Warm Mix Asphalt / Low temperature asphalt

Investigation of field performance of warm mix asphalt produced with foamed bitumen

Ayberk Özcan[1], Zeliha Temren[2], Muhammet Komut[3], Seyit Ali Yıldırım[4]
[1]Ösak Construction Co., [2]Turkish Asphalt Contractors Association, [3]General Directorate of Highways, [4]Abt Lab.Co.

Abstract

Warm Mix Asphalt-WMA trial sections have been constructed by using different techniques(organic and chemical agents, mineral foaming additives and foamed bitumen) since 2012 in Turkey. In consequence of gaining knowledge and experience, WMA with foamed bitumen has been preferred to be implemented in a road project. In this context, the first implementation of WMA was realized on state road located on severe climatic conditions.In this project, approximately 300.000 ton WMA has been used for base and binder courses.Surface course hasn't been completed yet, but the road has been opened to traffic in sections at the level of binder course since 2015. Additionally a trial section of WMA with foamed bitumen was constructed as a surface course on an urban road served at mild climatic condition in 2017.Around 200 ton WMA was paved and trial section has been on traffic service since 2017. To realize long- term benefit of WMA, it is required to investigate field performance. It is expected that WMA would be as good as hot mix asphalt-HMA.Therefore, the field performance of WMA pavements needs to be examined. In this study, to investigate the field performance of WMA, the data from pre-construction mix design and information for construction process and post construction will be collected. Significant material properties by laboratory tests integrated into mix design are identified by taking core samples from the road. Distress surveys such as wheel-path longitudinal cracking, rutting and moisture damage will be performed on the pavements. Additionally the other critical factors such as pavement structure, traffic and climate will be described. All of the findings will be evaluated to compare field performance of WMA with adjacent or similar HMA pavements in term of specific performance parameters. Key words: Warm mix asphalt, foamed bitumen, field performance.

This paper was first published in 2020 in version 1.0 of the proceedings of the 7th E&E Congress. This second edition (version 1.1.) of the proceedings is published in June 2021. The content of this paper has not changed, but the author(s) may have provided additional information in the form of an annex.

1. INTRODUCTION

Environmental sustainability can be achieved by using low energy and low emission technologies, such as Warm Mix Asphalt-WMA, in the road industry. Compared with traditional Hot Mix Asphalt-HMA, WMA technologies can reduce the mixing and compaction temperatures by approximately 20°C to 50°C , resulting in lower energy consumption and reduced greenhouse gase emissions to the environment. The use of WMA technologies have provided many other benefits, such as creating a better work conditions, good workability, easy compaction, paving in cold season and long hauling distances, therefore it improves the overall sustainability of asphalt industry.[1)]

Numerous WMA technologies are available generally categorized into three groups: Organic additives, chemical additives and water-based foaming products including and water-containing foaming products.[1)]

Over the past decade, the use of warm mix asphalt -WMA for asphalt production has increased around the World. In accordance with the data in 2017[2)], while the use of this technology originated in Europe is 7%, it has increased up to 30% in the USA. Mainly WMA with foamed bitumen techniques are about 80 % of the total WMA production in USA.

Foamed bitumen is produced by a process in which water is injected into the hot bitumen, resulting in spontaneous foaming. The water rapidly evaporates and is encapsulated in the binder, producing large volume of foam. The foam dissipates in less than a minute and the bitumen then resumes its original properties. The foaming action in the binder temporally increases the volume of the binder and lowers the viscosity, which improves coating and workability. [3)]

WMA production technique has been used as alternative to hot mix asphalt. However, sustainable techniques should not compromise field performance; evaluation of the long-term field performance of WMA has become critical for WMA users.

In Turkey, WMA trial sections have been constructed by using different additives and techniques since 2012. In consequence of gaining knowledge and experience, the Highways department has prepared the specification and permitted contractors to use WMA techniques providing the same quality of hot bituminous mixtures.[4)] In this context, the first implementation project of WMA with foam bitumen was carried out on the state road located on severe climatic conditions. In the project, approximately 320.000 ton WMA has been used for base and binder courses. The surface course hasn't been paved yet, but the road has been opened to traffic in sections at the level of binder course since November 2015.

Additionally in 2017 a trial section of WMA with foamed bitumen was constructed as a surface course on an urban road served at mild climatic conditions in 2017. Around 200 ton WMA was paved and the trial section has been on traffic service since 2017.

