Development and performance of new additives for warm mix asphalt technologies

Ahmet Sağlık[1, a], Birol Demir[1], Hakan Oral[1], Tuğba Ozturk[1], Ahmet Gürkan Güngör[2]

[1] Research and Development Department, General Directorate of Turkish Highways, Ankara, Turkey
[2] Inspection Board, General Directorate of Turkish Highways, Ankara, Turkey

[a] asaglik@kgm.gov.tr

Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.267

ABSTRACT

Warm mix asphalt (WMA) is a growing sustainable pavement technology reducing the production and paving temperature of asphalt mixture by 20-40 oC without compromising the performance. The main advantages of WMA are reduced fuel consumption, increased hauling distance, extended paving season, better compaction, reduced emissions and binder oxidation.
In this study, it was attempted to develop a new zeolitic and paraffinic WMA additives. Warm mix asphalt mixtures with commercial and newly produced additives were subjected to the rutting, fatigue, water sensitivity (ITSR) and workability tests in laboratory. The two of the additives performing best in laboratory were used in WMA production in real field application. It was seen that all additives gave small amount of reduction in ITSR performance but similar performance in rutting and fatigue in laboratory. However actual field application showed that the additives provide better compatibility and same as or better performance than hot mix in all respects. This paper evaluates laboratory and field performance of commercial and newly developed WMA additives.

Keywords: Additives, Compatibility, Emissions, Warm Asphalt Mixture, Workability

1. INTRODUCTION

Increased environmental consciousness has caused prominent developments in asphalt production and implementation techniques with minimal environmental effects. Currently, the world is facing a serious threat of global warming, and as a result, more stringent environmental and emission specifications are being introduced. One of the factors causing global warming by inducing greenhouse gases to form is the variety of emissions occurring during the heating of asphalt. To save energy and decrease emissions during the production and application of hot mix asphalt (HMA), new technologies have been developed so that production can be done at lower temperatures. This technology, known as "Warm Mix Asphalt" (WMA), is used in all bituminous mixtures including mixtures of dense gradation asphalt, stone mastic asphalt, porous asphalt and mastic asphalt.

Warm Mix Asphalt (WMA) is the generic term for a variety of technologies that allow producers of Hot Mix Asphalt (HMA) pavement material to lower temperatures at which the material is mixed and placed on the road. It is a technology that can reduce paving costs, extend the paving season, improve asphalt compaction distances and improve working conditions by reducing exposure to fuel emissions, fumes, and heat.

A report by the Environmental Protection Agency (EPA) states that during the production of 200.000 tons of bituminous hot mix, 13 tons of carbon monoxide (CO), 5 tons of volatile organic compounds (VOCs), 0.4 tons of sulfur dioxide (SO_2), 2.9 tons of nitrogen oxide (NO_x) and 0.65 tons of other polluting gases are emitted to the atmosphere [14]. In the case that there is 46.2 million tons of bituminous hot mix production in Turkey in 2013 [15], emissions will be 231 times that of the above values. It's estimated that 30%-90% of emissions are reduced due to usage of WMA technology. By taking the average of this range (60%), release of 1802 tons of carbon monoxide (CO), 693 tons of volatile organic compounds (VOCs), 55 tons of sulfur dioxide (SO_2), 402 tons of nitrogen oxide (NO_x) and 90 tons of other polluting gases can be prevented by using WMA technology in Turkey in one year according to 2013 values.

Worldwide warm mix asphalt production technologies generally utilize organic (wax) or chemical additives and foam bitumen by zeolite or water injection. In the scope of this project, the goal is the production of warm mix asphalt by exploiting two of these techniques, which are zeolite and wax additives. In addition to the present technologies, production will be done using bentonite minerals in order to use the national reserves efficiently as well as to further develop current technologies.

After characterization of warm asphalt mixes prepared by addition of manufactured additives is completed, field studies and performance tests have been carried out. This paper aims to present the result of all these studies.

2. INVESTIGATION OF LABORATORY PERFORMANCES OF WMA ADDITIVES

In this study, primarily two commercial synthetic zeolites, one natural zeolite and one organic additive used in the production of WMA were gathered from the market to investigate the performance characteristics and to make a comparison. Afterwards, four types of domestic new synthetic zeolite and three different organic wax additives developed and their performance was investigated. At the same time, one bentonite clay were gathered from the market and tested to explore the usability in WMA as a natural resource

The types of additives used in the study and abbreviations used in this report are given in Table 1.

Table 1: WMA additives used and their abbreviations.

Abbreviation	Type of additive	Abbreviation	Type of additive
CSZ-1	Commercial synthetic zeolite	DW-2	Developed Organic Additive
CSZ-2	Commercial synthetic zeolite	BEN	Bentonite
CNZ	Commercial Natural Zeolite	DSZ-1	Developed synthetic zeolite
CW	Commercial Organic Additive	DSZ-2	Developed synthetic zeolite
DOZ	Developed Organo-zeolite	DSZ-3	Developed synthetic zeolite
DW-1	Developed Organic Additive	DSZ-4	Developed synthetic zeolite

After evaluation of the laboratory performances of the new additives in question, DSZ-4 additive has been decided to be worked with for next steps and two pilot plants have been established for the production of this additive and approximately 3600 kg of synthetic zeolite have been manufactured in those two plants. After laboratory tests, a field trial application was carried out with CSZ-1 and DSZ-4 additives.

2.1. Workability Tests

CSZ-1, CNZ and CW additives were added to and mixed with 50/70 penetration grade of bitumen at the dosage of standard usage to see the additives on workability of binders. The workability of the bituminous binders then have been examined in accordance with TS EN 13302 rotational viscosity test.

