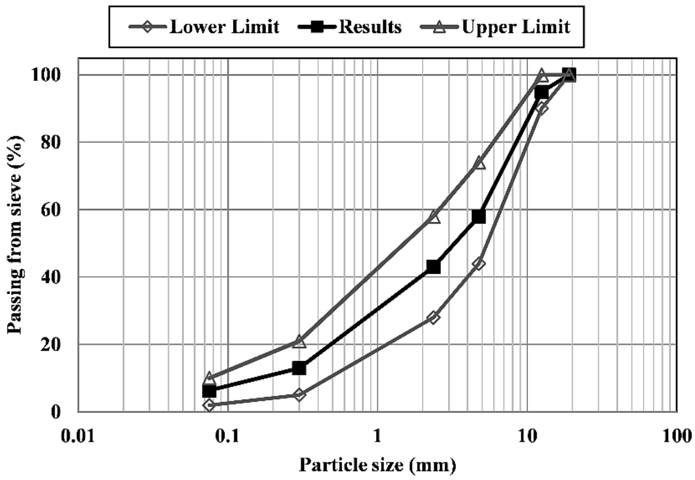


Figure 1. Aggregate gradation

In this study hydrated lime and Zycosoil were selected as anti-stripping agents. Zycosoil is a water-soluble reactive organo-silicon component, which reacts with the surface of aggregates and forms hydrophobic aggregates. The dosage of this anti-stripping additive is normally between 0.05% and 0.1% by weight of the bitumen.

Table 2. Physical properties of aggregate

Test	Standard	Value (%)	Asphalt Institute MS–2 specifications (%)
LA Abrasion loss	AASHTO-T96	18	30>
Crushed in one face	ASTM-D5821	96	90<
Crushed in two face	ASTM-D5821	84	-
Flakiness	BS – 812	17	25>
Sand equivalent	AASHTO-176	72	50<
Sodium sulphate soundness (Coarse)	AASHTO-104	1.3	12>
Sodium sulphate soundness (Fine)	AASHTO-104	7.1	8>

Table 3. Engineering properties of aggregate

Fraction	Standard	Specific gravity (g/cm^3)		Absorption (%)
		Apparent	Bulk	
Retained on 2.36 mm (No. 8)	AASHTO T85	2.66	2.53	2.00
Passed from 2.36 mm and retained on 0.075 mm	AASHTO T84	2.67	2.50	2.60
Passed from 0.075 mm	AASHTO T100		2.68	
Bulk specific gravity on blended aggregate			2.53	

The organic additive is Sasobit that is produced during coal gasification. It is a Fischer-Tropsch (FT) wax with fine crystalline and long-chain aliphatic polyethylene hydrocarbon. By lowering the viscosity of the bitumen, Sasobit improves asphalt flow during the asphalt mixing and laying down operations. Reduced working temperature is a result of this decrease in viscosity [36]. According to the producer recommendation, Sasobit can be used at a rate of 0.8 percent or more by weight of the bitumen that limited to 3 percent. It does not need a high shear mixer for blending into hot bitumen [37]. In this paper, Sasobit was added 1.5% by weight of the bitumen.

The water-containing additive, Aspha-min, is a synthetic Zeolite that is hydrothermally crystallized. It seems like a fine powder and was added at the rate of 0.3% by weight of the mixture. Simultaneously, the bitumen and Aspha-min were added to the mixture. Contained water in Aspha-min is evaporated that causes volume expansion and resulted in increasing workability and compactibility of the mixture [8, 25].

