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TO EVALUATE MOISTURE DAMAGES AND RUTTING POTENTIAL OF WARM MIX ASPHALT IN LABORATORY-REVIEW

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ABSTRACT

In the performance of warm mix asphalt (WMA) two majors concern which are evaluated during this study which are rutting and moisture damage distresses. By using foam bitumen technology in order to produce mixes of WMA two various processes were used. During first process , preparation of samples was done in order to transform mixes of total bitumen into foam bitumen. While in second process,soft and hard bitumen's were added in mix in which latter was in foaming state. Which resulted same bitumen penetration in the final cured specimens. It was observed that for both foam mixes of WMA the moisture susceptibility and rutting potential increased by reducing mixing and compaction temperature. More ever, it was also concluded that foam mixes of WMA rutting potential during values of Marshall quotient, and results of wheel tracking were significantly more than control hot mix asphalt (HMA). Foam mixes of WMA rutting and moisture susceptibility was found to be decreased when hydrated lime powder was added and observed to be more effective.

Keyword's
Warm Mix asphalt, moisture susceptibility, rutting potential, Foam mixes ,Marshal quotient, Hot mix asphalt

I. INTRODUCTION

At low compaction and mixing temperature with technologies of warm mix asphalt (WMA) mixes of high quality were prepared when compared to hot mix asphalt (HMA). This was privilege of WMA on HMA. Using WMA technologies minimized the bitumen viscosity and particles of aggregates got coated completely at low temperatures (20–50^{0}C less than that ofcontrol HMA). In WMA choosing there was large number of potential benefits. Emission and fuel consumption reduction was one benefit of WMA (Angelo et al. 2008).

This itself reduces workers' exposure and results in pavingbenefits including ability to pave at cooler temperatures. According to (Tao et al. 2009) enabling mixes of hauling was another benefit of WMA and mixes was compacted with lower compaction efforts (Hurley and Prowell 2006). More ever, Tao and Mallick (2009) studied percentages of reclaimed asphalt with larger values was incorporated at low temperature.

Various methods were used to produce warm mix asphalt. Different researchers' different studies which included organic waxes used by Gandhi et al. (2010) while Barreto et al. (2008) studied chemicaladditives. More ever materials of hydrophilic was investigated by Visscheret al. (2010) and study of emulsified bitumen was conducted by Takamura (2008). In addition, mixes of WMA were prepared to convert bitumen into foam(Larsen and Robertus ,2005, Johnston et al. 2006,Romier et al. 2006 and Xiao et al. 2011).

During mix design of WMA, the important point was production having same performance as that of control HMA. Bitumen age hardening was reduced as a result of WMA mix temperature reduction. So, less stiffness of bitumen resulted due to which rutting susceptibility and moisture damage increased (Kvasnak et al. 2009). According to investigation of Hurley and Prowell(2006) and Zaumanis (2010) it was concluded that mixing properties of WMA was affected by compaction temperature in laboratory.

Based on above described process of WMA production, the process which was not used any type of additive for enhancing of bitumen workability in process of mixing was foam bitumen technology. There are two process used currently to produces mixes of WMA.

(a) Total bitumen of the mix transforms into foambitumen (WMA foam A).

(b) Addition of bitumen to the mix in two stages (WMAfoam B).

Using method, A, a multi-nozzle foaming manifold was used typically , while for supplying of bitumen (hard and soft) separately two bitumen feeding lines were required. During this study, two WMA foam mixes (Method A and B) characteristics were investigated and compared the results with control HMA. Thus, for achieving this objective of WMA foam mixes preparation, foam making unit of Laboratory was used. The temperature during mixing process for WMA foam mixes was kept 20^0C below when compared with control HMA. Gyratory compactor was used for compaction purpose in order to study the influence of compaction temperature on properties of WMA foam mixes. Volumetric characteristics of WMA foam mixes were compared with control HMA. In addition, for those mixes the moisture susceptibility and rutting potential were also studied.