Rotational viscosity tests have been repeated in different dosages of additives and different temperatures. Test results are given in the following histogram comparatively. According to the test results it has been seen that all zeolite additives do not make a substantial difference on the workability of the bituminous binder.

When the same rotational viscosity tests were carried out on bituminous binder with organic additives, it was seen that especially CW lowered the viscosity of the bituminous binder, and thus increased the workability.
As a result, although rotational viscosity test was initially thought to be used as a quick spot test to examine the effect of the additives on workability, it was revealed that RV test could not be used to measure WMA performance of inorganic additives but organic additives (Figure 1).

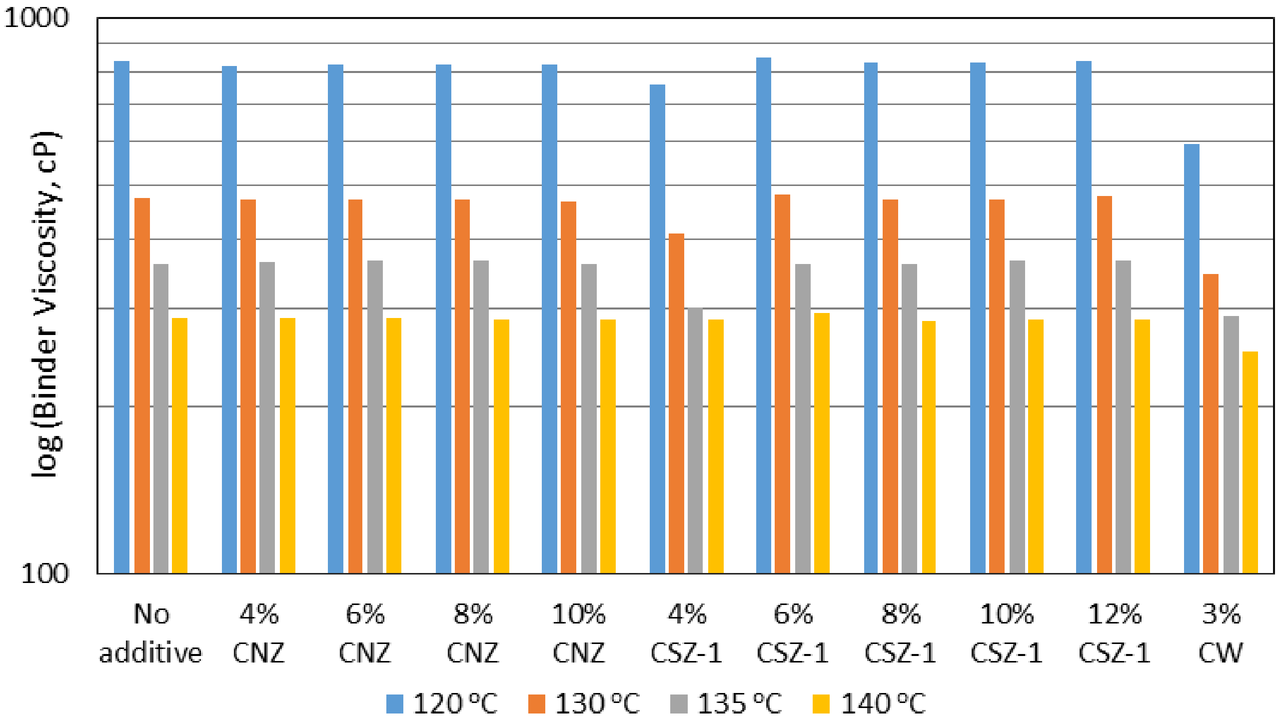

Figure 1: Chart showing the viscosity of pure and additive added binders by temperature.

Upon finding that the effect of the mixture of zeolite type additives on the workability could not be predicted on bituminous binders, direct effect of additives was studied on the asphalt mixtures. For this purpose, the workability characteristics of normal (without additive) and CSZ-1 added mixtures were tested with superpave gyratory compactor in KGM Laboratory. Normal and CSZ-1 added mixtures were compacted in Gyratory Compactor device in a height of approximately 17.5 cm by using 6 inch diameter samples. Each sample was compacted with 100 gyrations. Temperature-density graph of warm and normal mix at the end of 100 gyrations is shown in Figure 2.