3.2. Mixture Design

The optimum bitumen content was determined using Marshall mix design procedure with 75 blows on each side of cylindrical samples according to the MS-2 specification [The Asphalt Institute 1997]. At the optimum bitumen content, mixture has maximum stability, maximum unit weight, and about 4% air void. The selected optimum bitumen content was 5.5% by weight of the mix. Based on the National Centre for Asphalt Technology (NCAT) recommendation, the same optimum bitumen content was used for fabricating of WMA mixtures. Research showed that the reduction of bitumen in WMA mixtures lead to some issues regarding durability, permeability, and water susceptibility of them [38]. Therefore, the same optimum asphalt content (5.5%) was adopted for WMA and HMA mixtures. Table 4 shows mixing and compaction temperature for different types of asphalt mixtures. In production process of WPMA mixture, bitumen was modified by SBS (5%) and then WMA additives were added to SBS-modified bitumen.

Table 4. Asphalt mixture composition and fabricated temperature

Mixture type	WMA		HMA	PMA (with 5% SBS)		
Warm mix additive	Aspha-min	Sasobit	-	Aspha-min	Sasobit	-
Type	foaming	organic	-	foaming	organic	-
Content (%)	0.3%*	1.5%	-	0.3%*	1.5%	-
Mixing temp (°C)	130-135	130-135	150-155	140-145	140-145	165-170
Compaction temp (°C)	115-120	115-120	145-150	135-140	135-140	160-165

* Content of Aspha-min additive is by percent weight of the mixture

3.3. Modified Lottman Test

At least six specimens with diameter of 100 mm, height of 63.5±2.5 mm, and air void of 7±0.5 for each mixture were prepared. The specimens were divided into two groups: unconditioned or dry and moisture-conditioned or wet. The dry group specimens were tested at 25°C with no special conditioning, whereas the wet group specimens were tested at the same temperature after partial saturation and moisture conditioning specified in AASHTO T 283. The tensile strength of the specimens was calculated as follows [39]:

$$S_t = \frac{2000P}{\pi t D} \tag{1}$$

Where, S_t is tensile strength (kPa), P is maximum load (N), t is specimen thickness (mm), and D is specimen diameter (mm).

The numerical index of resistance of mixtures to the damaging effect of water expressed as the ratio of the original strength test that is retained after the moisture conditioning. Tensile Strength Ratio (TSR) was calculated using Eq. (2) [35]:

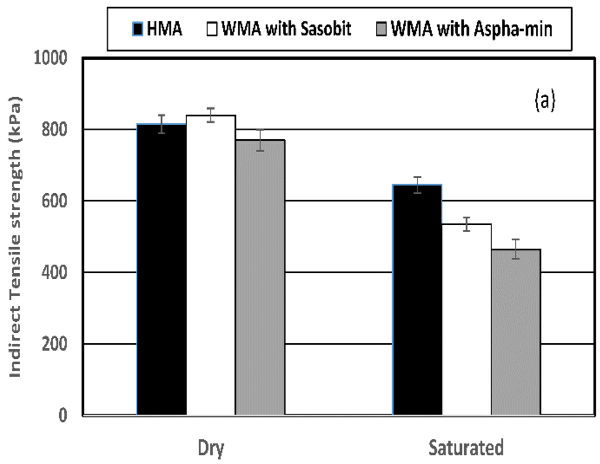
$$Tensile\ Strength\ Ratio\ (\mathrm{TSR}) = \frac{S_2}{S_1} \quad (2)$$

Where, S_1 is the average tensile strength of the dry subset (kPa) and S_2 is the average tensile strength of the conditioned subset (kPa).

4. Results and Discussion

4.1. Analysis of WMA Mixtures

The dry indirect tensile strength of HMA mixture is approximately same as WMA samples (Figure 2a). In wet condition, HMA has the highest value of ITS followed by WMA with Sasobit and WMA with Aspha-min. It may be due to lack of aggregate coating with asphalt weakens bonds between aggregates because of lower viscosity of WMA binders. This matter is more obvious for WMA with Aspha-min that evaporated water bubbles, produced through fabrication, make voids for water seepage and consequently weakening of asphalt-aggregate bonds. As shown in Figure 2b, WMA mixtures have TSR values about 60%, lower than 80%; make them vulnerable for application in wet conditions.



