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3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
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EFFECTS OF A CHEMICAL WMA ADDITIVE ON AGING CHARACTERISTICS OF BITUMINOUS MIXTURES

Peyman Aghazadeh Dokandari¹, Julide Oylumluoglu Oner¹, Ali Topal², Burak Sengoz²

¹ Dokuz Eylul University – The Graduate School of Natural and Applied Sciences, Turkey

² Dokuz Eylul University – Civil Engineering Department, Turkey

Abstract

Utilization of warm mix asphalt (WMA) in pavement construction is a relatively new technology, therefore there is nearly no chance to practically evaluate the long-term characteristics of the existing WMA pavements. Due to lower application temperatures, it can intuitively be expected that a WMA pavement would be less subjected to aging-induced failures. This study attempts to evaluate the effects of a chemical WMA additive on aging characteristics of bituminous mixtures. The chemical additive tested within the scope of this study is a combination of both organic additive and a kind of cationic surfactant developed by Akzo Nobel. Short- and long-term aging conditions were simulated on mixtures containing various contents of chemical WMA additive as well as on control specimens. To estimate the proportions of hardening, aging indices were determined based on indirect tensile strength (ITS) results. The aging indices unveiled that the specimens containing chemical WMA additive demonstrate higher resistance against hardening than conventional hot mix asphalt (HMA) specimens.

Keywords: warm mix asphalt; chemical WMA additive, short term aging; long term aging; indirect tensile strength

1 Introduction

Most of the field pavement practices around the world consist of the conventional Hot Mix Asphalt (HMA). For last decade, implementing of WMA technologies has gained popularity in Europe and some other countries as well as in the United States of America. Nowadays, many new WMA technologies have been introduced to the market. One of the well-known chemical WMA additives in the market is Rediset® WMX developed by Akzo Nobel which is a combination of both organic additive and a kind of cationic surfactant. This study attempts to evaluate the effects of this chemical WMA additive on aging characteristics of bituminous mixtures. Premature failures of asphalt pavements are often caused by diminishing of the binding forces in the mixture by the effect of moisture or mechanical stresses or aging of bitumen. The durability of asphalt concrete is a measure of its level of resistance to hardening (also called aging) over time [1]. The effect of time and environmental factors on the aging of bitumen is a subject of continuous interest [2]. Earlier studies conducted on the effect of temperature and relative humidity on the oxidation of bitumen as a function of exposure time showed that the rate of oxidation is dependent on both of these environmental factors [2], [3]. The effect of ambient temperature on the ageing characteristics of the bitumen is rather well documented. Petersen (1984) pointed out that three basic factors control the changes that would result in ageing in bitumen [4]. First factor better called volatilization is the loss of the oily components of bitumen by volatility or by absorption of porous aggregates. Second factor called oxidation is known as the Change in the chemical composition of bitumen resulted from reaction with

oxygen. Third factor known as steric hardening is molecular structuring that produces thixotropic effects. Among these factors, oxidation is mainly considered as a major factor contributing in the hardening of the asphalt pavement.

The literature review shows that aging of asphalt occurs in two terms called Short- and Long-term in order [5]. Short-term ageing occurs during mixing and final placement when the asphalt is at elevated temperatures. This is probably caused by volatilization. Long-term aging occurs partially throughout the short-term aging frame and while the asphalt is in service and exposed to environment. This long-term aging is predominantly caused by oxidation. Aging of asphalt may be influenced simultaneously by several factors, such as characteristics and content of the bitumen, nature and particle size distribution of the aggregates, void content of the mixture, production related factors, and external conditions such as temperature and time [6]. Asphalt additives would considerably change the mixture characteristics. Beside the effect of modification in bitumen, it can intuitively be expected that a WMA pavement would be less subjected to aging than a HMA pavement in construction and hauling phases.

2 Experimental

2.1 Materials

The bitumen used in this study was 50/70 penetration grade bitumen which was provided from TUPRAŞ Aliağa refinery. This grade of penetration is commonly used in İzmir; Turkey due to climatic conditions. Conventional test results for virgin bitumen conducted at laboratory of bituminous materials in Dokuz Eylül University are given in Table 1.