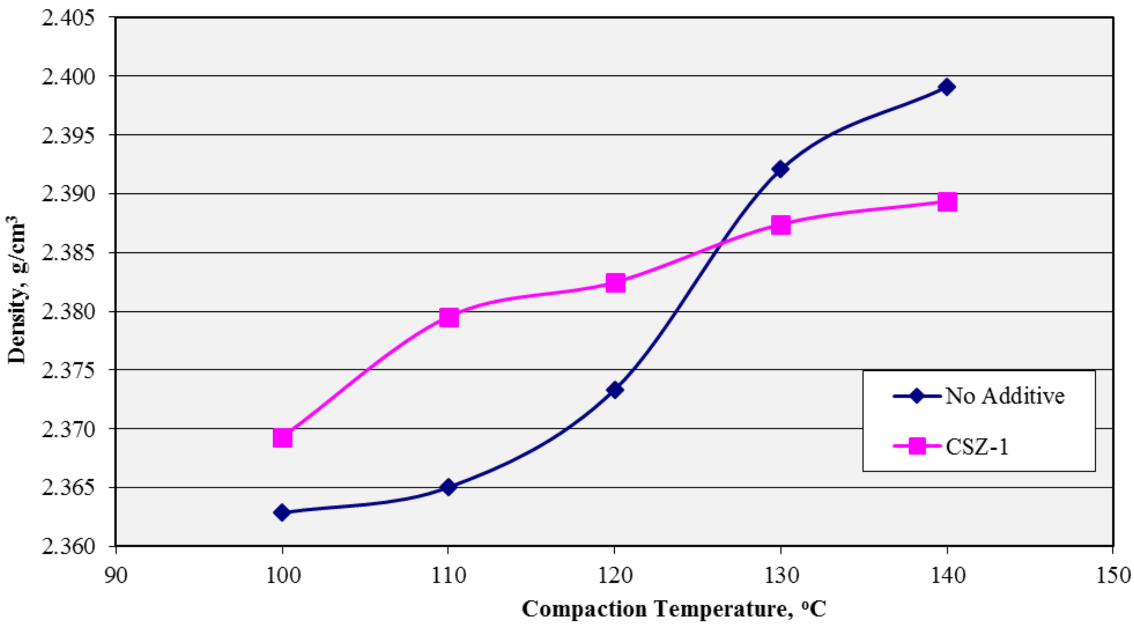

Figure 2: Change in density of mixtures with temperature.

As seen in the chart above, density, indication of compatibility or workability, decreases while the temperature is decreasing. Workability decreases more quickly at normal mixture with temperature but CSZ-1 added mixtures maintain their workability levels quite longer. In Figure 2, normal and CSZ-1 added mixtures have same workability at 135 ºC, which indicates that CSZ-1 additive provided a 15 ºC decrease in production temperature of mixture which vas normally 150 ºC in laboratory.

2.2. Bituminous Mixture Design

First of all, a reference hot mix asphalt without additive was prepared to compare with the warm mixtures in laboratory. For this purpose, asphalt concrete wearing course was chosen as a reference control mixture type since it exposes more traffic and environmental damage. First, required aggregate was provided from Yeşilçiftlik Quarry within the boundaries of in 3th Regional Directorate of KGM (Konya). Aggregate test results and design gradation conforming to Highways Technical Specifications Section 407 are given Table 2 and Table 3.

Table 2: Aggregate properties used in AC wearing course mix design.

Property	**Quarry**	**Standard**
Type of rock	Limestone	-
Los Angeles Fragmentation Loss, %	19	TS EN 1097-2
$MgSO_4$ Loss, %	4	TS EN 1367-2
Flatness Index, %	18.9	TS EN 933-3
Methylene Blue	0.3	TS EN 933-9
Water Absorption, %	0.7	TS EN 1097-6

Table 3: Aggregate gradation of AC wearing course.

Sieve Opening		**Design Gradation**	**Specification KTŞ Section 407 [2]**
mm	inch		
19.1	3/4"	100	100-100
12.7	1/2"	90.0	88-100
9.52	3/8"	78.0	72-90
4.76	No.4	48.0	42-52
2	No.10	30.0	25-35
0.42	No.40	13.5	10-20
0.177	No.80	8.5	7-14
0.075	No.200	5.4	3-8

Marshall Design was carried out in accordance with Highways Technical Specifications (KTŞ) Section 407 (conforming TS EN 12697-34 European standard as well) using aggregate and 50/70 penetration grade of bitumen. Mix design was prepared as a regular hot mix design and used in the other warm mixes as a reference mixture. Design values of AC wearing course is given in Table 4.

Table 4: Mix Design Values of AC wearing course.

Property	Design Value	**Specification KTŞ Section 407 [2]**
Optimum Bitumen,%, (of aggregate)	4.85	4 - 7
Density, g/cm3	2.487	-
Air Void, %	4.04	3 - 5
Voids between Aggregates, VMA, %	14.2	≥ 14
Voids filled with bitumen, ADB, %	71.6	65 - 75
Stability, kg	990	≥ 900
Flow, mm	3.06	2 - 4
Filler/Bitumen ratio	1.11	-

2.3. Preparation of Mixtures

After preparation of hot mix control design; rutting, fatigue and indirect tensile strength performance tests has been conducted on the hot reference mixtures without additive and on the warm mixtures with and without additives. When preparing the mixtures for the tests, all additives but organics were added to aggregate at the rate of 0.3% of mixture at the same time with bitumen and mixed for 3 minutes. Organic (wax) additives was added to the binder (50/70) at the rate of 2% of binder and mixed for 10 minutes. While hot mixes was prepared at 150 ºC and compacted at 140 ºC, mixtures with additives mix was stirred at 130 ºC and compacted at 120 ºC decreasing the temperature by 20 ºC.

2.3.1. Rutting Performance of Hot and Warm Mixtures

Rutting test was carried out according to Hamburg method (TS EN 12297-22) on all mixes with and without additive. In the test, 20000 load cycles at 50 ºC was applied to the samples prepared using Hamburg mixer and compactor in the dimensions of 26cm x 32 cm x 5 cm (Figure 3).
The average of two sample's rutting reading was recorded for each mixtures. Rut depth results at 20000 load cycles are given in Figure 4.

Figure 3: Pictures showing devices used in Hamburg rutting test.