This means that the usage of WMA in Turkey is still far from the usage of conventional hot mix asphalt. There are many questions remained in the minds of deciders about the long-term performance and durability of WMA pavements. Therefore it is very important to find out that WMA with foam bitumen technique provides performance-wise compared tp HMA technology.

In this context, this paper presents a study on investigating the field performance of the WMA pavements constructed in the projects given above.

The main objectives of this study include the following:

- to identify material and engineering properties of WMA mixes that are significant determinants of their field performance,
- to compare the field performance of WMA and HMA pavements

The conducted studies for two different WMA pavements (State road project and trial section)

- Determination the traffic, weather conditions and pavement thicknesses of the roads paved with WMA
- Collection data for the used materials and mixture design for WMA mixtures
- Getting information for production and paving and evaluating quality control test results
- Taking core samples from the roads and determining significant material properties by laboratory tests integrated into mix design
- Distress surveys such as wheel-path longitudinal cracking, rutting and moisture damage performed on the WMA and HMA pavements.

2. THE TRAFFIC, CLIMATIC CONDITION AND PAVEMENT THICKNESES OF THE ROADS PAVED WITH WMA

For highway project and trial section on the urban road, the traffic, climatic condition, pavement thickneses and the length of the pavements are given in Table 1.

Table 1. Traffic, climatic condition, pavement thickneses and the length of the pavements

Pavement	Highway project	Trial section Urban road
Layer thickness, cm Surface coarse Binder Bitum. Base Granular base Sub base	 **5 (not paved yet)** **7** **9** **20** **15**	 **5** **7** **10** **20** **15**
Length of WMA pavement	33 x2 km double way road	150m
Traffic AADT(annual daily avarage traffic)	4500	City traffic
Climate	Sub humid and warm in summer Cold and snowy in winter Frost dept: 1,00 m T_{max}= 28,5°C T_{min}= - 7,5°C	Humid and warm in summer Warm and rainy in winter T_{max}= 26°C T_{min}=3°C

3. MATERIALS PROPERTIES OF WMA MIXTURES FOR THE PAVEMENTS OF THE ROADS

3.1 Aggregate Properties

For highway project, bituminous mixtures for binder and bituminous base layers were prepared with the same lime stone quarry. The aggregate were crushed and sieved at 4 different sizes.The properties of the aggregate and the limits of the National Highways Specification are given in Table- 2. The table also shows the properties of the aggregate derived from limestone aggregate for the urban road trial section.

Table 2. Aggregate properties

Properties	Unit	Highway project		Trial section Urban road	
		Specification	Result	**Specification**	Result
Flakiness index TS EN 933-3 BS 812	 % %	Max.25 Max.20	12 -	 - 15	15
Abrasion value (LA) TS EN 1097-2	%	Max. 30	23,9	27	22
Water absorption; TS EN 1097-6 -For coarse aggregate -for fine aggregate	 % %	max.2,5	0,39 0,55	2,0	0,40 0,90
Soundness , MgSO4 TS EN 1367-2	%	Max. 18	2,4	Max. 16	2,0
Stripping strength TS EN 12697-11	%	Min. 60	70-75	Min. 60	65-70
Metilen blue (0/2mm fraction) TSEN 933-9		For Base: max.2,0 /$MB_{2,0}$ For binder: max.1,5	0,75	Max 1,5	1,25

3.2 Bituminous Binder Properties

For the highway project and trail section, respectively B 70/100 and B 50/70 grade bitumens were used. The properties of bitumen and the specification limits are given in Table-3.

Table 3. Properties of bitumens

		Highway Project B70/100		Trial section B50/70	
Properties	**Unit**	**Specification**	**Result**	**Specification**	**Result**
Penetration TS EN 1426	0.1mm	70-100	78	50 - 70	53
Softening Point TS EN 1427	° C	43-51	49	46 - 54	50,8
Specific gravity TS EN 15326	g/cm^3	-	1,016	-	1,014
Solubility TS EN 12592	%	Min. 99.0	99,8	Min. 99.0	99,9

4. MIXTURES DESIGN

Since the foaming techniques are strictly related to the production process. At the present time, the laboratory method of incorporating foam into the mix is not readily available. Some of the differences may exist between the properties of an asphalt mix designed in the laboratory without foam and the job-mix formula produced in a batch with foam. To examine the major differences between laboratory and plant mixes, significant material properties by laboratory tests integrated into mix design were identified by taking samples from the plant.