A mix of basalt and limestone aggregates provided from Dere Madencilik Inc. (Quarry located in Belkavhe – İzmir) is used in this study. Physical properties of each kind are given in Table 2. After conducting the associated tests based on ASTM C 136, a mix gradation of basalt and limestone is intentionally chosen to provide desired performance in conformity with Turkish specifications concerning the Type 1 wearing course. Basalt plays the role of strengthening constituent as coarse aggregate while limestone participates in fine aggregate framework. The gradation is given in Table 3.

Table 1 Laboratory test results for virgin bitumen

Test	Standard	Results	Turkish Specifications
Penetration (25°C ; 0.1 mm)	ASTM D5	55	50-70
Softening Point (°C)	ASTM D36	49	46-54
Viscosity (135°C)	ASTM D4402	412.5	–
Viscosity (165°C)	ASTM D4403	137.5	–
TFOT (165°C)	ASTM D1754		
Mass change (%)		0.04	<0.5
Penetration Change (%)	ASTM D5	25	–
Softening Point after TFOT (°C)	ASTM D36	54	48<
Ductility (25°C; cm)	ASTM D113	100	–
Specific Gravity	ASTM D70	1.03	–
Flash Point (°C)	ASTM D92	+260	230<

The chemical WMA additive tested in this study is Rediset® WMX which is a combination of both organic additive and a kind of cationic surfactant [7]. The surfactants simply increase the coating ability of the aggregate with the bitumen by “active adhesion.” and the other constituents have role in reducing the viscosity of the bitumen [8], [9]. Using this additive can reduce the production temperature by about 10°C to 15°C and consequently results in 20%

reduction in fuel consumption [8], [10]. This additive can either be added to the bitumen or to the mixture. Plant modification is not needed or minor changes are sufficient [8]. The supplier recommendation about the sufficient dosage is 1.5% to 2% by the virgin bitumen weight [11].

Table 2 Physical properties of aggregates

Test	Specification	Limestone	Basalt	Limits
Specific gravity (coarse agg.)	ASTM C 127			
Bulk		2.686	2.666	-
Saturated Surface Dry		2.701	2.810	-
Apparent		2.727	2.706	-
Specific gravity (fine agg.)	ASTM C 128			
Bulk		2.687	2.652	-
Saturated Surface Dry		2.703	2.770	-
Apparent		2.732	2.688	-
Specific gravity (Filler)		2.725	2.731	-
Los Angeles Abrasion (%)	ASTM C 131	24.4	14.2	< 45
Flat and elongated particles (%)	ASTM D 4791	7.5	5.5	< 10
Sodium sulfate soundness (%)	ASTM C 88	1.47	2.6	10-20
Fine aggregate angularity	ASTM C 1252	47.85	58.1	40<

Table 3 Mixed gradation of basalt and limestone

Test	19 – 12.5 mm (Basalt)	12.5 – 5 mm (Basalt)	5 – 0 mm (Limestone)	Combined (%)	Limits
Mix ratio (%)	15	45	40		
Gradation					
(3/4)"	100	100	100	100	100
(1/2)"	35.7	100	100	90.5	83-100
(3/8)"	2.5	89	100	80.5	70-90
No 4	0.4	16	100	47.3	40-55
No 10	0.3	1.2	81	33	25-38
No 40	0.2	0.7	33	13.5	10-20
No 80	0.15	0.4	22	9	6-15
No 200	0.10	0.2	13	5.3	4-10

2.2 Experimental Plan

Based on the regarding production temperature and mixing times for chemical WMA additive, WMA bitumens were produced just before the mixing with aggregates process. Production temperature was supplied by a heater similar to Thermosel™ and controlled by a digital industrial thermometer. An industrial stirrer was used in production of WMA bitumens. Stirring was done in normal shear stresses (1000 rpm by a stainless steel stirrer bar with about a 4 cm cross crown) since the production of WMA bitumens don't demand for high shear stresses. Mixing temperatures and periods were determined based on trial and error method. 15 minutes production period at 150 °C temperature was determined as optimum process.