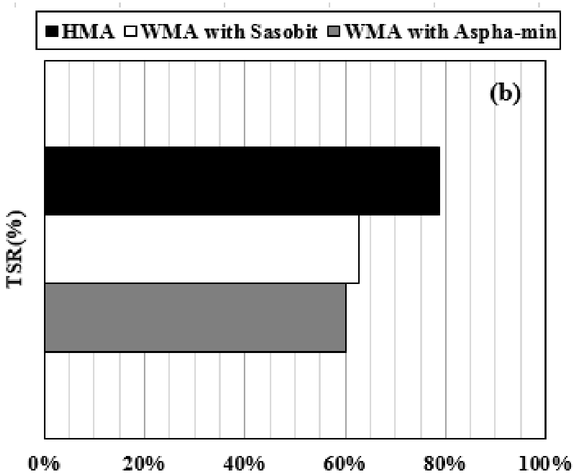
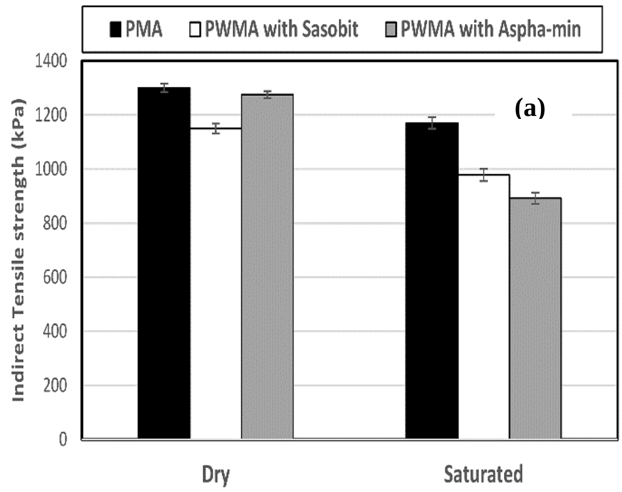


Figure 2. (a) Dry and saturated ITS of HMA & WMA mixtures (b) TSR of HMA & WMA mixtures

4.2. Analysis of WPMA Mixtures

Figures 3a and 3b. illustrates dry and saturated ITS and TSR values of asphalt mixtures, respectively. As can be seen, PMA mixture has the highest value of ITS. The saturated ITS values of WPMA with Sasobit are higher than WPMA with Aspha-min whereas the dry ITS values of WPMA with Sasobit are lower than WPMA with Aspha-min, which can be related to the release of evaporated water bubbles formed between aggregate and bitumen.



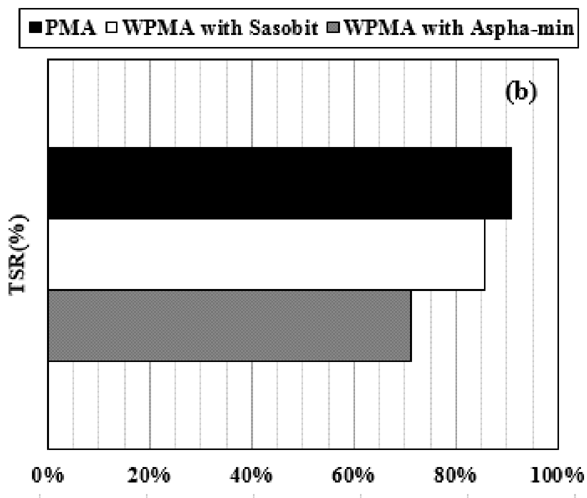


Figure 3. (a) Dry and saturated ITS values and (b) TSR of PMA & WPMA mixtures

In addition, PMA mixture and WPMA mixture with Sasobit have TSR values greater than 80%, which is the criterion specified by the AASHTO T 283. TSR value of WPMA with Aspha-min was 71%, which is lower than 80%. The PMA mixtures have highest value of TSR, which can be related to lower water presence in mixtures due to higher mixing temperature of them. Based on these results, WPMA prepared with Sasobit shows desirable behavior from moisture susceptibility view. However, some cautions must be considered because of lower tensile strength of them. It emphasizes that only TSR cannot be enough for moisture damage evaluation and individual ITS values may be considered for better evaluation of moisture susceptibility.