In accordance to National Highways Technical Specification[4)], Marshall Design method is used to design the asphalt concrete for binder, bituminous base and also surface course. All of the mixtures were designed to meet the requirements of asphalt concrete for binders and base course. All mixtures were prepared in accordance with EN 12697-30 in the laboratory. The loose mixtures were compacted to the specified density and air voids at 150°C. Basic tests - void content, bulk density, maximal density and marshall stability -flow test were carried out on these asphalt mixtures Mix formula, the gradations, properties of the mixtures and the specification limits are given in Table 4 for highway project and trial section on urban road.

Table 4- The mix formula of the bituminous mixtures

Road	**Highway project**				**Trial section Urban road**	
Layers	**Binder**		**Bituminous base**		**Surface course**	
Bituminous mixture	**AC 25 bin 70/100**	**Spec. Limits**	**AC38base 70/100**	**Spec. Limits**	**AC19surf 50/70**	**Spec. Limits**
Gradation- Sieve size, mm	Passing %	Passing%	Passing%	Passing%	Passing %	Passing%
37,5			100	100		
25	100	100	88,5	72-100		
19,0	90,3	80-100	78,6	60-90	100	100
12,5	68,3	58-80	63,7	50-78	90,9	88-100
9,5	55,3	48-70	55,9	43-70	79,9	72-90
4,75	43,1	30-52	43,7	30-55	49,1	42-52
2,00	25,1	20-40	25	18-42	28,3	25-35
0,425	9,8	8-22	9,7	6-21	12,8	10-20
0,180	6,5	5-14	6,5	2-13	9,3	7-10
0,075	4,0	2-7	4,0	0-7	6,6	3-8
Optimum bitumen content % by weight	4,6	3,5-6,5	4,2	4,0-7,0	4,9	4-8
Density t/m^3 TS EN 12697-6	2,410		2,414		2,388	
Void content , %	4,60	4-6	4,8	4-6	4,9	3-5
Void filled with bitumen %	68,0	60-75	65,0	55-75	67,8	65-75
Void between mineral aggregates % TS EN 12697-8	14,4	13-15	13,9	12-14,5	15,1	14-16
Marshall - TS EN 12697-34						
Stability, kg	1290	> 750	1380	> 750	964	> 900
Flow, mm	3,66	2-4	4,2	2-5	4,9	3-5
Filler /Bitumen rate	0,87	<1,4			1,35	< 1,5
Antistripping additive	Not used					

5. WMA PRODUCTION, PAVING AND QUALITY CONTROL TEST RESULTS

For the highways project and trial section, batch type asphalt plants were used to produce WMA. The constructor supplied the generator for foam bitumen production as shown in Figure 1 and integrated into the plant. The foaming nozzle is installed in-line with the binder addition system. It is fed by a water supply system (water pump, reservoir tank) and water metering system. The water addition process is controlled through a control unit from the plant operation centre. %2 cold water by the weight of bitumen at 4 bar pressure is injected to the hot bitumen inlet pipe to produce foam bitumen. The foaming equipment supplier recommended heating bitumen up to 170^{o} C.

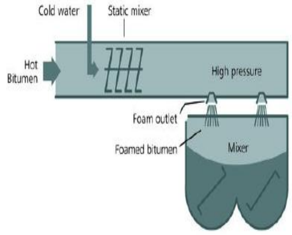


Figure 1: Foaming system

The produced foam was fed to the mixer and mixed with dried and heated aggregate at the temperature of about 130°C. After the mixing process, the mixture was ready at 125- 130°C and aggregate was coated properly**.** WMA mixes had significantly less smoke and odor during production and paving. The mixtures were notably more workable than HMA. Since the moisture contained in the aggregate may not completely evaporate during mixing due to low mix temperatures, water may be retained in the aggregate which could in turn lead to increased susceptibility to moisture damage such as raveling and stripping. WMA production temperatures were all high enough to dry the moisture on the outside of the aggregates. Conducted tests on samples taken from hot bins of the plant indicated that dry aggregates were fed to the mixer.

To produce a good quality mixture, the construction team suggested minimizing aggregate stockpile moisture, tuning burners, good plant maintenance and generous use of insulation.