WMA Method A:

Total bitumen of the mix transformsinto foambitumen in this process. Thus, particles of warm aggregates were mixed to foam bitumen (Xiao et al. 2011). Chamber was used for preparing of foam by water addition to hot bitumen at ambient temperature (heated at 160–180^0C) at the rate of2–5%. Due to this process expansion of bitumen was resulted approximately 15 times to original volume.

WMA Method B:

WMA foam mixes were produced by addition of bitumen (in hard and soft form) to the mix in two stages during in this method(Larsen and Robertus 2005). The bitumen (soft) was added to particles of warm coarse aggregates firstly and hard bitumen is transformedinto foam and spread onto the whole mix and using this process design bitumen penetration was produced with both bitumen blending.

In total binder of mix 20-30% soft were used bitumen was used typically.More ever, particles of coarse aggregates were coated with minimum amount of soft bitumen. In addition, with soft bitumen, particles of coarse aggregates were coated to fulfill the aggregates bitumen absorption demand.

II. RESEARCH METHODOLOGY

Materials and Methods: Aggregates

Table 1 showed physical properties of aggregates used in mixes of WMA and HMA foam. While table 2 shown grading of aggregates.

Table.1 Physical properties of Aggregates

Testing	Los Angles abrasion Value %	Soundness weight loss (%) (NaSO4)		Sand Equivalent (%)	Water Absorption (%)		Total density (g/cm^3)	Aggregate Type
		Fine Materials	Coarse Materials		Coarse Particles	Passing # 8 & retained on # 200 sieve		
Value	14	0.5	0.3	60	2.54	3.14	2.54	Siliceous
Specification	Max	Max	Max	Min	Max	Max	-	
Limits	30	12	8	50	2.5	2.5		

Table 2. Grading of Aggregates

Sieve Size (mm)	Grading requirements (% passing)		Selected Grading
	Lower Limit	Upper Limit	
19	100	100	100
12.7	90	100	95
4.75	44	74	59
2.36	28	58	43
0.3	5	21	14
0.075	2	10	6

Bitumen:

In this study grade 60/70 bitumen was used form WMA method A while from WMA method B, 40/50 and 200/300 grade bitumen was used as hard and soft binder respectively. Table 3 shown specifications of these bitumen

Table 3. Specifications of Bitumen

Testing	Bitumen Penetration Grade		
	60/70	40/50	200/300
Penetration (0.1mm)	60	44.1	260
Softening point (^{0}C)	50	53.9	39.5
Specific gravity at 25 ^{0}C (g/cm^3)	1.017	1.02	-
Flash point (^{0}C)	319	342	-
Ductility (cm)	>100	>100	-
Viscosity (cST) 100^{0}C	1082	-	667.9
110^{0}C	837.1	-	380
120^{0}C	-	-	226
130^{0}C	-	-	81.7
135^{0}C	396.3	-	-
TFOT	Retained Penetration	40	38.3
RTFOT	Weight Loss	0.02	0
		0.3	-

Different amount of soft and hard bitumen was mixed to design foam B mixes WMA and obtained control HMA equal penetration grade bitumen. The mixed composed of 30% and 70% soft and hard bitumen, respectively and bitumen corresponding to penetration of 85-90 was obtained approximately. While 15% soft and 85% hard bitumen corresponding to penetration of 60/70 pen bitumen of control HMA. After these coarse aggregates having size more than 4.75mm were blended with soft bitumen. Controlling of particles coating was done by visual inspection. Hence, latter on (15% soft and 85% hard) was utilized to produce samples of WMA method B foam mixes.