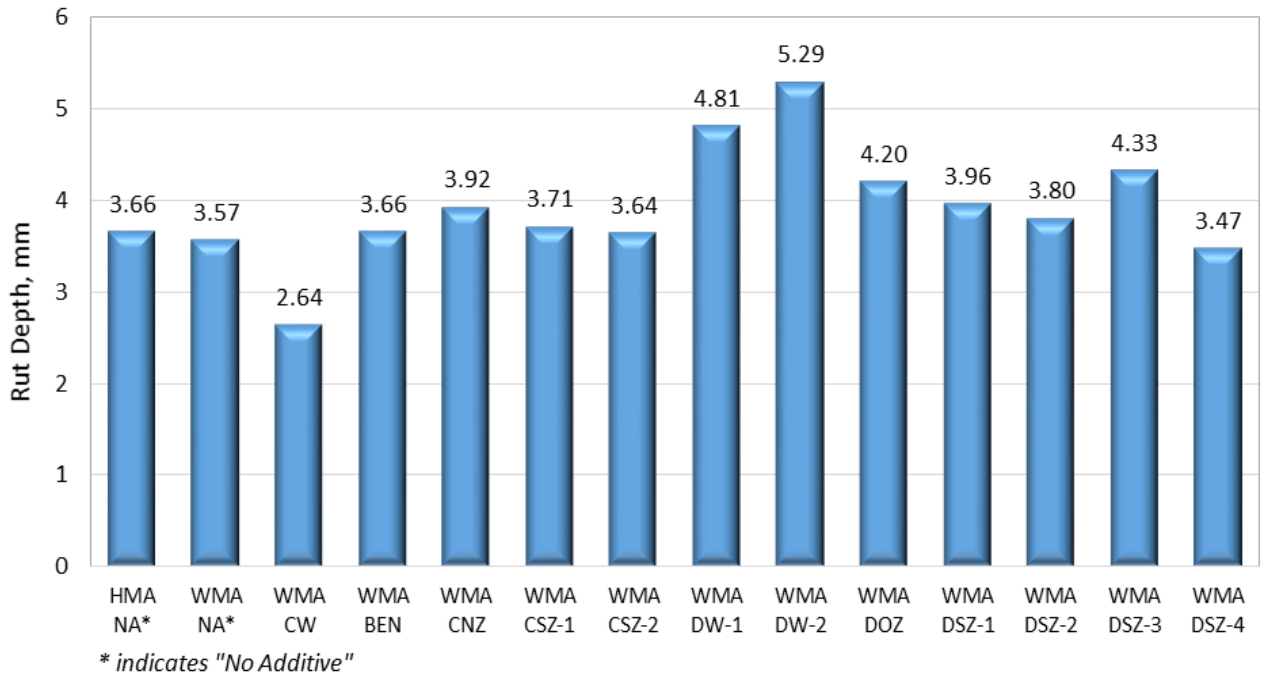

Figure 4: Chart showing Hamburg rut depth of the mixtures.

2.3.2. Moisture Damage Sensitivity of Mixtures

One of the most important performance indicators of warm mix additives is the water damage sensitivity. Because it is the one of the major concern that WMA may reduce compaction and adhesion between aggregate and binder which may causes stripping and raveling problems.

AASHTO T283 (Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage) is used in Turkey to determine HMA moisture damage susceptibility. T283 evaluates the tensile strength ratio (TSR) of conditioned specimen to control specimens. Damage caused by water of the mixtures is determined by Indirect Tensile Strength Ratio (ITS). 10 Marshall Briquettes were prepared for HMA and WMA mixtures according to Marshall Design Bulk specific gravity, void content and average heights of the briquettes were determined. The briquettes were divided into two groups by fives so that each group has almost same average specific gravity. One was spared as conditioning group, the other one as unconditioning. The briquettes to be conditioned are soaked with water and they were placed into vacuum desiccator, the vacuum was applied up to the degree of the saturation between 55% and 80%. These samples were wrapped with a plastic sheet and put into a plastic bags containing 10 mL of water. Then, they were placed into the deep freezer at -18 °C and left there for 16 hours. After the samples were taken out of the freezer, they were removed from the plastic bags and placed in a water bath at 60 °C and conditioned for 24 hours in a water bath. After this process, samples were removed from the water bath and placed in another water bath at 25 °C and conditioned for 2 hours. The conditioned 5 samples were placed into the Indirect Tensile Strength device and broken by loading with constant speed 5 cm per minute and breaking load was read. Other 5 samples were broken after placing in the water bath of 25 ° C for 2 hours without preconditioning and their breaking loads were also read (Figure 6). Then ITS values and ratios were found with following equations.

$$ITS = \frac{2P}{\pi t D}, \qquad \text{and} \qquad ITS\ Ratio = \frac{ITS_2}{ITS_1}$$

Where;

ITS= Indirect Tensile Strength, kg/cm^2
P = Maximum load, kg
t = Sample thickness, cm
D = Sample diameter, cm
ITS_1 = Average Indirect Tensile Strength of Unconditioned Samples, kg/cm^2
ITS_2 = Average Indirect Tensile Strength of Conditioned Samples, kg/cm^2

ITS ratios of all HMA and WMA samples are as shown in Figure 5.