Hauling distance was maximum 30 km for the highway project and 20 km for the trial section. In highway project during hauling the tracks were insulated to prevent temperature reduction of the mixtures. WMA was produced and paved within September to December. The minimun ambient temperatures were above 5°C with wind. Although the surface temperature was lower than the ambient temperature, the required density was achieved easily by conventional paving and compaction equipment. Steel wheel vibratory roller and pneumatic tire roller was used for compaction. When the temperature was cold it was used 2 vibratory and 2 pneumatic tire rollers. The final compaction was completed by 80°C. Binder course was opened to traffic almost within 4 hours after compaction.

During the paving process of both of the WMA pavements , it was taken samples from plants, then gradation, bitumen content, temperature of the mixture were determined. After compaction, it was taken cores from the layer to determine density, air voids and the thicknesses of the layer. All of the results of the quality control tests complied with the criteria given in the specification. Therefore the predicted performance in the laboratory was achieved in the field.

From the placement standpoint, WMA appearance was almost the same as HMA. Contractors have commented that equipment remained cleaner with less asphalt buildup when placing WMA It had been easier to obtain density with WMA mixes as compared to HMA mixes, even with the reduced compaction temperatures and cold ambient temperature.

For the bituminous base and binder layers of the highway project the total produced was of 300.000 tonnes of WMA and paved 33 km dual carriageway in sections in the year 2015, 2016 and 2017. Every year, the completed binder layers were opened to the traffic. Surface course hasn't been paved yet. The profile of the pavement sections constructed by years is shown in Figure 2.

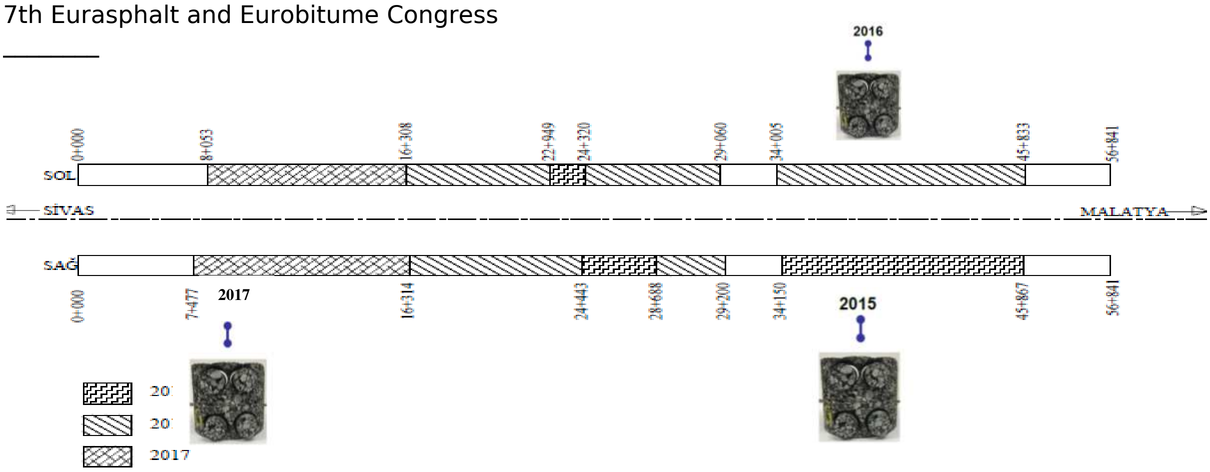


Figure 2: Pavement profile and the sampling points on highway project

In the trial section, 200 ton WMA was produced as surface course and open to traffic in the 2017.

6. FIELD PERFORMANCE STUDIES

6.1 Laboratory Studies on Core Samples

For highway project The 3 core samples showed in the profile above were taken from the sections opened to traffic in the years of 2015, 2016 and 2017. Because of heavy vehicle traffic on the road it couldn't be possible to take samples for rutting.

For the trail section, one core was taken from the surface course.

Results of laboratory tests conducted on the field cores are shown in Table 5. All of the results have shown good compliance with the national highways specification.