Mixing and compaction temperatures for chemical WMA additive modified bitumen were derived from equiviscous method in accordance to AASHTO T 312. The graphics for viscosities vs. temperature were plotted for all additive contents. Acceptable temperature for mixing was chosen as the range matching 0.17±0.02 Pa·s and acceptable temperature for compaction was chosen as the range matching 0.28±0.03 Pa·s. For various additive contents of chemical

additive by virgin bitumen weight, mixing and compaction temperatures are given in Table 4. Data for virgin bitumen used in HMA is presented by 0 % (no additive) in the table.

Table 4 Mixing and compaction temperatures

Additive Content (%)	Mixing Temp. (°C)	Compaction Temp. (°C)
0	157 – 164	144 – 150
1	151 – 157	138 – 144
2	145 – 149	136 – 140
3	144 – 147	133 – 138

Following the production of chemical WMA additive modified bitumens, WMA mixtures were prepared based on the determined mixing temperatures. The industrial mixer used for mixing the aggregates and the bitumen. The optimum bitumen content was determined by Marshall mix design method. The optimum bitumen content for both virgin bitumen and chemical WMA additive modified bitumen were respectively determined as 4.76% and 4.46% by weight of aggregates. The aggregates were placed in an oven adjusted for proper temperature the day before to be completely dried and ready for mixing. Specimens were compacted with Marshall compactor regarding their compaction temperatures after mixing process. Conditioning as per AASHTO R 30 standard were done on the specimens intended to be aged. Short-term aged specimens were conditioned in a forced-draft oven set for 135°C for 4 hours and then compacted and cured since the long-term aged specimens were conditioned for 124 hours in a forced-draft oven set for 85°C after passing the short-term aging conditions. All processes regarding the conditioning of the mixtures are shown on a flowchart in Fig. 1.

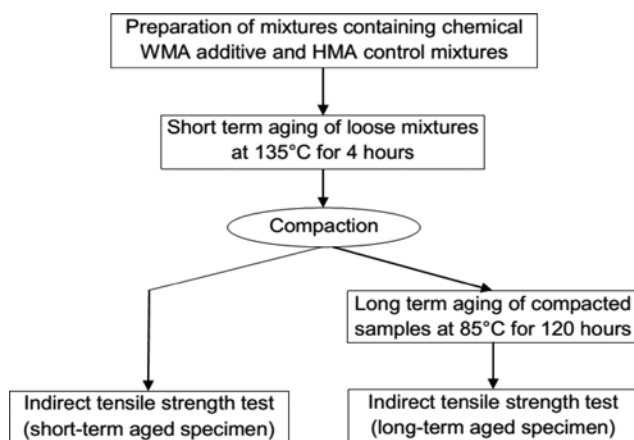


Figure 1 Short- and long-term conditioning flowchart

All specimens were tested for Indirect Tensile Strength (ITS) after being cured. To perform this task, ASTM D6931 -the standard test method for indirect tensile strength of bituminous mixtures- has been taken into account. The ITS test was conducted by Marshall stability and flow apparatus. The loading rate was set to 51(mm/min) in case for ITS. To be adequate and unbiased, three specimens for all additive contents were prepared and tested randomly. The ITS results can give the evaluation keys in terms of low temperature and fatigue cracking of asphalt pavements. Some studies introduce ITS result as a good indicator in predicting laboratory rutting potential of asphalt mixtures [12].

The bitumen becomes more brittle and stiffer as it ages, thus the ITS results of an aged mixture are rather more than the results of an un-aged mixture. This fact can simply provide us

with aging indices to investigate the aging characteristics of asphalt mixtures. Burak Sengoz (2003) has implemented ITS results of mixtures with various air voids, to assess aging and moisture susceptibility characteristics of HMA mixtures [13]. Another study on short- and long-term aging behavior of rubber modified asphalts has also proved the fact that the short-term and long-term aging increased the measured tensile strengths [14]. Sengoz and Topal (2008) investigated the effects of SBS polymer modified bitumen on the aging properties of asphalt mixtures using ITS results [15]. They calculated aging indices as the ratio of short- and long-term aged specimen's ITS values to the values of un-aged control specimens prepared with the same additive content.