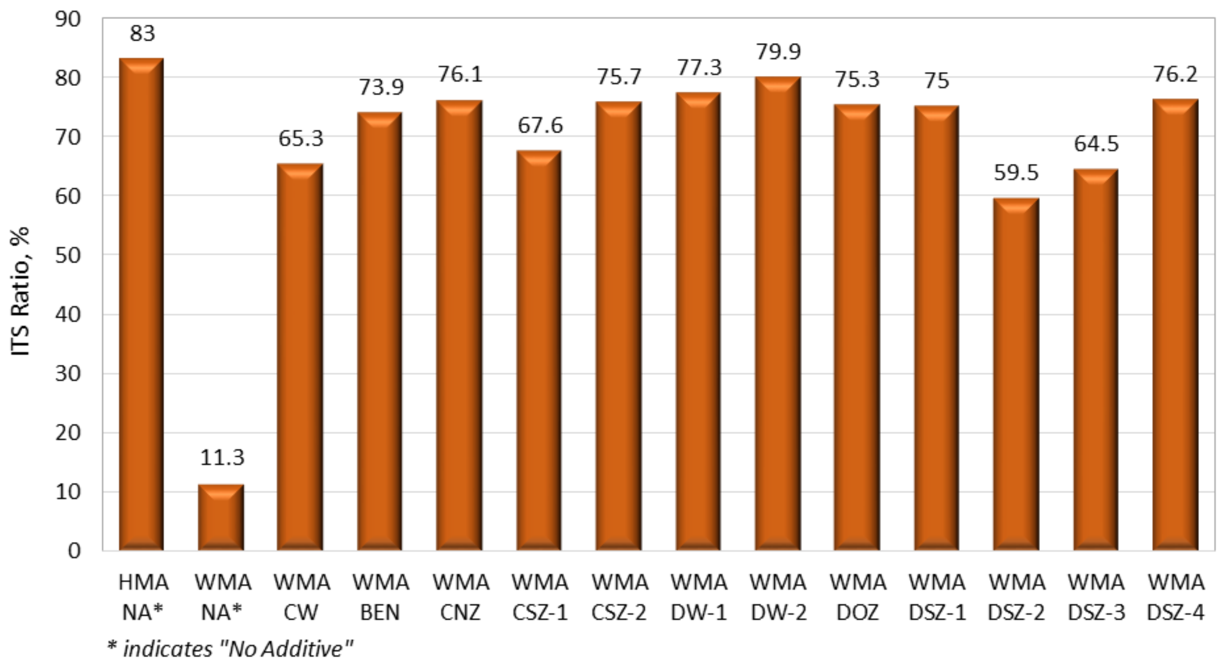

Figure 5 Chart showing ITSR values of the mixtures.

Figure 6: Pictures showing Indirect Tensile Test.

2.3.3. Fatigue Performance of Mixtures

Determination of fatigue resistance of the mixtures under repeated load were carried out using four point beam fatigue tester in accordance with TS EN 12697-24 Annex D (see Figure 7). For this purpose, all mixtures prepared according to design recipe is compacted into the mold of 30,5x40x5 cm dimensions in roller compactor. Each compacted mold was cut into 5 asphalt beams 5cm x 5 cm in cross section and 40 cm in length. Each asphalt beam was placed into four point fatigue frame and exposed to a repeated sinusoidal loading of 20 Hz frequency under the 200 µm constant strain conditions. Test was performed at 20 ºC and continued until the instantaneous stiffness drops to half of initial stiffness of the beam or until it breaks. Load repetition at the end of the test was recorded as fatigue life of the subject beam sample. Test results of each mixtures are shown in Figure 8.

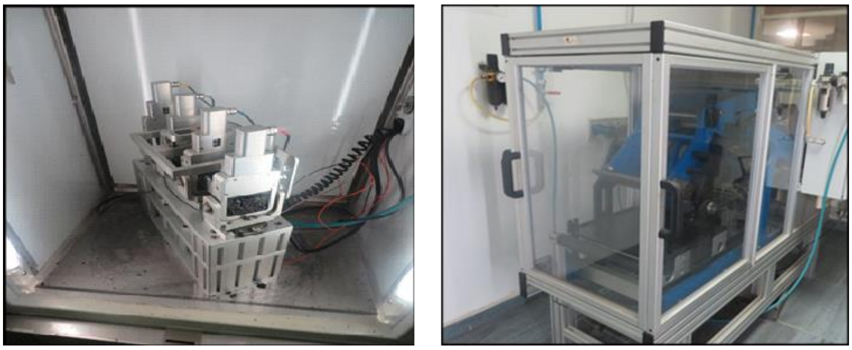

Figure 7: Pictures showing four point fatigue tester and roller compactor.

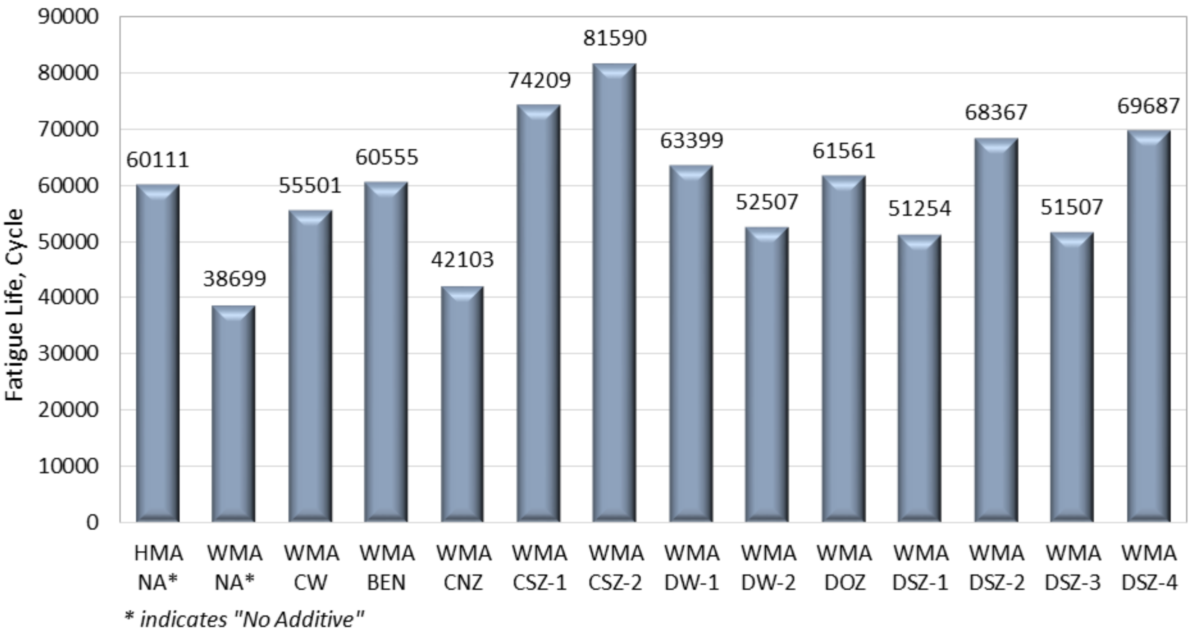

Figure 8: Chart showing fatigue life of the mixtures.