4.3. Analysis of WMA Mixtures with Anti-Stripping Agents

Figures 4, 5, and 6 depict dry ITS, saturated ITS, and TSR values of HMA and WMA mixtures modified by anti-stripping agents (Lime and Zycosoil), respectively. In dry condition (Figure 4), the tensile strengths of all mixtures were nearly same and effect of ASAs was not noticeable.

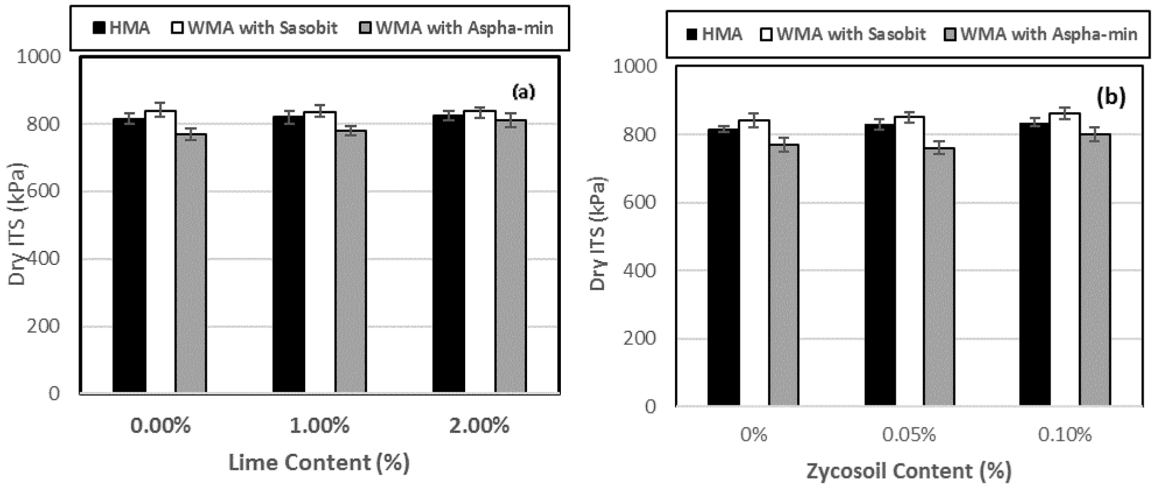


Figure 4. Dry ITS values of HMA & WMA mixtures containing (a) Lime and (b) Zycosoil