3 Results and discussions

The ITS results for un-aged, short- and long-term aged specimens are given in Figure 3. In this figure, additive content corresponding 0 simply demonstrates the HMA control specimens. The results of un-aged specimens indicate that using Rediset® WMX can potentially increase the indirect tensile strength of a specimen. This fact is observable in additive contents more than 2%. Higher ITS value in case of un-aged specimens points out the specimen strength in terms of internal bonds. This fact is in conformity with previous studies that all stated about the “active adhesion.” which plays role in increasing the coating ability of the aggregate with the bitumen by means of surfactants and consequently can result in higher internal bonds [8], [16].

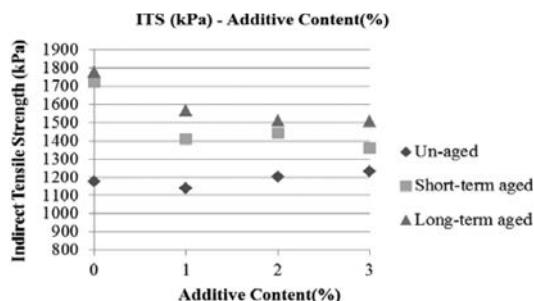


Figure 2 ITS results corresponding additive contents

As seen in the Figure 3, the differences between the ITS values of un-aged and aged specimens obviously decrease by increasing in additive content. This fact is basically born of aging effects of use of chemical WMA additive. Aging indices can provide better evaluation for the effects of chemical WMA additive on aging characteristics of bituminous mixtures. In this study, these indices were calculated as the ratio of ITS values of short-term and long-term aged specimens over ITS values of HMA control specimens. The calculating formulas for Short-term Aging Index (SAI) and Long-term Aging Index (LAI) are as follows:

$$SAI = \frac{\text{ITS value of short – term aged specimen}}{\text{ITS value of un – aged specimen}} \quad (1)$$

$$LAI = \frac{\text{ITS value of long – term aged specimen}}{\text{ITS value of un – aged specimen}} \quad (2)$$

By means of these indices, we are able to observe how hardened an aged specimen has become after the aging process. The less an aging index of a mixture is, the more resistive that mixture is against hardening. The SAI and LAI values for all contents of chemical WMA additive are demonstrated in Figure 4.

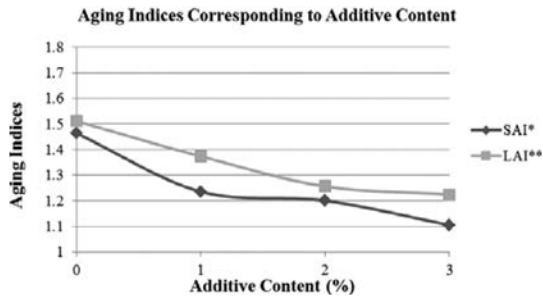


Figure 3 ITS results corresponding additive contents. Note: * 'SAI': Short-term Aging Index; ** 'LAI': Long-term Aging Index

As seen in the graph, chemical WMA additive modified mixtures exhibited lower aging indices than control specimens as it was expected. As discussed before, temperature is a vital factor in occasion of the aging. Lower application temperatures can cause less aging especially in case of short-term aging. Having a glance on the slope of the trendlines for both SAI and LAI values, It can simply be realized that the drop in SAI values is more than the drop in LAI values. This can be explained considering the effect of application temperatures on aging of bituminous mixtures during construction phase. The short-term aging occurs during production, storage and hauling in particular temperatures. These temperatures differ for WMA and HMA pavements, since the long term conditions for both pavement types are mostly equal during the service life of the pavements.

Chemical WMA additive modified mixtures demonstrated better strength against aging in comparison with HMA mixtures. Test results showed that less hardening occurred when the additive content increased. The reduction slope seemed to become less in step by step increasing in additive content.

4 Conclusion

Asphalt pavement has a service life. The more the service life of an asphalt pavement, the more economic that asphalt pavement is. From economical point of view, simply considering the initial cost of a structure is not efficient and it is also vital to consider the long term characteristics of the structure in service. Although WMA technologies have a lot of economic benefits in comparison to HMA pavements in terms of energy, it is essential to consider the long term properties of WMA pavements. As aforementioned, this study was allocated to evaluate the effects of a chemical WMA additive on WMA pavements in terms of long term and short term aging.

