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Effect of Commercial Wax and Typical Additives on Moisture Susceptibility of SMA Mixtures

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Abstract: The deteriorating effect of moisture could result in premature failure of asphalt concrete caused by segregating the asphalt film from the aggregate surface. Warm mix asphalt has been recently known as a new method used in pavement industry that provides a range of technologies by which the construction temperatures of asphalt mixtures could decrease. This fact could bring some problems in terms of moisture sensitivity of asphalt concrete. The effect of warm mix asphalt additives on moisture sensitivity of asphalt mixtures (especially Stone Matrix Asphalt (SMA) mixtures) has not been completely identified. In this study, two types of additives such as a warm mix asphalt additive (wax) and regular additives (Styrene-Butadien-Styrene, cellulose fiber and mineral fiber) were added to SMA mixtures to investigate the effect of these additives in improving the susceptibility of SMA mixtures when exposed to the moisture. Moisture susceptibility of each kind of mixtures was evaluated by performing Indirect Tensile Strength (ITS) test in dry and preconditioned forms. The results indicated that Fischer-Tropsch waxes did not have the capability to reduce the binder drain down, thus the use of fibers should be considered as an obligation in warm SMA mixtures. Although, waxes could not significantly improve the moisture sensitivity, 3% and 4% of wax slightly increased the Tensile Strength Ratio (TSR) value. It was also observed a very good trinomial correlation between percents of wax and ITS or TSR values using statistical analysis ($R^2 = 1$). In addition, SBS modified mixtures had the highest ITS/TSR values among all SMA specimens. There was no significant difference between ITS/TSR values of two types of fiber.

Key words: Indirect tensile strength, warm mix asphalt, durability, styrene-butadien-styrene, fiber

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INTRODUCTION

Damage due to moisture has been identified as a critical problem for asphalt concrete pavements in the United States (Hicks *et al*., 2003), as well as in other areas of the world. As described by Kiggundu and Roberts (1988), an extensive definition of stripping could be written as a progressive deterioration in structure of asphalt pavements in presence of moisture as a result of loss of adhesion between binder and aggregate or decrease of binder cohesion or aggregate degradation.

Meanwhile, in recent years, WMA technology has been employed to reduce the construction temperatures of asphalt concrete (Hamzah *et al*., 2010; Hurley, 2006). Lower temperatures could result in numerous positive consequences. Emissions reduction, longer haul distances, cost savings, possibility of implementation in cold seasons and decrease in mixture aging could be considered as the most distinguished advantages of utilizing WMA technology (Gandhi, 2008).

One of the widely used categories of WMA technology is by employing some types of organic additives or waxes. These additives are directly added to the mixtures in order to lower the level of desired construction temperatures. Among organic additives, FT waxes have been often used in order to decrease asphalt temperature without significantly affecting the properties of the mixtures. Waxes may slightly increase the moisture susceptibility of asphalt mixtures through decreasing the adhesion between binder and aggregate (Kanitpong *et al*., 2007; Wasiuddin *et al*., 2008; Sheth, 2010). Nevertheless, some other investigations have reported an improvement in moisture sensitivity when using waxes in decreasing the construction temperatures (Gandhi, 2008; Merusi *et al*., 2010; Sanchez-Alonso *et al*., 2010). Also, numerical reports concluded there are inconsistent results in terms of moisture susceptibility of WMA mixtures (Hurley and Prowell, 2005; Hurley, 2006; Sampath, 2010).