Foam Bitumen:

For production of foam bitumen foam producing unit of WLB-10 Wirtgen laboratory was used. In this procedure,Chamber was used for preparing of foam by water addition to hot bitumen at ambient temperature (heated at 160–180^{0}C) at the rate of2–5%. Due to this process expansion of bitumen was resulted approximately 15 times to original volume. For both types of penetrations (40/50 and 60/70), the optimum water content was determined and was shown in table 4. Bold numbers represent selected water content

Table.4 Foam Bitumen half Life and Expansion ratio

Water Content(% of bitumen weight)	Expansion Ratio		Half Life (s)	
	40/50	60/70	40/50	60/70
1.5	**8**	10	36	44
2	**19**	20	28	35
2.5	**20**	22	25	29
3	**22**	24	16	23
3.5	**23**	26	13	18

Mix Design:

Using procedure of Marshal to perform design of HMA mix. At every side of specimens 75 blows were applied of Marshall hammer for compaction. HMA mixes compaction and mixing temperature were calculated to be 140 and 150^{0}C based on relationship of viscosity-temperature. Results of HMA sample mix design was shown in table 5.

Table.5 HMA Volumetric Properties

Mixing Temperature	Bulk Specific gravity	Air Voids %	VMA (%)	VFB (%)	Stability (kN)	Flow (mm)	OBC %
HMA,150^{0}C	2.26	4.3	15.6	73.6	12.9	3.5	5.8
Specification limit	–	3–5	Min 13	60–75	$\geq$8	2.0–3.5	–

Where VMA= voids in Mineral Aggregates, VFB=Voids filled with Bitumen's, OBC= Optimum Bitumen Content

To prepared samples of WMA foam Superpave Gyratory Compactor was used. This compactor was used because of its kneading compaction action. To find gyrations design number, specimens of HMA were compacted at various level of gyrations. The gyration

number was selected as result control HMA same bulk specific gravity (i.e.2.26) while for all foam mixes of WMA the value was kept constant. The designnumber was found to be 80 gyrations and remained constant for all foam mixes of WMAas per Table 6. Where bold numbers represented number of gyrations.

Table 6. Number of gyrations versus samples' bulk specific gravity in gyratory compactor

No of Gyrations	Bulk Specific gravity
175	2.3
150	2.29
125	2.29
100	2.28
90	2.27
80	**2.26**
70	2.24
60	2.23

Soft binder viscosity chart was used to find the WMA foam-B mixing temperature. Warm coarse aggregates were coated with soft binder. This will be obtained if binder viscosity at stage of mixing was lower than 200 cSt (Larsen and Robertus 2005) and viscosity obtained at 130^0C as shown in Table 3. By using gyratory compactor compaction of WMA foam mixes was done at 5 various temperature. For WMA foam mixes, OBC values was remained identical with the control HMA (i.e.5.8% of mix total weight). Table 7 represented WMA foam mixes parameters of Marshall.

Table 7. Marshall parameters of WMA foam samples

Mix Type	Avg Compaction Temp (^{0}C)	Stability (kN)	Air Void %	VMA %	VFB %	Bulk Specific gravity	Flow (mm)
WMA Foam-A	75	10.56	4.45	15.93	72.09	2.26	5.9
	85	11.08	3.98	15.52	74.36	2.27	5.8
	95	11.73	3.77	15.34	75.43	2.27	5.3
	105	12.14	3.47	15.08	76.97	2.28	5.4
	115	13.01	3.43	15.05	77.19	2.28	5.4
WMA Foam-B	75	9.34	5.17	16.57	68.82	2.24	6.3
	85	9.78	4.66	16.12	71.1	2.25	6
	95	10.73	4.15	15.67	73.52	2.26	6
	105	11.34	3.89	15.45	74.78	2.27	6.1
	115	11.94	3.47	15.08	76.97	2.28	5.9
Specification limits		$\geq$8	3-5	Min 13	60-75	-	2-3.5

From table 7 it was shown that Marshall parameters meet all specifications at compaction temperature of 85^0C except values of flow-for WMA foam-A mix. Similarly, for mix of WMA Foam-B specimens only air voids were found out of range at temperature of 85^0C. Stability values for both WMA foam mixes was found to be increased as compaction temperature increased which resulted in less stiffness and decrease densifications of bitumen. The values of air voids were found less than control HMA at compaction temperatures above 85^0Cand 95^0C for mixes of WMAfoam-A and B, respectively and better compactability was resulted for WMA foam mixes. In addition, WMA foam specimens flow values was observed 1.67 times greater which also resulted of less stiffness bitumen as compared to control HMA.