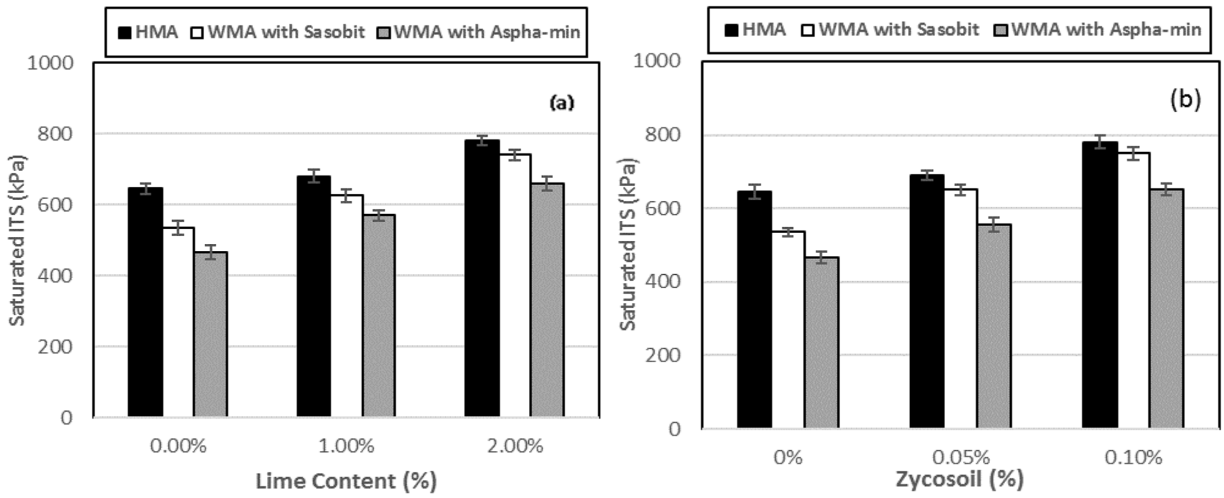


Figure 5. Saturated ITS values of HMA & WMA mixtures containing (a) Lime and (b) Zycosoil

The saturated ITS values, as shown in Figure 5, increased by addition of more percentages of ASAs, especially for WMA mixtures. In the other word, the effect of ASAs on wet tensile strength of WMA mixes was more significant than HMA samples. This may be representative of good compatibility between WMA additives and ASAs. Comparing the TSR values of samples, all the mixtures satisfied standard criterion (80%) and the ratio was greater for HMA that followed by WMA with Sasobit and WMA with Aspha-min (Figure 6). Lime and Zycosoil showed similar effect on tensile strength and TSR values despite lower dosage of Zycosoil added to mixtures (about 5% of lime).

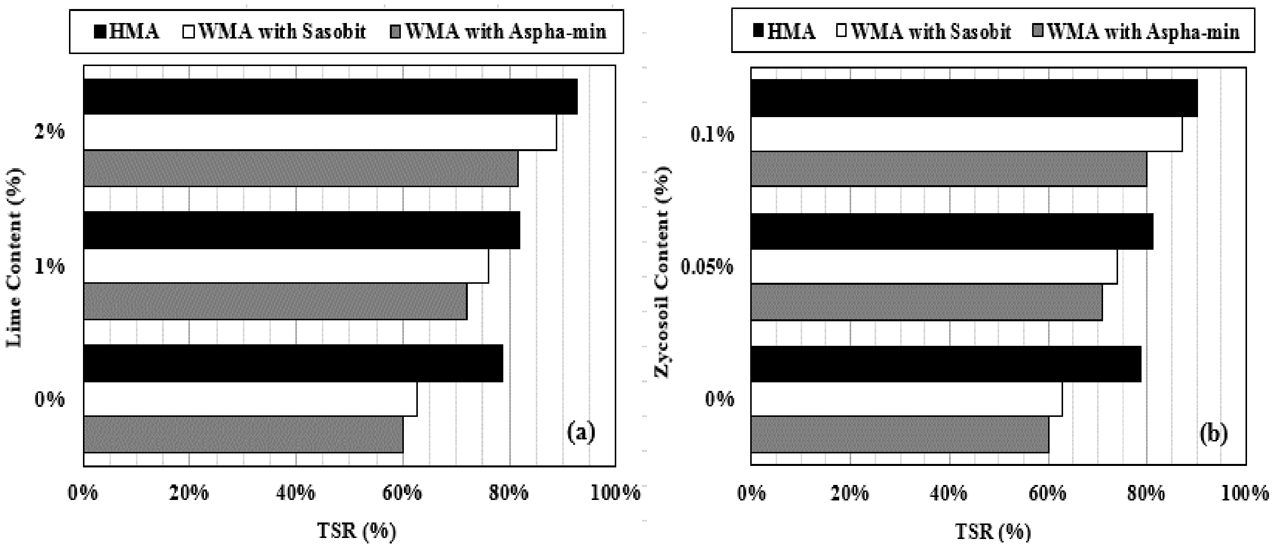


Figure 6. TSR of HMA & WMA mixtures containing (a) Lime and (b) Zycosoil

By comparing the results of unmodified HMA and WMA mixtures with ASA-modified ones, it can be inferred that dry tensile strengths were identical but saturated tensile strengths improved about $200\ kPa$. TSR values grew about 20%, therefore will not be vulnerable to water conditions.