As a conclusion, generally WMA technologies can be categorized as acceptable alternatives for conventional HMA pavements in terms of aging. Utilization of WMA additives in lower temperatures is the dominating advantage of WMA technologies from the aging point of view. Rather than lower application temperatures, based on catalogue information, chemical WMA additive contains anti-stripping agent within its chemical structure which can play role in reducing aging effects parallel to reducing stripping.

References

- [1] Bell, C.A.: Summary Report on Ageing of Asphalt Aggregate Systems, Oregon State University, Corvallis, 1989.
- [2] Campbell, P.G., Wrigth J.R. & Bowman P.B.: The Effect of Temperature and Humidity on the Oxidation of Air Blown Asphalts, *Materials Research Standards*, 2, pp. 988-995, 1962.
- [3] Chipperfield, E. H.: Asphalt Characteristics in Relation to Road Performance, *Annual Journal of Association of Asphalt Paving Technologists*, 39, pp. 79-88, 1970.
- [4] Petersen, J.C.: Chemical Composition of Asphalt as Related to Asphalt Durability: State of Art, *Transportation Research Record*, 999, pp. 13-30, 1984.
- [5] Bell, C.A., Wieder, A.J. & Felin, M.J.: Laboratory Ageing of Asphalt Aggregate Mixtures: Field Validation – SHRP-A-390, Oregon State University, Corvallis, 1994.
- [6] Xiaohu, L. & Isaccson, U.: Artificial ageing of polymer modified bitumens, *Journal of Applied Polymer Science*, 76, pp. 1811-1824, 1999.
- [7] Chowdhury, A. & Button, J. W.: A Review of Warm Mix Asphalt, Texas A&M University System College Station, Texas Transportation Institute, Texas, 2008.
- [8] Lai, J. S. & Tsai, J. Y.: Evaluating Constructability and Properties of Advera and REVIX Warm Mix Asphalt: Final Report, Georgia Dept. of Education Office of Materials & Research, Forest Park, Ga, 2008.
- [9] Prowell, B. D. & Hurley, G. C.: Warm Mix Asphalt: Best Practices, National Asphalt Pavement Association, 2007.
- [10] D'Angelo, J., Harm, E., Bartosze, J., Baumgardner, G., Corrigan, M., Cowser, J., Harman, T., Jamshidi, M., Jones, W., Newcomb, D., Prowell, B., Sines, R. & Yeaton, B.: Warm Mix Asphalt: European Practice, FHWA Report No. FHWA-PL-08-007, American Trade Initiatives, Alexandria, Virginia, 2008.
- [11] Rubio, M. C., Martinez, G., Baena, L. & Moreno, F.: Warm Mix Asphalt: an Overview *Journal of Cleaner Production*, 24, pp. 76-84, 2012.
- [12] Anderson, R. M., Christensen, D. W., & Bonaquist, R.: Estimating the Rutting Potential of Asphalt Mixtures Using Superpave Gyratory Compaction Properties and Indirect Tensile Strength, (With Discussion), *Journal of the Association of Asphalt Paving Technologists*, 72, pp. 1-26, 2003.
- [13] Sengoz, B.: The Effect of Asphalt Film Thickness on the Aging and Moisture Susceptibility of Hot Mix Asphalt, PhD Thesis, Istanbul Technical University, Graduate School of Natural and Applied Sciences, Istanbul, 2003.
- [14] Liang, R. Y. & Lee, S.: Short-Term and Long-Term Aging Behavior of Rubber Modified Asphalt Paving Mixture, *Transportation Research Record*, 1530, pp. 11-17, 1996.
- [15] Topal, A. & Sengoz, B.: Effect of SBS Polymer Modified Bitumen on the Ageing Properties of Asphalt, *Proceedings of the 4th Eurasphalt and Eurobitume Congress*, Copenhagen, pp. 1147-1153, 2008.
- [16] Hurley, G. C. & Prowell, B. D.: Evaluation of Sasobit® for Use in Warm Mix Asphalt, US: National Center for Asphalt Technology, Auburn, 2005.