3. IMPLEMENTATION OF WARM MIXTURE ADDITIVES ON THE TEST ROAD

A field application was performed to see real performance of one commercial synthetic zeolite additive and one newly developed synthetic zeolite additive. To do this, a trial section was planned in Ankara Peripheral Motorway where the pavement had been rehabilitating placing 8 cm of binder course and 4 cm Stone Mastic Asphalt (SMA) top layer on the milled and repaired old asphalt concrete. It was decided to use additives in SMA layer to evaluate the WMA performance in a layer composed of basalt aggregate and modified bitumen and to be able to monitor the performance afterwards.
Being used worldwide and giving good performance in laboratory, CSZ-1 was selected as a commercial zeolite. Amongst the newly developed additives, DSZ-4 was selected for trial section since giving the best performance. Two pilot plant were established in order to manufacture sufficient amount of DSZ-4 for application.

3.1. Marshall Mix Design for Trial Section

SMA mix design was prepared using of (0-5) mm (5-10) mm and (10-13) mm basalt aggregate produced in Yakubabdal quarry and additional filler aggregate provided from Başkent limestone quarry. Aggregate physical properties and design gradation are given in Table 5 and Table 6.

Table 5: Aggregate properties used in SMA mix design.

Property	Quarry	Test Standard
Type of rock	Basalt	-
Los Angeles Abrasion Test, %	14.0	TS EN 1072-2
$MgSO_4$ Freezing Loss, %	14.5	TS EN 1367-2
Flatness Index, %	21.6	TS EN 933-3
Methylene Blue	3.75	TS EN 933-9
Water Absorption, %	1.76	TS EN 1097-6

Table 6: Aggregate gradation of SMA.

Sieve Opening		Design Gradation	KTŞ Specification 2013 [2]
mm	inch		
12.7	1/2"	100	100
9.52	3/8"	90.5	90-100
4.76	No.4	41.6	25-35
2	No.10	26.9	20-30
0.42	No.40	16.9	12-22
0.177	No.80	14.5	9-17
0.075	No.200	11.6	8-12

PG 70-22 performance grade of SBS polymer modified bitumen was used in SMA production. Polymer modified bitumen was tested in pursuant to KGM Road Technical Specification Section 412. Test result are given in Table 7.

Table 7: Properties of the polymer modified bitumen used in SMA production.

No	Test	Standard	Unit	Test Results	PMB Specifications PG 70-22 [2]
1	Penetration (25°C,100g,5sn.)	TS EN 1426	0,1mm	46,1	45-80
2	Softening Point	TS EN 1427	°C	72,0	≥ 60
3	Force Ductility (25°C, 5cm/min)	TS EN 13589	J	1,77	≥ 0,5
4	Elastic Recovery (25°C)	TS EN 13398	%	85,5	≥ 70
5	Flash Point	TS EN ISO 2592	°C	280	≥ 220
6	Specific Gravity	TS EN 15326	g/cm^3	1,029	1,0-1,1
7	Dynamic Shear Rheometer (DSR) (G*/sinδ >1kPa)	TS EN 14770	°C	80,2	≥ 70
8	*Storage Stability*	TS EN 13399			
8,1	Softening Point Variation	TS EN 1427	°C	7,0	≤ 5
8,2	Penetration Variation	TS EN 1426	0,1mm	49,0	≤ 13
9	Rolling Thin Film Oven Test (RTFOT Method)	TS EN 12607-1			
9,1	Mass Change		%	0,3	≤ 1
9,2	Increase In The Softening Point	TS EN 1427	°C	-	≤ 8
9,3	Decrease In The Softening Point		°C	5,9	≤ 5
9,4	Residual Penetration	TS EN 1426	%	68,3	≥ 50
9,5	Dynamic Shear Rheometer (DSR) (G*/sinδ >2,2kPa)	TS EN 14770	°C	78,4	≥ 70
10	*RTFOT+PAV Aged PMB*	TS EN 14769			
10,1	DSR (G*sinδ <5000kPa)	TS EN 14770	°C	15,8	≤ 28
10,2	Bending Beam Rheometer (BBR) Flexural-Bending Stiffness (S≤300 MPa, m≥0,300)	TS EN 14771	°C	-12	≤ -12

SMA mix design prepared according to Marshall Design procedure using fine and coarse basalt aggregates, limestone filler aggregate and PG 70-22 grade PMB as a hot mix design in which compaction temperature was 160 °C. Design values of SMA are given in Tablo 8.

Table 8: Mix Design Values of SMA used in trial section.

Property	Design Value	**KTŞ Section 408 [2]**
Optimum Bitumen,%, (of aggregate)	7,50	≥ 6,5
Density, g/cm3	2,215	-
Air Void, %	3,70	2-4
Voids between Aggregates, VMA, %	18,1	≥ 16
ITS ratio, min %	86,6	≥ 80
Amount of Fiber, %	0,3	≥ 0,3
Binder Drainage - Schellenberg method, (%) max	0,08	≤ 0,3

3.2. Performance Tests on Laboratory-Prepared Mixtures

SMA mixtures prepared in laboratory as a hot mix without additive and warm mix with CSZ-1 and DSZ-4 additives to perform performance tests. Both zeolite additives were used in the ratio of 0.3% of mixture. While hot mix SMA without additive was stirred at 170 °C and compacted at 160 °C, WMA mixtures with additives mix was prepared at 150 °C and compacted at 140 °C decreasing the temperatures by 20 °C (Figure 10). Rutting test, indirect tensile strength and fatigue tests were carried out on the prepared mixtures as indicated at Section 2.3. But rutting test was performed at 60 °C. Test results are summarized in Table 9.