In addition, a rut resistant mixture, SMA is a gap graded hot mix asphalt that acquire its resistance from

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stone skeleton of coarse aggregate. Coarse aggregate fraction of this type of mixture is glued together with a durable and moisture-resistant mortar comprising asphalt cement, filler and stabilizing additive (Brown and Manglorkar, 1993). According to the reports, stone matrix asphalt has indicated more durability as a surface asphalt concrete (Al-Hadidy and Tan, 2009). Some of positive properties of SMA mixtures comprise its high rut resistance, high skid resistance, high durability, improved resistance to reflective cracking, better drainage condition and reduced noise pollution. The main reason of using a gap gradation in these mixtures is to establish stone on stone condition to resist against permanent deformation. Due to both the gap-graded nature of SMA mixes and the relatively large amount of asphalt content (typically 5.5-7.5%), it needs to be stabilized in order to inhibit drain down of asphalt binder (Nejad *et al*., 2010). There are two mainly types of additives used in these mixtures: Fibers and Polymers. Fibers such as polyester fiber, mineral fiber and cellulose fiber are often used in ordinary SMA mixtures to significantly decrease the amount of binder drain down (Behbahani *et al*., 2009; Tayfur *et al*., 2007). In contrast, a polymer may used in these mixtures to improve the mechanical properties of asphalt mixtures and relatively decrease the binder drain down. Different types of polymers (such as styrene-butadiene-styrene (SBS), polyethylene or polypropylene) may be used to gain desired mixture properties. To construct more rut-resistant SMA mixtures, it is possible to use both polymers and fibers at the same time.

Altogether, the number of studies performed to evaluate the effect of FT waxes on moisture susceptibility of HMA mixtures may be considerable, while there is a strong need to identify how these additives affect the properties of SMA mixtures in terms of moisture sensitivity.

The main purposes of this research were as followings:

- Feasibility of using 9.5 mm SMA gradation recommended by NCHRP No. 425 (Brown and Cooley, 1999) on the Iranian materials
- Make a laboratory comparison between properties of base, wax-modified and SBS-modified binders
- Evaluation of ITS values for SMA mixtures modified with different additives
- Compare the ability of different fibers (cellulose and mineral) to improve the moisture sensitivity of SMA mixtures
- Evaluate the effect of a WMA additive (FT wax) on moisture susceptibility of SMA mixtures
- Investigate how fibers and polymers can improve the moisture sensitivity of SMA mixtures and make a comparison between them

MATERIALS AND METHODS

Materials

Mineral aggregate: To begin the experimental phase of this study (Summer and Fall in 2010), Mineral Aggregate was supplied from Kandovan-Pars Asphalt Plant (Asb-cheran mine) located in the northeast part of Tehran, Iran. The properties of aggregate were presented in Table 1.

Mineral filler: Because of the large amount of the mineral filler used in SMA mixtures (usually up to 10%), it plays an important role to specify the properties of the mixture. In this investigation, Rock dust, Passed through sieve No. 200 was used as mineral filler. The bulk specific gravity of used filler is 2.702 kg cm^{-3}.

Asphalt cement: In order to construct SMA samples, asphalt binder (AC-60/70) was provided from Tehran Refinery and Pasargad Oil Company, Tehran, Iran. Physical properties of this binder were provided in Table 2.

Fiber: In order to reach 3-4% of air void in SMA mixtures, using a large amount of bitumen is essential. Therefore, drain down could be one of the most important problems in these mixtures. The main objective of adding fibers in SMA mixtures is to reduce binder drain down. Among

Table 1: Properties of coarse and fine aggregates

Properties	Method (AASHTO M 43-88 (2003), 2004)	Requirement	Values
Coarse aggregate			
Los Angeles Abrasion (%)	AASHTO T96	30 max.	20
Water absorption (%)	AASHTO T85	5 max.	0.8
Bulk specific density (g cm^{-3})	AASHTO T85	-	2.654
Flat and Elongated (3 to 1) (%)	ASTM D4791	20 max.	12
Soundness (Sodium Sulfate) (%)	AASHTO T104	15 max.	4.8
Crushed Content (One Face) (%)	ASTM D5821	100 min.	100
Crushed Content (Two Faces) (%)	ASTM D5821	90 min.	100
Fine aggregate			
Water absorption (%)	AASHTO T84	-	1.4
Bulk specific density (g cm^{-3})	AASHTO T84	-	2.617