Indirect tensile strength test (ITST):

To find the moisture susceptibility of WMA and HMA foam mixes this test was conducted (AASHTO T283). In this method, compaction of samples up to air void level of 6-8%. In total of six samples three were tested under controlled normal condition while remaining three were tested after conditioning. The samples were tested in ITS at temperature of 250C. After testing required forces were calculated to break the samples. The indirect tensile strengths (ITSs) ratios of the conditioned samples to those of the control samples were calculated and termed as tensile strength ratio(TSR). As per Iranian Technical Specifications for Asphalt Road Pavements (2003) minimum requirement for TSR is 80%. Compaction of HMA and WMA foam samples at 1350C and at various compaction temperatures, respectively (AASHTO T 283) and was shown in table 8.

Table 8. Results of HMA and WMA foam samples ITS Testing

Mix Type	Compaction Temperature (^{0}C)	Average air voidcontents (%)		ITS (kPa)		
		Dry	Conditioned	Dry	Conditioned	TSR %
HMA	135	7.03	6.96	980	683	69
	SD	0.1	0.06	50	63	–
WMA Foam-A	115	7.49	7.51	837	575	68
	SD	0.09	0.11	65	53	–
	105	7.56	7.57	804	550	68
	SD	0.07	0.05	90	63	–
	90	6.68	6.71	782	521	66
	SD	0.06	0.03	55	34	–
WMA Foam-B	115	7.07	7.03	860	490	56
	SD	0.11	0.12	57	39	–
	105	7.62	7.68	821	424	51
	SD	0.07	0.09	45	57	–
	90	7.91	7.88	791	354	44
	SD	0.09	0.12	51	28	–

Based on above table TSR values for HMA samples was found below specifications of 80% which resulted in aggregates type and mostly from siliceous sources. More ever, WMA foam -A and B mixes showed similar and greater moisture susceptibility, respectively as compared to control HMA. It was observed from table 8 that value of dry ITS was greatest for controlling HMA. In addition, when compaction temperature decreased ITS values for both WMA foam-A and B mixes which resulted in lesser stiffness bitumen.hydrated lime powder was added to both HMA and WMA foam mixes in order to control moisture susceptibility. Mixes of bitumen moisture susceptibility was improved with this filler (Kabir 2008, Xiao et al. 2010). Table 9 shown addition of different amount of hydrated lime powder results to HMA in which bold numbers shown selected lime content.

Table 9. ITS testing results of HMA and WMA foam samples including hydrated lime powder.

Mix Type	Compaction Temperature (^{0}C)	Lime content (%)	Average air void contents (%)		ITS (kPa)		TSR %
			Dry	Conditioned	Dry	Conditioned	
HMA	135	1.5	7.08	7.02	989	784	79
		SD	0.09	0.08	89	74	–
		2	**7.14**	**7.18**	**973**	**902**	**92**
		SD	0.05	0.07	126	75	–
WMA Foam-A	115	2	6.72	6.32	930	900	96
		SD	0.07	0.11	49	67	–
	105	2	7.12	7.17	927	857	92
		SD	0.09	0.08	140	56	–
	90	2	7.88	7.91	769	644	84
		SD	0.11	0.14	35	69	–
WMA Foam-B	115	2	6.97	7.01	938	929	98
		SD	0.12	0.08	68	89	–
	105	2	7.04	6.98	846	831	98
		SD	0.12	0.08	79	81	–
	90	2	7.1	7.09	739	561	76
		SD	0.13	0.06	67	48	–

Based on above table, hydrated lime powder content of 2% in HMA showed improved value of TSR. It was also concluded the values of TSR was found more than specified limit except for WMA foam-B mixes compacted at 90^{0}C. More ever, temperature was inversely proportional to TSR values for WMA foam A and B mixes.Similarly, with reduction in compaction temperature values of dry ITS also decreased. It was concluded that with lowering compaction temperature ITS and TSR values were also reduced.