Figure 9: The samples after rutting and fatigue tests.

Table 9: Laboratory performance test result of mixture used in trial section.

PARAMETER			Control HMA	DSZ-4	CSZ-1
Rutting at 20000 cycle, mm			2.95	3.80	3.40
Fatigue Life, 20 Hz, 200 µm			768511	562617	558943
Water Sensitivity	ITS. (kg/cm^2)	Unconditioned	6.56	6.45	5,97
		Conditioned	5.68	5.54	5,47
	ITSR (%)		86.6	85.9	91.6

3.3. Test Road Application

Test road was constructed in Ankara Peripheral Motorway Karapürçek intersection. Asphalt plant was located about 1500 m right side of Lalahan and had the approximately 20 km distance from trial section (see Figure 10).

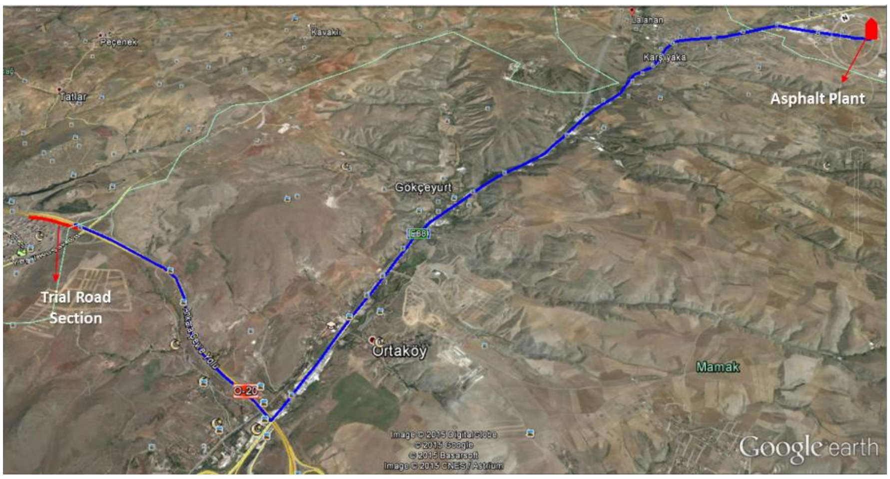

Figure 10: Location map of the asphalt plant and trial section.

In trial section, zeolite additives was decided to been fed with plastic bags. A cover was added to pugmill which was only modification of pant to feed additives. Additives were brought to the field in bags 3 kg each for manually feeding from the covered system. Asphalt Plant was a batch-type one with capacity of 5 tons. However, in practice, it has been operated with a capacity of 2 tons. Two bags of additives (6kg, 0.3%) was manually fed to each 2 tons of batch by an operator. Additive was added to the mixer 2 seconds later than the bitumen. Feeding system and feeding synchronization are given in Figure 11.

Figure 11: Pictures of asphalt plant showing feeding system and time synchronization.

Whilst, production temperature of the hot mix SMA mixture was normally between 175 – 180 ºC, it was 150 ºC in the warm mix SMA mixture with additive decreasing the temperature 25-30 ºC. Warm mix SMA was laid with a paver in a total length of 800 m., one half with CSZ-1 and the other half with DSZ-4. Compactions were measured with nuclear density meter after each roll pass and compatibility was controlled. At the same time, the thermal segregation and heat distribution was controlled with thermal camera (Figure 12).

Figure 12: Pictures from field application showing paver, roller and thermal camera.

3.4. Performance Tests of the Cores Taken From Road

The cores of 10 cm and 15 cm diameters were taken from each three sections (1 HMA and 2 WMA sections) to determine and to compare their actual field performance. While bulk density and water sensitivity (ITSR) tests were performed on the cores of 10 cm diameter and air void and compaction value was controlled. Hamburg rutting tests were carried out on the cores of 15 cm in diameter (Figure 13). Test results can be seen in Figure 14 and Figure 15.

Figure 13: Samples after rutting and ITSR tests.

Figure 14: Graph showing rutting values of mixture applied in field.