Table 2: Physical properties of asphalt cement

Parameter measured	Test method	Test value
Specific gravity at 25°C, (g m^{-3})	AASHTO T228	1.01
Penetration at 25°C, (0.1 mm)	AASHTO T49	63
Softening point (R and B) (°C)	AASHTO T53	51
Viscosity at 135°C, (centistokes)	AASHTO T201	361
Ductility at 25°C, (cm)	AASHTO T51	>100

Table 3: Physical properties of FT wax

Properties	Values
Penetration at 25°C (0.1 mm)	0.9-1.6
Melting point (°C)	68-72
Density at 70°C (kg cm^{-3})	780
Color	white
Recommended dosage, (% by weight of binder)	2-4

Table 4: Properties of ITERPRENE SBS/G-L®

Properties	Test method	Unit	Typical value	Specification limits
Specific weight at 23°C	ASTM D792	(g L^{-1})	0.94	0.92-0.95
Styrene content	ASTM D1416	% wt	32	30.5-33.5
Ash content	ASTM D1416	% wt	0.9	≤1
Oil content	ASTM D1416	phr	0	<2
Volatiles content	ASTM D1416	(%)	0.6	<1
Hardness	ASTM D2240	Shore A	75	72-78

different types of fibers, cellulose and mineral fibers have been widely used. Cellulose and mineral fibers were added to the SMA mixtures at the rate of 0.3% and 0.4% by weight of the mixture, respectively. At the time of preparing samples and exactly before adding the asphalt cement, the measured amount of fibers was added and mixed with aggregate to result in a uniform mixture.

FT waxes: As described before, FT waxes are usually used to reduce the cost of asphalt concrete producing through decreasing mixing and compaction temperatures. Rheofalt®LT-70 that is easily accessible in Iran is a FT wax used for preparation of WSMA specimens. In order to blend binder and FT wax, a calculated amount of wax was carefully added to the preheated binder at 150°C; the combination was then stirred for at least 10 min by using a low speed stirrer. The basic properties of this wax was presented in Table 3.

Styrene-butadien-styrene: Among different kinds of polymers, SBS is one of the most widely used, which can extremely improve the high as well as low temperature performance of asphalt mixtures at. In this research, ITERPRENE SBS/G-L® was used to modify asphalt binder. In order to mix the binder with polymer, 5% of SBS by weight of asphalt cement was added to the heated binder (170°C). At this temperature, the rotation speed was regulated at 1500 rpm. After about 30 min, the speed increased up to 4000 rpm for 1 h to make a homogeneous modified binder. The specification of the used SBS in this study is as shown in Table 4.

Mixture design

Mixing and compaction temperatures: The mixing and compaction temperatures for constructing SMA specimens were selected in a way that the viscosities are 170±20 and 280±30 cSt, respectively (Brown and Manglorkar, 1993). This criterion was considered to determine the mixing and compaction temperature for base and modified binders. Based on the producer's recommendation, the selected dosages of wax in this study were 2, 3 and 4% by weight of binder. However, construction temperatures for SBS modified binder were 175 and 165°C recommended by manufacturer.

Table 5: SMA mixtures specifications for marshall hammer compacted designs (Brown and Cooley, 1999)

Property	Requirement
Air Void (%)	3-4
VMA (%)	17 min
VCA_{MIX}	Less than VCA_{DRC}
TSR (%)	70 min
Drain down @ production temperature (%)	0.30 max

Optimum gadation: The mixture design method used for SMA was as proposed by NCHRP Report No. 425 (Brown and Cooley, 1999). The 9.5 m SMA gradation was selected to prepare all SMA specimens. The data accumulated from a study performed by Cooley and Brown (2003) showed that fine gradation SMA mixture (9.5 and 4.5 mm) could be successfully designed to have stone-on-stone contact and be rut resistant. Additionally, finer SMA mixes are more durable than coarser ones; however, it needs more effort to be compacted. To evaluate volumetric properties of mixtures with different gradation limits, a number of 12 samples (four identical samples for each) were fabricated according to the Marshall mix design (ASTM D-1559) procedure. Laboratory specimens were prepared using fifty blows of the Marshall hammer per side. Seventy-five compaction blows were not used since they would not result in a significant increase in density over that provided by 50 blows (Al-Hadidy and Yi-Qiu, 2009) and would also cause more breakdown in coarse aggregate (Asi, 2006). The optimum gradation should be selected in such a way that the VCA ratio was less than 1 in order to establish stone on stone condition in all SMA samples.