Wheel Tracking Test (WTT):

To know the mixes deformation resistance which occurred at high temperature and loading wheel tracking test (WTT) was used under standard method (EN 12697-22). During this test, loaded wheel was passed repeatedly on asphalt hot field sample or a laboratory-compacted slab and monitoring of rut depth was done to achieve result. In the research the performed WTT was different

from Hamburg wheel tracking test (HWTT). In latter test loaded steel wheel moved directly back and forth on sample of HMA. The test was conducted on submerged sample for 20,000 cycles oruntil 20mm of deformation occurred. The sample having size of 300x300x50mm were compacted using a roller compactor during this study. The compacted sample were kept for 6 hours at temperature of 60^{0}C in an environmental chamber beforetesting. The tests were conducted at 42 passes/min and noted the depth in mm. WMA foam samples were used to perform WT testing at various compaction temperature while samples of HMA was compacted at 140^{0}C as per results of mix design. Table 10 shown Results of WTT in summarized form.

Table 10. Results of WTT

Avg compaction Temperature (^{0}C)	Mix type			
	HMA	WMA foam A	WMA foam A +2% hydrated lime	WMA foam-B +2% hydrated lime
140	3.6	-	-	-
115	-	6.2	3.4	3.1
105	-	6.8	3.6	3.6
90	-	11.8	4.8	4.6

III. RESULTS

Based on methodology WMA and HMA foam mixes ITST and TSR compacted at various temperature was shown figure 1.

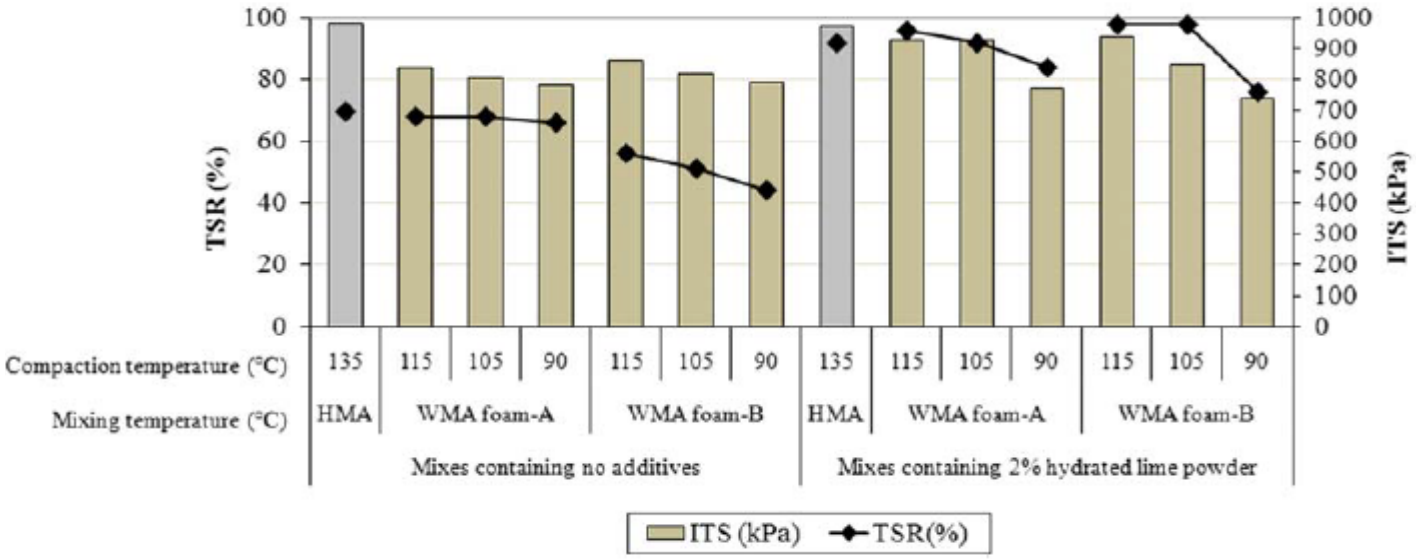

Figure 1. Comparison of dry ITS and TSR values of WMA foam mixes with control HMA

From figure 1, it was concluded that for TSR specification addition of hydrated lime powder was important. More ever, for both type of mixes reduction in values of dry ITS was observed at compaction temperature of 90^{0}C. while for mixes of WMA foam B values of TSR was found below specified limit at compaction temperature of 90^{0}C. To compare HMA and WMA foam mixes mechanical properties and Marshall quotient (Q) were shown in figure 2.

