DEVELOPMENT OF PRODUCTION TECHNOLOGIES FOR WARM MIX ASPHALT ADDITIVES

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ABSTRACT

In last decade, warm mix asphalt (WMA) technology has been used as an alternative to hot mix asphalt (HMA) that reduces the temperature during production and placement, and minimizes greenhouse gases while maintaining the properties of HMA. In Turkey, between 2012-2015, a project named "Development of Production Technologies for Warm Mix Asphalt Additives" was implemented by the Institute of Chemical Technology of TUBITAK Marmara Research Center (MAM), and R&D Department, General Directorate of Highways, Republic of Turkey. The objective was to develop and produce zeolitic base WMA additive. Additives were synthesized in a laboratory, a semi pilot plant and a pilot plant. Pilot asphalt laying was applied in Ankara for 400 meters by produced and commercial zeolitic base additive. The results showed that the performance of the additive produced in TUBITAK MAM had better wheel tracking results and higher TSR (Tensile strength ratio) values than commercial additives.

Keywords: *warm mix asphalt, warm mix asphalt additives, zeolite, warm mix asphalt performance tests.*

1. INTRODUCTION

Hot mix asphalt (HMA) is used as the primary paving material in the world, which consists of aggregate and asphalt binder which are heated and mixed together. The primary sources of emissions in an asphalt plant are the mixers, dryers and hot bins, which emit particulate matter, such as dust, smoke, exhaust vapor and other gaseous pollutants. Some other sources of emissions found at an asphalt plant are the storage silos, truck loading operations, binder storage tanks, stockpiles, etc. In order to reduce the emissions from asphalt plants, the asphalt industry is constantly trying to reduce mixing and compaction temperatures of mixes, without significantly affecting their properties. The asphalt industry has been experimenting with warm and cold asphalt mixtures for decades to reduce energy requirements and for environmental benefits [Sutton, 2002].

Warm mix asphalt (WMA) is an asphalt mixture which is combined at temperatures lower than conventional hot mix asphalt. Typically, mixing temperatures of warm mix asphalt range from 100°C to 140°C compared to mixing temperatures of 150°C to 180°C for hot mix asphalt. Thus, warm mix asphalt has been gaining an increasing popularity in recent years. Rising energy prices, global warming and more stringent environmental regulations have resulted in an interest in warm mix asphalt technologies as a means to decreasing energy consumption and emissions associated with conventional hot mix asphalt production [Jones, 2004].

European countries are already using warm asphalt technologies that allow reductions in mixing and compaction temperatures of about 20°C to 55°C. The asphalt industry has developed several methods to reduce mixing and lay-down temperatures of asphalt mixtures. In principle, there are three major methods for the preparation of asphalt mixtures at low temperatures. These methods are foaming, organic additives and chemical additives. Foaming is done either by adding water directly or adding water bearing additives that are generally natural or synthetic zeolites into the asphalt mixture [Koenders, et al., 2000].

Warm mix asphalt technology has many advantages as compared to hot mix asphalt. It reduces emissions, provides better working conditions because of the absence of harmful gases and lower energy consumption in mix production. Since, the compaction and mixing temperature is lower with WMA technology, it provides quicker turnover to traffic, longer hauling distances and extended paving period.

2. WARM MIX ASPHALT

Bitumen is used as a binder in asphalt overlaying. Bitumenous binders are in solid form under normal weather conditions and its viscosity should be reduced for fluidizing and its workability should be increased to mix with agregates for producing asphalt concrete and to fill the aggregate voids for a good adhesion. This process is accomplished by heating the bitumenous binders to high temperatures in asphalt plants for hot mix asphalt concrete production.