Optimum binder content: In this section, it is important to select Optimum Binder Content (OBC) to meet the requirements presented in Table 5 described by NCHRP Report No. 425. With this regard, three series of SMA mixtures should be prepared for each set of mixture to calculate the OBC for control/SBS/wax, cellulose and mineral modified mixtures. Different percentages of binder should be added to each subset to both evaluate volumetric properties of mixtures and determine the amount of OBC. It should be noted that the OBC for each subset in this section was considered in such a way that all specimens met 4% air void.

Drain down: In order to evaluate the potential of drain down for SMA mixtures, a test procedure described by

NCHRP Report No. 425 was conducted for all mixtures. Thus, for each set of mixture, a standard wire basket containing uncompacted SMA sample along with a plate were placed in an oven at the mixing temperature. After about 1 h, the amount of binder drain down was calculated by Eq. 1:

$$\text{Draindown}(\%) = \frac{B - A}{W} \times 100 \quad (1)$$

where, A is Initial plate mass: B is weight of plate plus drained materials: and W is Loose sample mass.

MOISTURE SENSITIVITY

Mechanism and concept of moisture damage: For many years, it has been considered that the failure rate of pavements may increase considerably when water can easily get into the pavements. In some cases the failure includes complete separation of the asphalt mixes just within a few years after its construction (Sha, 1999).

The moisture can affect asphalt mixtures in three different ways: loss of cohesion, loss of adhesion and aggregate degradation. The loss of cohesion and adhesion are more prominent to the process of stripping. A reduction in cohesion results in a reduction in strength and stiffness. The loss of adhesion is the physical separation of the asphalt cement and aggregate (Fig. 1), primarily caused by the action of moisture (Khosla and Harikrishnan, 2007). There is a close relationship between the permeability of the mixture and possibility of moisture damage to occur. If asphalt pavements are impenetrable, moisture damage would seldom happen; however, it may result in a excessive permanent deformation of pavement under heavy traffic and occurrence of bleeding phenomenon at high temperatures (Terrel and Al-Swailmi, 1994).

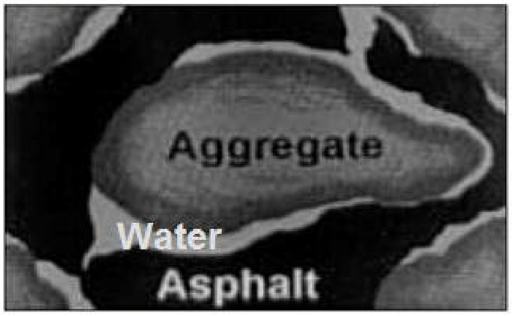

Fig. 1: The Effect of Water in Asphalt Mixture (D'Angelo and Anderson, 2003)

Moisture damage measurement: In the case of moisture damage measurement, tensile strength is one of the most critical parameters to be always taken into consideration for performance evaluation. This test is used to determine the tensile properties of the asphalt concrete, which can be further related to the cracking properties of the pavement. The tensile strength is primarily a function of binder properties. The amount of asphalt binder in a mixture and its stiffness affect the tensile strength. Tensile strength also depends on the absorption capacity of the used aggregates (Khosla and Harikrishnan, 2007).

Moisture sensitivity of a mixture could be evaluated by performing the AASHTO T-283 test. As defined in this procedure, the indirect tensile strength of mixtures should be measured by applying compressive loads along a diametrical plane through two opposite loading strips for both dry and preconditioned specimens. This test does not seem to be a very accurate indicator of stripping but it could help to minimize the problem (Brown *et al.*, 2001).