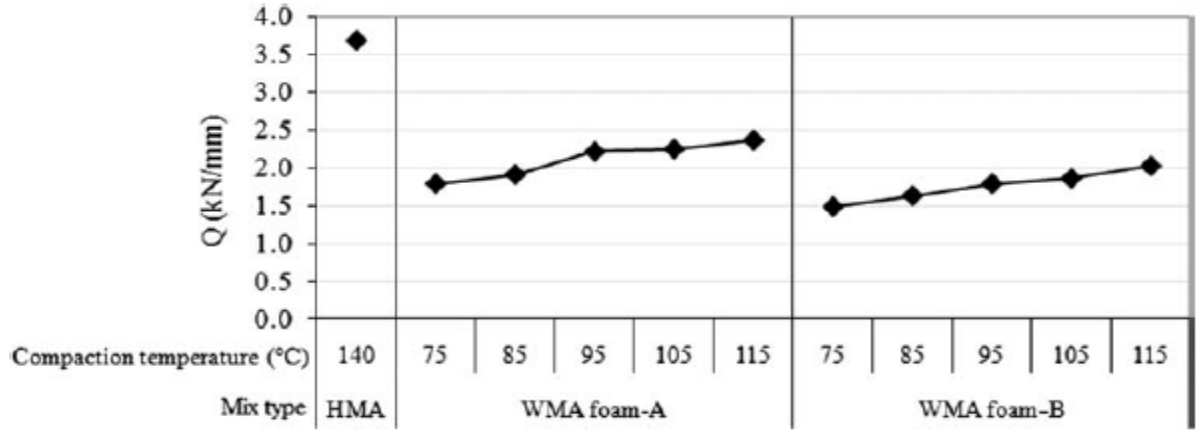

Fig.2 WMA foam mixes with control HMA -Q values comparison

The values of Q for WMA foam mixes were found less as compared to HMA having highest values and was shown in Figure 2.While on other hand WMA foam mixes rutting depth were found more as compared to HMA (Reference Table 10) which indication greater rutting potential for WMA foam mixes. More ever, decreased in Q values were found at lowering the compaction temperature (Fig.2) and increased in rutting depth were observed (Table 10). Thus, it was concluded that increase in rutting potential was observed when compaction temperatureswere decreased. Based on results of WTT and ITS addition of 2% hydrated lime was essential to obtained same properties of WMA foam mixes with HMA. In this condition, minimum temperature for compaction should kept 105^0C. Beside this, all parameters of design met the requirement of mix specification when compacted at 90^0 for WMA foam mixes excluding value of flow (reference table.7). Based on latter results, it was concluded that for evaluation of WMA foam mix design ITS and WTT were taken as effective tests.

IV. CONCLUSIONS

In this study, WMA foam mixes production through two various approaches having following conclusions.

- No significant differences were found WMA foam mixes physical properties but having mechanical properties better slightly.
- Low Marshall stability and high flow values were observed when mixing and compaction temperature was reduced and resulted in bitumen less stiffness along with reduction in aggregates coating quality in WMA foam mixes as compared to WMA mixes.
- WMA foam mixes showed good workability because of its low air voids content.
- During results of ITS testing less tensile strength and moisture resistance was found at low mixing and compaction temperature for WMA foam mixes as compared to HMA.
- Moisture susceptibility was observed to be improved by adding 2% of hydrated lime powder in WMA foam mixes.
- WMA foam mixes rutting protentional was found high based on Marshall quotient and WTT results.

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