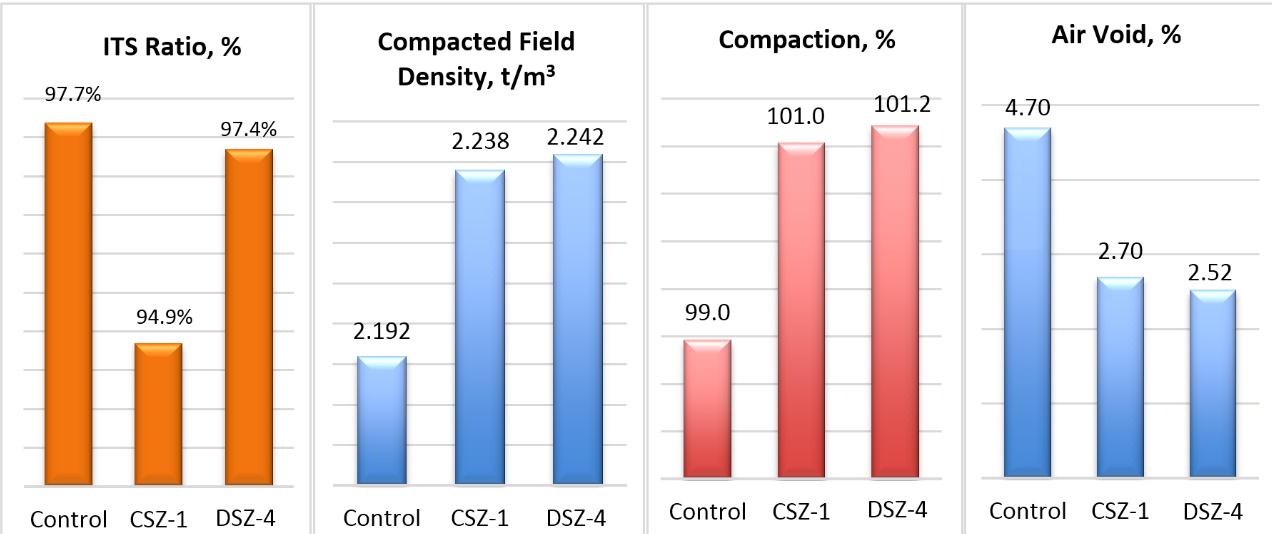

Figure 15: Charts showing performance test results of the mixtures.

4. FINDINGS AND CONCLUSIONS

In this study, different types of commercial and newly developed warm mix additives were compared in terms of laboratory performance. One commercial and one developed zeolite additive were selected to try in the road condition. A trial warm mix stone mastic asphalt was constructed with the chosen additives. Compatibility and workability properties of the mixtures were examined and performances according to the applied tests were compared. The achieved results in this study mainly are:

- There was no significant change in dynamic viscosity values of the zeolite added bituminous binders and bitumen viscosity test is not used to determine the performance of the zeolite additive.
- Warm mix performance of all additives was better than warm mix asphalt without additive which especially showed a very poor water sensitivity performance.
- CW additive showed the best performance in terms of rutting on laboratory, but same performance has never reached in newly developed organic additives.
- It was seen that there was a slight decrease in the resistance to water damage at performances of all additives in laboratory. But it is still possible to get the performance meeting specifications.
- The additives were used at the rate of common usage which was 0.3% of mixture in inorganic additives and 2%of binder in organic additives.
- It was seen that grain size of zeolite additive effects the performance and as the grain size decreases, performance generally increases.

- DSZ-4 was found to have best performance especially in rutting, so it was decided to use in field together with a commercial zeolite (CSZ-1).
- Hot mix Marshall design was used as a reference both in laboratory and field application.
- Additive addition may require small plant modifications that can be easily handled
- WMA did not caused any reduction in plant capacity and used same plant synchronization as HMA production.
- Production temperature was reduced 25-30 ºC in WMA production in which fuel saving was about 20%. WMA explicitly reduced the amount of emission, smoke and odor reduced, which caused reduced environmental damage and improved working conditions.
- Whilst warm mix additives required roller 3-4 pass to get the sufficient compaction, hot mixtures required about 5 passes, therefore, it has been found to provide at least a 25% reduction in compaction energy.
- The results obtained from the cores were better than the ones obtained in the laboratory studies. This shows that, laboratory studies do not represent the performance of the warm mix, actual performance is determined with the application.
- That the cores obtained from zeolite added warm mixes were compacted more was inferred that the additives increased the compatibility and workability.

REFERENCES

[1] ACOTT, M., *Warm Mix Asphalt In the U.S.A. State Of The Practice*, EAPA,2008
[2] Karayolları Genel Müdürlüğü, *Karayolları Teknik Şartnamesi*, Ankara, 2013
[3] Prowell, Brian D. and Hurley, Graham C., *Warm-Mix Asphalt: Best Practices*, National Asphalt Pavement Association, Quality Improvement Series 125, 2007.
[4] Harrison, T., & Christodulaki, L., *Innovative Processes in Asphalt Production and Application Strengthening Asphalt's Position in Helping to Build a Better World.* Proceedings, First International Conference, World of Asphalt Pavements, Australian Asphalt Pavement Association, Kew, Victoria, Australia, 2000.
[5] *Warm Mix Asphalt: European Practice*, Federal Highway Administration, Publication No. FHWA-PL-08-007.
[6] 15. *NCAT Evaluates Warm Mix Asphalt*, Asphalt Technology News, Volume 17, Number 2, Fall 2005, pp. 1-8.
[7] Electronic mail from Øyvind Moen, Kolo Veidekke, Norway. February 10, 2006.
[8] De Groot, P.C., C. Bowen, B.G. Koenders, D.A. Stoker, O. Larsen, J. Johansen., *A Comparison of Emissions from Hot Mixture and Warm Asphalt Mixture Production*, IRF World Meeting, Paris, 2001.
[9] Gandhi, Tejash, *Effects of Warm Asphalt Additives On Asphalt Binder and Mixture Properties*, A Dissertation Presented to the Graduate School of Clemson University, In Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy Civil Engineering, 2008.
[10] Kristjansdottir, O., *Warm Mix Asphalt for Cold Weather Paving*, A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering University of Washington, 2006.
[11] The Asphalt Pavement Association of Oregon, *Warm Mix Asphalt Shows Promise for Cost Reduction, Environmental Benefit*, The Asphalt Pavement Association of Oregon, Salem, OR, Fall 2003.
[12] Temren,Z., *Ilık Karışım Asfalt Uygulamaları ve Performansı*, 5.Ulusal Asfalt Sempozyumu, YTMK Yayın No: 29, Kasım 2009
[13] Acott, Mike. Warm Mix Asphalt In the U.S.A. State of the Practice, EAPA, May 2008
[14] *Hot Mix Asphalt Plants Emission Assessment Report*, U.S. Environmental Protection Agency, North Carolina, 2000
[15] *Asphalt in Figures*, European Asphalt Pavement Association, Brussel, 2014