Specimen preparation and test procedure: Each SMA mixture in this phase was compacted at 6±1 percent of air void by adjusting the number of blows as described by NCHRP Report No. 425. Two subsets (three identical samples for each) were produced in the laboratory for each set of mixtures. One subset was tested dry at 25°C and the other one was preconditioned before testing in warm-water bath for 24 h at 60°C. Maximum applied force was measured for each set; Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR) were then calculated by Eq. 2 and 3.

$$\text{ITS} = \frac{2P}{\pi t D} \quad (2)$$

$$\text{TSR}\ (\%) = \frac{\text{ITS}_{\text{WET}}}{\text{ITS}_{\text{DRY}}} \times 100 \quad (3)$$

where, ITS is indirect tensile strength (MPa); P is maximum load (N); T is specimen thickness (mm) and D is specimen diameter (mm).

Higher TSR values mean that the less amount of strength was affected by the water soaking condition, or the mixtures were more water-resistant (Al-Hadidy and Tan, 2010).

As mentioned by NCHRP Report No. 425, SMA mixtures should meet applicable specification (70% minimum) as their TSR values. Therefore, mixtures with TSR less than 70% are moisture susceptible and it might be necessary to use antistripping additives or adjust mixtures to meet the requirement.

Statistical analysis: In order to predict the relationship between the amount of wax and ITS or TSR values, a statistical analysis should be used. To this end, the Microsoft Office Excel program was conducted for results of indirect tensile strength test. For each parameter, a trend line with the corresponding equation and R^2 value was provided to identify the predicted relationship with its relevant accuracy.

RESULTS AND DISCUSSION

Rheological tests: The Rheological tests including Penetration and Softening Point tests were performed for unmodified and modified binders. The results as presented in Fig. 2 indicate that different percents of wax can significantly improve the binder properties; In addition, 5% of SBS can also reduce the amount of penetration and increase the softening point of base binder by 30% and 31%, respectively. Altogether, 4% of wax had the best effect on rheological properties of binder. It does not mean this amount of wax should inject to the base binder; mixture performance tests should run to all SMA mixtures to evaluate the efficiency of these mixtures.

Mixture design: According to Fig. 3 the mixing and compaction temperatures of base binder for preparing control and cellulose/mineral included SMA specimens were 158 and 146°C, respectively. From Fig. 3, it could be observed that the construction temperatures for wax-modified binder are less than that for base binder; for instance, 4% of wax had the capability to decrease the mixing temperature up to 144°C which is less than the desired compaction temperature for unmodified SMA specimen.

To optimize the gradation, three limits (upper, middle and lower) were first considered as shown in Fig. 4. In addition, 6.2% of binder was initially added to the mixture according to the report. The volumetric properties of SMA mixtures needed to calculate the parameters such as VCA, VMA and Va are presented in Table 6. As shown in Table 6, the VCA ratio for middle limit is 0.927 at 6.95% of air void. This amount of air void in these samples seems to be relatively high to be filled with binder and it seems not logical to select the middle limit as optimum gradation. A more wisely way is to select the optimum gradation between upper and middle limits in a way that the VCA ratio is nearer to 1. The aim of this is to produce mixtures more economically in terms of the amount of used binder. Therefore, the optimum gradation is as shown in Fig. 4. The properties of specimens prepared with this optimum gradation are presented in Table 6. It is obvious that all VMA values were more than 17% specified in Table 5.

The results of binder optimization showed that the amount of 7.1% for control/SBS, 6.8% for cellulose and 6.7% for mineral modified mixtures were considered as OBC (Table 7). In the following part, it will be described that because of the drain down problem in only-wax modified mixture, 0.3% of cellulose fiber was also added to reduce the binder drain down. Therefore, the OBC value for WSMA mixtures was selected as 6.8%. This amount of binder was kept the same for all percentages of waxes to prevent the consistency of asphalt cement being variable during the laboratory tests.