Table 5. Test results of core samples taken from the pavements

	Highway project				Trial section	
	Binder course				Surface course	
	WMA			HMA	WMA	HMA
Age of the pavement, years	4	3	2	2	2	2
Bitumen Penetration Softening point	40 54,5	37 54,4	38 54,6	40 52	45 53	45 52
Indirect tensile strength %, AASHTO T 283	88,7	76,8	85	-	90,7	91
Rut dept prop.% TSEN 12697-24 procedure B 20.000cycles	-	-	-	-	1,9	-
Course thickness, cm	8,2	7,3	7,2	-	6,0	5,5
Compaction degree % Void %	98,4 6,9	100,3 4,3	100,3 4,3	-	98 7	99 5

For the WMA binder course of the highway project, ITS results are compliant with the specification except the section opened to the traffic in 2017. The result of HMA section also comply the specification criteria. But there are stripping on the heavy traffic lane along the way of both pavements.

However, there is no evidence of any rutting in either WMA or HMA sections except the section at the age of 4 years. The performance observation shows that both sections are performing equivalently.

Normally because of warm mix asphalt production, bitumen aging during the production process would be expected lower than that of hot mix asphalt process,[5)] but the test results show that bitumen has aged like traditional hot mix. One of the reason is to heat bitumen up to 170°C during the foam generation and the other is the effects of freezing and thawing actions on the road.

For the trial section, ITS result confirms the specification limit, and the bitumen has aged like traditional hot mixtures.

6.2 Distress surveys on the WMA and adjacent HMA pavements

Distress survey on the WMA section was carried out on the highways in September 2019. At the same time the adjacent HMA pavement was examined. The section of HMA pavement, likewise WMA pavement, has no surface course, the road opened to traffic at binder course level in 2017. The thickness of the pavement (5cm wearing + 7 cm binder + 9 cm bituminous base courses) was determined for 21,3 million ESAL's within 20 years in accordance to the AASHTO-93 design guide. Since the pavement opened the traffic without wearing course, the traffic carrying capacity of the existing pavement (7cm binder+ 9 cm bituminous base) is determined by back calculation method . On the other hand the carried traffic values are taken from actual annual trafic data . The traffic values of highway project are given in Table 6 by ages.

Table 6. Traffic values of the pavements

	Highway project Project traffic for 20 years with surface course : 21,3 million ESAL				**Trial section** City traffic
	WMA pavement			HMA pavement	WMA pavement
The age of pavement	4	3	2	2	2
Carried traffic million ESAL*	2,97	2,22	1,49	1,74	-
Heavy traffic rate %	75	77	79	67	-
Calculated traffic capacity without surface course, million ESAL **	3,84	3,84	3,84	3,84	-
The rate of carried traffic %	77	57	39	45	-

** Calculated from AADT values of the years 2016, 2017,2018*
*** Calculated from the existing pavement's thickneses by SN(structural number).*

The sections of WMA pavement at 4, 3, 2 years old have been carried respectively 77%, 57%, 39 % of the traffic carrying capacity, for the HMA section, the rate is 45% . So it means that the WMA pavement at the age of 4 years have completed almost three quarters of its life and the others are within the half of their life expectancy

Because of heavy traffic flow, only observation was possible on the highways, any measurement on the surface couldn't be carried out . In the context of the survey, the detected distresses and visual performance are given in Table 7.

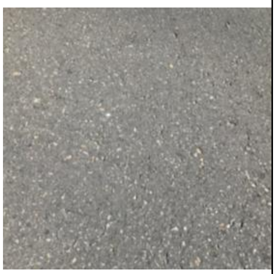
As a result, there was no structural distress, the whole sections of pavements were quite sound and durable even though there is no surface course on both WMA and HMA pavements. But moisture related distress such as raveling and stripping was found at light severity level on the surfaces of both WMA and HMA pavements.

These distresses are certainly related to the aggregate quality, severe climatic condition and heavy traffic loads. In fact the aggregate used for binder course shouldn't be exposed directly heavy traffic loads and severe weather conditions unless higher Polished Stone Value-PSV aggregates are used instead of limestone. But due to the insufficient allowance for the project, the binder course sections have been carried out traffic since 2016, 2017 and 2018 without surface course.