In comparison with WPMA mixtures, the ASA-modified WMA mixtures have fewer tensile strengths about $300\ kPa$. However, TSR values were nearly same except one of WMA with Aspha-min that was about 20% more than corresponding WPMA. The authors deduced that modification of Aspha-min WMA with anti-stripping agents is more effective and favorable than polymer modification. This conclusion is only according to TSR values. The ITS values of Aspha-min WPMAs were better than ASA-modified WMAs.

5. Conclusion

This study reported a comparison between moisture susceptibility of WMA and WPMA mixtures. In addition, a part of the research work focused on examining the effects of anti-stripping agents including lime and a nanomaterial, Zycosoil, on moisture sensitivity of control HMA samples and WMAs prepared with Sasobit and Aspha-min additives. Based on the results of this study the remarkable conclusions is as follows:

- The warm mix asphalt mixtures prepared with Sasobit and Aspha-min additives presented undesirable behavior under water conditioning. The saturated tensile strengths (about $500\ kPa$) were fewer than control HMA mix (with strength more than $600\ kPa$) and TSR values (fewer than 65%) did not satisfy the standard criterion of 80%.
- The warm polymer modified asphalt mixtures have extended indirect tensile strengths both in dry and wet conditions, about $500\ kPa$ more than unmodified mixes. TSR values of PMA and WPMA mixtures improved in comparison with unmodified ones and reached more than standard criterion of 80% except for WPMA mixture prepared with Aspha-min that did not satisfied this requirement.
- The mixtures modified with anti-stripping agents of lime and Zycosoil had nearly similar dry tensile strength but the saturated ITS values were better than control mixtures. The effect of lime and Zycosoil on tensile strength of samples in wet condition was same. With addition of anti-stripping agents, TSR values for all mixtures satisfied the standard requirement and the specimens showed favorable behavior against moisture. Zycosoil with concentrations about 5% of lime had good performance in mitigating the moisture damage of WMA mixtures.
- Despite of lower tensile strength of ASA-modified WMA mixtures versus WPMA ones, they had same TSR values except for Aspha-min WMA with improved TSR, nearly 20% more than corresponding WPMA mix. This behavior may be strengthen a hypothesis that ASAs are more effective than polymers for modification of WMA mixtures prepared with water containing additives.
- Occasionally, where the extended tensile strength is a design requirement, WPMA mixtures excel ASA-modified WMA mixes. Generally, it is more reasonable to consider individual ITS values rather than single TSR values for measuring moisture susceptibility of WMA mixtures.
- Further studies can be done on effects of different polymers and anti-stripping agents on moisture sensitivity of WMA mixes produced with various technologies, specifically foaming or water containing ones.

6. References

[1] Kilas, M.; Vaitkus, A.; and Paliukaitė, M. "Warm Mix Asphalts research, analysis and evaluation", 10th international conference "Modern Building Materials, Structures and Techniques", 2010 Vilnius Gediminas Technical University, Vilnius, 2010

[2] Zaumanis, M.; and Haritonovs, V. "Research on properties of Warm Mix Asphalt". Scientific Journal of Riga Technical University Construction Science, 11 (2010): 77-84.

[3] NCHRP, "Evaluation of the moisture susceptibility of WMA technologies", TRB's National Cooperative Highway Research Program (NCHRP) Report 763, Washington DC.

[4] Zhang, J., Wang, J., Wu, Y., Sun, W., & Wang, Y. "Thermal behavior and improved properties of SBR and SBR/natural bitumen modified bitumens", Iranian Polymer Journal, 18(6) (2009): 465-478.