Drain down: The results of the drain down test were presented in Fig. 5, which indicates that the drain down value of conventional mixture exceeded the required specification. The important point in this section is that

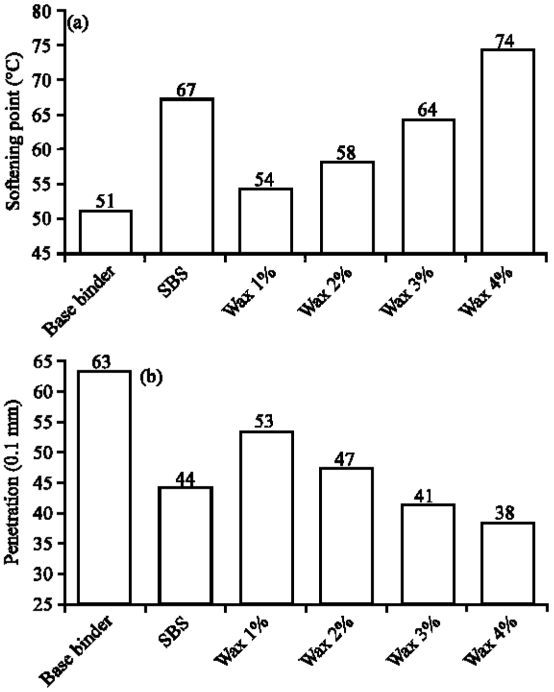

Fig. 2(a-b): Results of base and modified binder tests

Table 6: Volumetric properties of different limits of gradation

Gradation	Binder content (%)	Additive	G_{mb}	G_{mm}	G_{sb}	G_{CA}	γ_s	VCA_{DRC}	VCA_{MIX}	VCA ratio	VMA	V_a
Upper Limit	6.2	None	2.301	2.436	2.652	2.654	1572	40.65	41.45	1.02	18.61	5.54
Middle Limit	6.2	None	2.289	2.46	2.653	2.654	1548	41.56	38.52	0.927	19.07	6.95
Lower Limit	6.2	None	2.272	2.478	2.653	2.654	1517	42.73	35.76	0.837	19.68	8.31
Selected Gradation	6.2	None	2.297	2.442	2.653	2.654	1570	40.73	39.92	0.98	18.78	5.94

different amount of wax could not effectively decrease the value of drain down so that it seemed to be necessary to use fibers in WSMA mixtures modified with wax. For this, an amount of 0.3% cellulose fiber was added to the WSMA samples in order to decrease the binder drain down. Both cellulose and mineral fibers had a great ability to reduce the amount of drain down; however, SBS did not as much as fibers. This fact supported ideas presented in previous researches (Brown, 1997; Tayfur, 2007). As a result, all SMA mixtures except control and only-wax contained mixtures satisfied the drain down requirement.

Moisture sensitivity: In order to evaluate the indirect tensile strength of SMA mixtures in both dry and wet conditions and measure the TSR values, ITS test was performed according to AASHTO T283. Table 8 represents a summary of desired information of this test. From Table 8, it can be observed that the control and SBS modified mixtures had the least and the most ITS values (in both dry and wet conditions), respectively. In addition, cellulose fiber had a better effect on tensile strength of SMA mixtures than mineral fiber but this difference was not significant. However, SBS had a better effect in improving the ITS values than fibers, which is in support of the study performed by Tayfor *et al.* (2007). Although a slight increase was observed in ITS values (dry and wet) of WSMA mixtures by increasing the amount of wax, these values for 4% of wax (638 and 529, respectively) was less than 3% of it (641 and 532). The reason for that could be related to the detrimental effect of wax on existent adherence in asphalt mixture. Regarding the TSR values, cellulose fiber could relatively improve moisture sensitivity of SMA mixtures compared to the mineral fiber. Furthermore, positive effect of SBS was more than other additives so that it could increase the moisture resistance of SMA specimens up to 89%. However, different percents of wax did not effectively improve the TSR

Table 7: Results of selecting OBC

Gradation	Additive	V_a (%)	OBC (% mixture)
	Control/SBS	4±0.1	7.1
Selected Gradation	Cellulose/Wax	4±0.1	6.8
(previous section)	Mineral	4±0.1	6.7