The production of hot mix asphalt is responsible for a large consumption due to the heating of its components (aggregates and binder). This energy is spent on the burning of fossil-fuels and the consequent greenhouse gas emissions. The implementation of the Kyoto Protocol in 2005, which has been extended until 2020, aims to have the signatory countries undertaking measures to reduce

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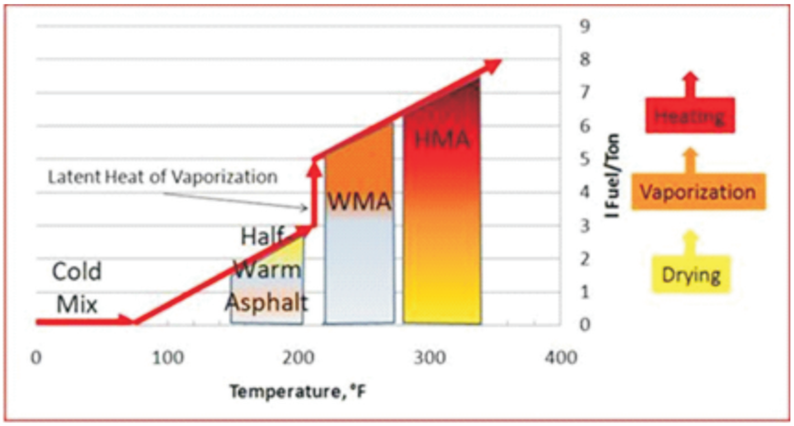

Figure-1: Classification by Temperature Range, Temperatures and Fuel Usage

those atmospheric emissions. Thus, new manufacturing techniques have been developed, and the decrease of temperature plays an important role in this technique (Figure-1).

WMA is a technology used in road construction and has the potential of improving energy efficiency by reducing the temperature at which the asphalt pavement material is mixed and placed on the road. WMA can usually lower asphalt-mixing temperatures by 15°C to 30°C compared to conventional hot mix asphalt (HMA). WMA can be used in all bitumenous mixtures including dense graded asphalt, stone mastic asphalt, porous asphalt and mastic asphalt.

The data gathered with the assistance of the members of the European Asphalt Pavement Association have been shown in Table-1 and Table-2.

The most important benefit of using WMA is the significant lower bitumen fume level during paving operations compared to HMA. Also, there are many advantages that are classified into three different categories shown in Table-3.

3. BENEFITS OF WARM MIX ASPHALT TECHNOLOGY

3.1 Reduced Fuel Usage

Since the main advantage of warm mix is the reduction of mixing and compaction temperatures, compared to HMA there is significant reduction in the usage of fuels. Before mixing the aggreagtes with asphalt, aggregates are heated to get rid of the moisture. The additives reduce the viscosity at lower temperatures making it easy to mix asphalt with the aggregate at a lower temperature. Thus, with the use of additives, it is possible to, lower the mixing and compaction temperature; therefore resulting in savings of up to 35% [Sampath, 2010].

3.2 Better Workability and Compaction

WMA allows better workability at lower temperatures due to inclusion of additives. Better workability would result in better compaction of the pavement since it would take fewer roller passes to obtain the desired air voids for the pavement. Figure-2 shows better working

Table-1: Total Production of Hot and Warm Mix Asphalt in 2008-2014 (in Million Tonnes) [EAPA, 2014]

Country	2008	2009	2010	2011	2012	2013	2014
EU-28	300	291.6	262.6	268.5	226.7	219.7	219.4
Europe	338	326.9	309.3	324.3	276.4	277.3	265.4
Australia	9.5	9.5*	7.5		8.8		9.1
New Zealand					1	1	
Japan	49.6	49.6	44.7	45.6	47.3	49.9	45
(Ontario) Canada	13.2*	13.2*	14	13.5	13		13.8
USA	440	324	326	332	326.9	318.1	319
South Africa				5.7	5.7	5.5	5.4
South Korea		35.6	20.7		23.2	26.2	
Note: **estimated values, blank: no data.*							

Table-2: Production of Warm Mix Asphalt in 2013 and 2014 [EAPA, 2014]