[5] Ping, P.E.; Xiao, Y. (2009). "Effects of aggregate gradation, aggregate type, and SBS polymer modified bitumen on Florida HMAC fracture energy properties (Report No. OMNI 021037)", Department of Civil & Environmental Engineering, College of Engineering, Florida A&M University- Florida State University, Tallahassee.

[6] Yildirim, Y. "Polymer modified asphalt bitumen", Construction and Building Materials, 21 (2007):66–72.

[7] Lavin, P. "Asphalt pavements: A practical guide to design, production, and maintenance for engineers and architects", Spon Press, London, 2003.

[8] Kim, H.; Lee, S.J.; and Amirkhanian, S.N. "Influence of warm mix additives on PMA mixture properties", Journal of Transportation Engineering, 138(8) (2012): 991-997.

[9] Sengoz, B.; and Isikyakar, G. "Analysis of styrene-butadiene-styrene polymer modified bitumen using fluorescent microscopy and conventional test methods", Journal of Hazardous Materials, 150(2) (2008): 424-432.

[10] Johnston, J.B.; and King, G. (2008). "Using polymer modified asphalt emulsions in surface treatments", A federal lands highway interim report.

[11] Behnood, Ali, and Jan Olek. "Rheological properties of asphalt binders modified with styrene-butadiene-styrene (SBS), ground tire rubber (GTR), or polyphosphoric acid (PPA)." Construction and Building Materials 151 (2017): 464-478.

[12] Yılmaz, Mehmet, Alaaddin Geçkil, and Baha Vural Kök. "Evaluation of the low temperature and elastic properties of crumb rubber and SBS modified bitumen and mixtures." (2013).

[13] Kok, Baha Vural, and Mehmet Yilmaz. "The effects of using lime and styrene–butadiene–styrene on moisture sensitivity resistance of hot mix asphalt." Construction and building materials 23.5 (2009): 1999-2006.

[14] Wei, Haibin, Ziqi Li, and Yubo Jiao. "Effects of Diatomite and SBS on Freeze-Thaw Resistance of Crumb Rubber Modified Asphalt Mixture." Advances in Materials Science and Engineering 2017 (2017).

[15] Zaumanis, M. "Warm mix asphalt investigation", M.S. Thesis. Technical University of Denmark, 2010

[16] Anderson, R. M., Baumgardner, G., May, R., & Reinke, G. "Engineering properties, emissions, and field performance of warm mix asphalt technologies", Interim Report, 2008.

[17] Hurley, G.C.; and Prowell, B.D. "Evaluation of Potential Processes for Use in Warm Mix Asphalt", Journal of the Association of Asphalt Paving Technologists, 75, 2006: 41-90.

[18] Xiao, F.; Wenbin Zhao, P.E.; and Amirkhanian, S.N. "Fatigue behavior of rubberized asphalt concrete mixtures containing warm asphalt additives", Construction and Building Materials, 23(10) (2009):3144-3151.

[19] Xiao, F.; Punith, V.S.; and Putman, B.J. "Effect of Compaction Temperature on Rutting and Moisture Resistance of Foamed Warm-Mix-Asphalt Mixtures", Journal of Materials in Civil Engineering, 25(9) (2013):1344-1352.

[20] Kvasnak, A., Taylor, A., Signore, J., & Bukhari, S. "Evaluation of gencor green machine ultrafoam GX (NCAT Report 10-03)". Auburn, AL: National Center for Asphalt Technology, 2010.

[21] Liu, J., Saboundjian, S., Li, P., Connor, B., & Brunette, B. "Laboratory evaluation of Sasobit-modified warm-mix asphalt for Alaskan conditions", Journal of Materials in Civil Engineering, 23(11), (2011):1498-1505.

[22] Rubio, M. C., Martínez, G., Baena, L., & Moreno, F. "Warm mix asphalt: an overview", Journal of Cleaner Production, 24, 2012:76-84.