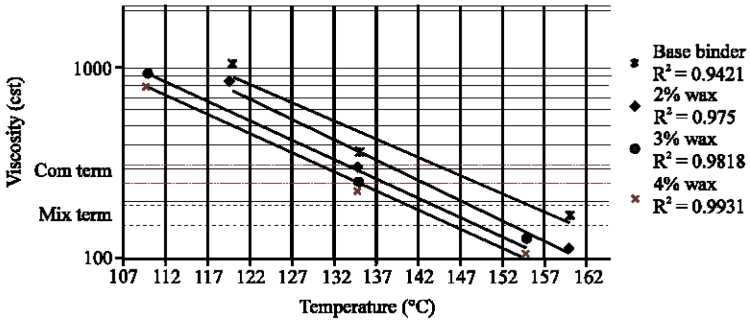

Fig. 3: Temperature-Viscosity Relationship for Modified and Unmodified Binders

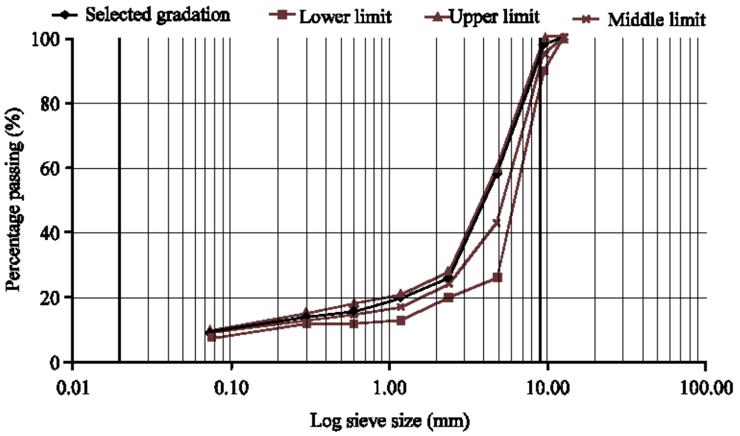

Fig. 4: Proposed Limits and Selected 9.5 mm Gradation

Table 8: ITS and TSR results of SMA mixtures

	Ave. height (cm)	Ave. diameter (cm)	Ave. P_{dry} (KN)	Ave. P_{wet} (KN)	Ave. ITS_{dry} (KPa)	Ave. ITS_{wet} (KPa)	TSR (%)	TSR standard deviation (%)
Control	6.89	10.15	6.48	4.80	590	437	74	1.06
Mineral	6.94	10.15	6.76	5.27	611	477	78	1.20
Cellulose	6.9	10.15	6.84	5.54	622	504	81	0.57
5% SBS	6.85	10.15	8.72	7.76	799	711	89	0.75
2% Wax + Cell	6.87	10.15	6.92	5.61	632	512	81	0.68
3% Wax + Cell	6.83	10.15	6.98	5.79	641	532	83	0.71
4% Wax + Cell	6.91	10.15	7.02	5.83	638	529	83	0.83