Cold and snowy climate conditions, freeze-thaw cycles and temperature fluctuations are a major cause of pavemetn stripping by weakened the bond between binder and aggregate in bituminous mixtures. [6)] On some sections of the road there is snow at 1,5 meter high in winter and snow and ice removal treatments are conducted on the sections with snow plowing vehicles. Traffic load is also a considerable factor for the moisture damage in the pavement.[7)] Pore pressure buildup and hydraulic scouring are two main reasons which could accelerate the moisture damage in the mixtures due to traffic load. When water pores inside the pavement and could'nt fluctuation, so it would tend to compress by the load of traffic. Where water move along to the surface of pavement due to wheel passing, scouring action could remove the binder form the aggregate which results in the deterioration of pavement layer.[7)]

Additionally there is light severe level rutting on the heavy traffic lane of WMA opened to traffic in 2016, This was due to the binder course is almost carried out three quarter of traffic capacity and high heavy traffic rate (75%). There was no significant difference in the performance of road sections opened to traffic in different years except rutting.

Table 7. Field performance of pavements on highway project

	WMA			HMA
Age	**4**	**3**	**2**	**2**
Distress	-No cracking - Rutting at very light severity level (<15mm) - No bleeding -No corrugation and shoving - No depression - Moisture related distress such as raveling and stripping at light severity level on the heavy traffic lane	-No cracking - Rutting at very light severity level (<15mm) - No bleeding -No corrugation and shoving - No depression - Moisture related distress such as raveling and stripping at light severity level on the heavy traffic lane	-No cracking - No rutting -No bleeding -No corrugation and shoving - No depression -Moisture related distress such as raveling and stripping at light severity level on the heavy traffic lane	-No cracking -Aggregate segregation - No bleeding -No corrugation and shoving - No depression - Moisture related distress such as raveling and stripping at light severity level on the heavy traffic lane
View from along the pavement				
View from the surface on heavy traffic lane				

7. THE COST OF WMA WITH FOAMED BITUMEN

Since there are some concerns about the implementation of WMA production technology mainly its cost. The cost of warm mix asphalt and hot mix asphalt prodution and paving for this project by the unit price of 2012. To calculate the unit price of asphalt, it was taken into consideration that the fuel consumption of the dryer of the plant (100 t/h capacity , 100-120 HP) are given below:
For hot mix asphalt -150 °C : 177 kg fuel /hour
For warm mix asphalt - 130 °C : 142 kg fuel /hour
As a result, it is provided 20 % saving on energy consumption for drying and heating of agregates for WMA production.
Table 8 shows the unit price of WMA and HMA., the unit price of WMA is lower than that of hot bituminous mixture. Although the investment and the depreciation of a new foam generator, the unit price of WMA is approximately 6% lower than that of HMA. Thus the road administration paid less than that of hot mixtures.

Table 8. The cost of WMA and HMA (except bituminous binder cost) by the unit price of 2012

Unit price TL/m^2	Hot bituminous mixture	Warm mix asphalt	Reduction Rate
9cm x 1 m^2 bituminous base	9,76	8,75	6,6
7 cm x1 m^2 binder course	7,87	7,42	5,7

On the other hand, WMA technology provided the contractor to pave asphalt in the out of construction season.. Because of the lower production temperature there is less wear of the asphalt plant, therefore maintenance cost of the plant is reduced.

8. CONCLUSION

The study conducted on foamed bitumen WMA pavements constructed on the highway project and trial section on the urban road. For the highway project, WMA produced totally 300.000 tonnes of bituminous base and binder courses to pave 33 km dual carriageway. WMA was paved and open to traffic in sections in the year 2015, 2016 and 2017 without surface course being paved. The adjacent HMA pavement, as with the WMA pavement, has no surface course yet, the road opened to traffic at binder course level in 2017. The trial section of WMA with foamed bitumen approximately 200 tons was paved as a surface course on an urban road served since 2017.

WMA mixtures were produced with batch type asphalt plants integrated foam generator. The mixtures were prepared at 125- 130 °C. It was recorded that aggregates were dried and coated properly, there was less smoke and odor during production and paving process .The mixtures were notably more workable. The construction team was suggested that it was required to minimize aggregate stockpile moisture, tuning burners, good plant maintenance and generous use of insulation for good quality .Contractors have commented that equipment remains cleaner with less asphalt buildup when placing WMA.

WMA for highway project was produced and paved within **S**eptember to December. The minimum ambient temperatures were above 5 °C with wind. Although the surface temperature was lower than the ambient temperature, the required density was achieved easily by conventional paving and compaction equipment and binder course was opened to traffic almost within 4 hours after compaction

During paving process of both of the WMA pavements, gradation, bitumen content, temperature of the mixture were determined on the samples taken from plants. After compaction, it was determined in-place density, air voids and the thicknesses of the layer by taking cores from the layer. All of the results of the quality control tests complied with the criteria given in the specification. Therefore the predicted performance in the laboratory was achieved in the field.