[23] Xiao, F.; and Amirkhanian, S.N. "Effects of liquid antistrip additives on rheology and moisture susceptibility of water bearing warm mixtures", Construction and Building Materials, 24(9), (2010):1649-1655.

[24] Smith, B.S. "Design and construction of pavements in cold regions: state of the practice", M.S Thesis, Brigham Young University, 2006.

[25] Hurley, G.C.; and Prowell, B.D. "Evaluation of Aspha-Min zeolite for use in warm mix asphalt (NCAT report 05-04)", National Centre for Asphalt Technology, Auburn University, 2005.

[26] Hurley, G.C.; and Prowell, B.D. "Evaluation of Sasobit for use in warm mix asphalt (NCAT report 05-06)", National Centre for Asphalt Technology, Auburn University, 2005.

[27] Xiao, F., Zhao, W., Gandhi, T., & Amirkhanian, S. N. "Influence of anti-stripping additives on moisture susceptibility of warm mix asphalt mixtures", Journal of Materials in Civil Engineering, 22(10), (2010):1047-1055.

[28] Khodaii, A., Khalifeh, V., Dehnad, M. H., & Hamedi, G. H. "Evaluating the effect of zycosoil on moisture damage of hot-mix asphalt using the surface energy method", Journal of Materials in Civil Engineering, 26(2), (2013):259-266.

[29] Hesami, S., Roshani, H., Hamedi, G. H., & Azarhoosh, A. "Evaluate the mechanism of the effect of hydrated lime on moisture damage of warm mix asphalt", Journal of Construction and Building Materials, 47, (2013):935-941.

[30] Arabani, M.; Roshani, H.; and Hamedi, G.H. "Estimating moisture sensitivity of warm mix asphalt modified with Zycosoil as an antistrip agent using surface free energy method". Journal of Materials in Civil Engineering, 24(7), (2011):889-897.

[31] Xiao, F., Punith, V. S., Amirkhanian, S. N., & Thodesen, C. "Improved resistance of long-term aged warm-mix asphalt to moisture damage containing moist aggregates", Journal of Materials in Civil Engineering, 25(7), (2012):913-922.

[32] Kavussi, A., Qorbani, M., Khodaii, A., & Haghshenas, H. F. "Moisture susceptibility of warm mix asphalt: a statistical analysis of the laboratory testing results", Construction and Building Materials, 52 (2014):511-517.

[33] Cortizo, M. S., Larsen, D. O., Bianchetto, H., & Alessandrini, J. L. "Effect of the thermal degradation of SBS copolymers during the ageing of modified asphalts", Journal of Polymer Degradation and Stability, 86(2) (2004): 275-282.

[34] Khodaii, A.; and Mehrara, A. "Evaluation of permanent deformation of unmodified and SBS modified asphalt mixtures using dynamic creep test", Construction and Building Materials, 23 (2009):2586–2592.

[35] The Asphalt Institute . "Mix design methods for asphalt concrete and other hot-mix types (MS-2)", 6th ed., Asphalt Institute, Lexington, 1997.

[36] Abraham, J., Butz, T., Hildebrand, G., & Riebesehl, G. "Asphalt flow improvers as' intelligent fillers' for hot asphalts-a new chapter in asphalt technology", Journal of Applied Asphalt Binder Technology, 2(1) (2002):36-69.

[37] Brits, C.H. "Sasobit investigation (Report No. 100035/S9/2004/11/05/CHB/Av/1). Geostrada Engineering Materials Laboratory", South Africa, 2004.

[38] Chowdhury, A.; and Button, J.W. "A review of warm mix asphalt", Report No. SWUTC/08/473700-00080-1, Texas Transportation Institute, the Texas A&M University System, College Station, 2008.

[39] AASHTO "AASHTO Designation T 283: Standard method of test for resistance of compacted hot mix asphalt (HMA) to moisture-induced damage", 2012.