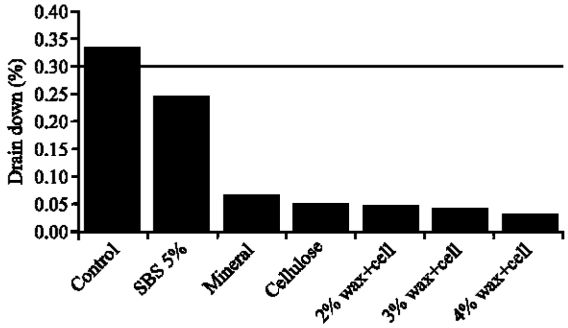

Fig. 5: Results of Drain down Test

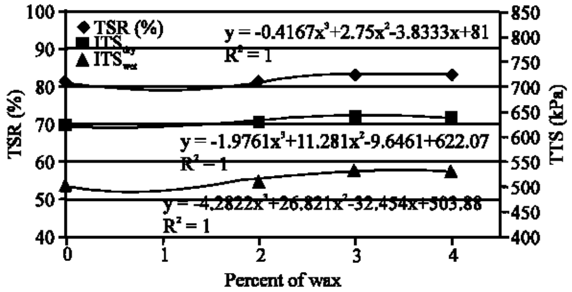

Fig. 7: ITS and TSR Results for Wax-Modified SMA Mixture

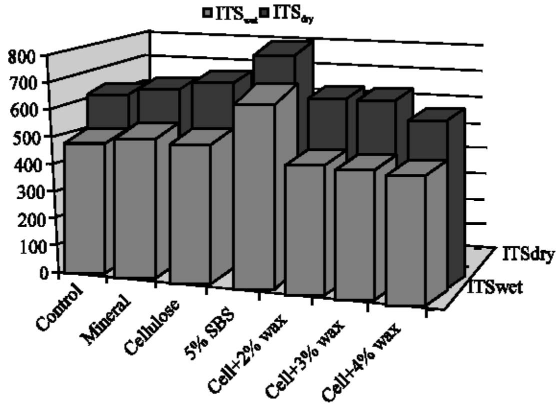

Fig. 6: Comparative Diagram of Moisture Sensitivity Results

values. 2% of wax did not have any effect on TSR value of mixtures but there was an increase of 2% in TSR value when using 3 or 4% of wax. Accordingly, it could confirm the ideas presented by some researchers (Gandhi, 2008; Merusi *et al*., 2010; Sanchez-Alonso *et al*., 2010). Observed increase in moisture resistance of WSMA mixtures could be attributed to the hydrophobic characteristics of wax used in these mixtures. However, it seems that because of the ability of waxes in decreasing the adhesion between binder and aggregate, the difference between TSR values of cell-modified (as a control mix for WSMA) and wax-modified SMA mixtures was insignificant. Meanwhile, for all SMA mixtures, it was observed that they were broken along a diametrical line; in addition, the aggregate surfaces in the broken section were visually checked to be still polished with binder after exposing to the moisture. As could be inferred from Fig. 6, a comparative diagram, the value of ITS_{wet} for each set was less than that of ITS_{dry} for the corresponding one, which could support the idea of detrimental effect of moisture. And as such, the difference between ITS values in dry and wet conditions were the least and most for SBS-modified and unmodified SMA mixtures, respectively. To set a relationship between different percents of wax and each tensile parameter of WSMA mixtures, trend lines with linear, binominal and trinimual equation was developed; among them , trinomual (cubic) equations resulted in the best fit equations in correlation of assumed variables. It can be inferred from Fig. 7 that there was an excellent cubic correlation between the amount of wax and ITS or TSR values ($R^2 = 1$).

CONCLUSION

The main results acquired from this limited research are as followings:

It is feasible to use 9.5 mm gradation recommended by NCHRP Report No. 425 on Iranian mineral aggregates; however, an adjustment should be applied to satisfy both binder content and VCA requirement. The OBC for fiber-modified mixtures are less than that for unmodified specimens. The reason is that the added fibers had a filling role in the mixtures and it caused a decrease in amount of desired binder in order to reach 4% air void when compared to unmodified mixtures.

Control and only-wax modified SMA mixtures did not meet the drain down requirement. It means that there was a necessity to use an additional modifier to prevent drain down when using waxes. In addition, the improving effect of fibers was more than the other additives.

All types of binder additives had positive effects in modifying the properties of base binder. Among them, the improving effect of 4% of wax was the most.

Although, as could be expected, the control mixture had the least TSR value, it met the desired specification described by NCHRP Report No. 425. Therefore, there would not be any problems in terms of moisture susceptibility when using different types of SMA mixtures investigated in this study. However, in spite of some observed improvement in TSR values of SMA mixtures, FT waxes may not have a great effect in decreasing the potential of moisture sensitivity of these mixtures.

Using SPSS,a cubic correlation emerged as the best fit regression equation with the correlation coefficient equals one ($R^2 = 1$) however, different amount of wax could not considerably decrease the moisture sensitivity of SMA mixes.

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