To evaluate the field performance of the WMA and adjacent HM A pavements after 4, 3, 2 years of service life, the core samples were taken from the pavements in September 2019. For WMA binder course of highway project, ITS results complied with the specification except the section aged 3 years. All of the results of HMA section also met the specification criteria. Although bitumen aging during WMA production process would be expected lower than that of hot mix asphalt , the test results shows that bitumen has aged like conventional hot mixes. One of the reason was to heat bitumen up to 170°C during the foam generation and the other was the effects of freezing and thawing actions on the road.

Distress survey on highway and trial section were carried out. For highway project ,the sections of WMA pavement at 4, 3, 2 years old has been carried respectively 77% ,57%,39 % of the maximum traffic capacity .For the HMA section, the rate is 45% .It is meant that the pavements at the age of 4 years has been almost completed three quarters of its life and the others are within the half of the life span. Therefore as soon as possible it is required to pave the surface course without any other distress on the binder courses.

Regarding the visual performance of the road, there was no structural distress, the whole sections of pavements were quite sound and durable even though severe climatic condition and without wearing course on both WMA and HMA pavements. But moisture related distress such as raveling and stripping was found at light severity level on the surfaces of both WMA and HMA pavements. These distresses are certainly related to the aggregate quality, severe climatic conditions and heavy traffic loads. In fact the aggregate used for binder course shouldn't be exposed to the direct action of traffic loads and and severe climatic conditions. There is no evidence of any rutting in either WMA or HMA sections except the section at the age of 4 years. Regarding the performance observation of the pavements, both of the sections are performing equivalently.

For trial section, under the effects of light city traffic and mild climatic conditions, there was no sign of distress on WMA and adjacent HMA section. Both of the pavement had achieved good in field performances.

Laboratory studies and field surveys demonstrated that the foam bitumen technique was capable of lowering the production temperature and meeting the specification criteria.

The cost of WMA foamed bitumen was analyzed and found that it was 6% lower than that of HMA due to 20% energy saving by reducing the temperature 20 °C, although the investment and the depreciation of a new foam generator . As a result the road administration paid less than that of hot mixtures. On the other hand, WMA technology provided the contractor to pave asphalt in the out of construction season .

To verify long-term performance, continued monitoring of the WMA projects is required. In general, the performance of WMA products may vary depending on the circumstances. Therefore, careful examination should be carried out on local constituent materials as well as specific climatic and traffic conditions to examine the characteristics of any particular WMA product before implementation in local projects.

ACKNOWLEDGEMENTS

This study was performed with the contribution of the bituminus mixtures laboratory from General Directorate of Highways and Construction Management Office. The authors would like to thank S. Nedim Tutan and Kuvvet Golbasi for their supports.

REFERENCES

[1] Brian D. Prowell, Graham C. Hurley, P.E. Bob Frank, Warm-Mix Asphalt:Best Practices 3rd Edition Quality Improvement Publication 5, *2012 National Asphalt Pavement Association,2012,72 pages*
[2] EAPA, Asphalt In Fıgures 2017,Versıon 13-12-2018, 11 pages
[3] EAPA The use of Warm Mix Asphalt – Position Paper,2014, 23pages
[4] KGM, highways Technical Specification ,2013,525 pages
[5] NCHRP RESEARCH REPORT 843,Long-Term Field Performance of Warm Mix Asphalt Technologies, 2017,124 pages
[6] O. Abd el Halim,Manthan Ramani ,Stripping Distress on Hot Mix Asphalt Pavements, 2016,5 pages
[7] Martin, A. E., E. Arambula, F. Yin, L. G. Cucalon, A. Chowdhury, R. Lytton,J. Epps, C. Estakhri, E. S. Park. NCHRP REPORT 763,Evaluation of the Moisture Susceptibility of WMA Technologies,2014,108 pages
[8] David E. Newcomb, Edith Arambula, Fan Yin Jun Zhang,Amit Bhasin, Wei Li, Zelalem Arega NCHRP REPORT 807 Properties of Foamed Asphalt for Warm Mix Asphalt Applications, Transportation Research Board of the National Academies,2015 126pages