Country	2013 (million tonnes)	2014 (million tonnes)
Austria	0.000	0.000
Belgium	No data	No data
Croatia	0.000	0.040
Czech Republic	0.030	0.001
Denmark	0.120	0.200
Finland	0.000	0.120
France	3550	4023
Germany	No data	No data
Great Britain	<1.000	<1.000
Hungary	0.020	0.038
Luxemburg	0.000	0.007
Netherlands	0.060	0.133
Norway	0.380	0.540
Slovenia	0.000	0.000
Spain	0.086	0.140
Sweden	0.500	0.700
Switzerland	0.870	0.388
Turkey	0.000	0.000
USA	69000	103000
Japan	0.152	0.231
Ontario-Canada	No Data	0.750
South Africa	0.150	0.150

Table-3: Potential Benefits of WMA [Sampath, 2010]

Potential Benefit	Economic	Operational	Environmental
Reduced fuel use	X		X
Late season (cool weather) paving		X	
Better workability and compaction	X	X	
Reduced plant emissions of greenhouse gases			X
Increased usage of RAP	X		
Improved working conditions for plant and paving crew		X	

conditions with less fume in warm mix asphalt pavement [Sampath, 2013].

3.3 Reduced Emissions of Greenhouse Gases

Asphalt mixing is a more energy intensive process as compared to other industrial activities. The energy consumed during the mixing process was as much as 60 percent of the total energy required for the construction and maintenance of a given road over a typical service life of 30 years [Sampath, 2013]. The use of WMA techniques allow for reduction in required mixing energy and subsequently allow substantial savings in energy costs. According to previous

Figure-2: Warm and Hot Mix Asphalt Pavement [Asphalt, 2013]

Table-4: Reduction in Emission of Greenhouse Gases [Sampath, 2010]

Emission	Reduction in measured Emission-WMA (compared to HMA)
CO_2	15-40 %
SO_2	18-35 %
NO_x	18-70 %
CO	10-30 %
Dust	25-55 %

studies, this correlates to burner fuel savings with WMA processes ranging from 20 to 35 percent. A lower temperature used during the production accounted for reduction in electrical usage to mix the material, as well as to transport the material through the plant. With the use of WMA technology, consumption of fuel and emission of Green House Gases (GHGs), such CO_2, SO_2 and NO_2, decreases [You, 2011]. The reduction in the mixing temperature causes a visible reduction in the smoke and odor, and may thus result in improved working conditions. Table-4 shows the reduction of emissions by using WMA.

3.4 Increased Usage of RAP

Reclaimed Asphalt Pavement (RAP) is the term given to asphalt that has been removed and/or reprocessed and can be used as aggregates for laying roads. The usage of RAP in HMA has been limited by many highway agencies due to the concern that the materials might get aged at high temperatures and would potentially lead to early cracking of the roads. The mixing temperature in WMA is significantly lower and can thus facilitate the use of RAP for construction.

There are three major methods for preparation of warm asphalt mixtures: foaming, organic additives and chemical additives. Two different foaming tecniques are applied to reduce the viscosity of bitumen, injection of water and adding minerals. The foaming process by injection of water generally produces tiny steam bubbles inside the asphalt binder, which causes a volume increase, leading to increased wettability of the binder and lower high shear viscosities [EAPA, 2014a].

The method with water bearing additives is based on the release of chemically bound water from the additives into the binder during the mixing process. Release of this water leads to a finely dispersed steam when it comes in contact with the heated aggregate and binder. The fine steam bubbles lead to micropores that improve the compaction properties of the binders. This indirect foaming technique uses hydrophilic minerals from the zeolite family [Sampath, 2010].

Water containing technologies use synthetic zeolite to produce the foaming process. The product is composed of aluminosilicates of alkali metals, and has been hydro-thermally crystallized. The zeolite has approximately 20% water, which is released from the structure with temperature rise [Rubio, 2012].

The second method is based on adding special organic additives to the binder to reduce its viscosity. Such types of additives typically consist of paraffinic hydrocarbons. Paraffins are generally soluble in the asphalt binder in the temperature range of 80-120°C

[Hill, 2011]. The process show a decrease of viscosity above the melting point of the wax, making it possible to produce aphalt concrete mixes at lower temperatures. After crystallisation, they tend to increase the stiffness of the binder as well as the asphalt's resistance against deformation. The type of wax must be selected carefully so that the melting point of the wax is higher than expected in service temperature and to minimize embrittlement of the asphalt at low temperatures [Zaumanis, 2010; Silva, 2010].

The chemical additives usually include anti-stripping agents that are designed to enhance coating, adhesion and workability of asphalt mixture. They do not change the bitumen viscosity. They regulate and reduce the frictional forces at the microscobic interface of the aggregates and the bitumen [EAPA, 2014a].

4. DEVELOPMENT OF PRODUCTION TECHNOLOGIES FOR WARM MIX ASPHALT ADDITIVES PROJECT

A project titled "Development of Production Technologies for Warm Mix Asphalt Additives" was implemented between 2012-2015 by TUBITAK MAM, Institute of Chemical Technology and R&D Department of General Directorate of Highways (KGM), Turkey.

Its scope, components and methodology is given as follows:

4.1 Scope

- Development of production technologies for warm mix asphalt additives,
- Production of WMA additives to use in highways,
- Development of design mixtures by using the produced WMA additives,
- Examination of the potential usage of natural resources (zeolite, bentonite) as WMA additive,
- Determination of performances of design mixtures produced by WMA additives with advanced methods,
- Application and performance determination of asphalt design mixture prepared by WMA additives produced in pilot scale,
- Development of application technologies for WMA,
- Preparation of technology knowledge package of product and production,
- Extension (commercialization) of technology knowledge package through legal arrangements (technical specification/circular order).

4.2 Project Components

- Project management,
- Literature research,
- Characterization of commercial products, choosing and making the performance tests, Using natural mineral resources as additive in WMA,
- Using synthetic zeolite as additive in WMA,
- Using parafinic wax as additive in WMA,
- Production of developed WMA additives in pilot plant,
- Application of produced additives in pilot areas and performance testing,
- Report preparation, workshop organization and preparation of technology knowledge package of product and production.

Chemical engineering and technology, chemical process engineering, civil engineering and technology, mining engineering and technology, chemical process equipments and materials, economical and technological analysis, environmental engineering and technology, energy and environmental politics areas were used for the implementation of work components.

Procurement of bitumenous binders and aggregates, determination of mixture type, making design mixture by using developed WMA additives, performance experiments, asphalt laying to pilot areas by using WMA additives produced in MRC were performed by specialized technical experts of General Directorate of Highways in bitumenous mixtures laboratories.

4.3 Methodology

Pre-studies: detailed literature research, procurement of raw materials and commercial products, test/analysis and characterization, procurement of device and equipments;
Laboratory studies: establishing systems, experimental studies, concept and design verification, product performance tests;
Pilot plant modification: process and auxiliary equipment, technical specification and procurements, pilot plant infrastructure needs, modification studies;
Pilot plant studies: experimental studies, process optimization, design verification, determination of progressive areas, production, product performance tests;

Pilot asphalt laying: WMA application technology, preparation of mixture design;
Preparation of technology knowledge package for product and production: process design, design drawings, P&ID schemes, 3D installation and placement drawings, technical and economical feasibility, plant manual.

5. RESULTS

Highways are important part of any transportation systems, and cater to commuting of 95% of passengers and 92% of cargo transportation. Asphalt surface course is made of some specialized pavements to increase the durability against traffic, environmental and climate conditions for safe and comfortable roads. Hot Mix Asphalt (HMA) and Surface Treatment (ST) are used in Turkey for asphalt pavement. As of 2015, General Directorate of Highways have 2,155 km motorways, 31,280 km state highway and 32,734 km provincial roads of total 65,909 km network. All the highways include motorways; 27% are HMA, 73% are ST and 34% are dual carriageway. HMA used in 2013 was 46.2 million tons (motorways, highway and provincial roads). During the next decade or so, Turkey is targeted to extend the total dual carriageway length, and asphalt concrete is targeted to be applied to all highways.

The WMA Addtives Project of TUBITAK MAM was aimed to develop and produce zeolite base WMA additive.

First, experiments were performed at laboratory scale for optimizing the production conditions of the additives. Additives were synthesized in 3 liter reactors and some detailed optimizations were made. After that step in a 50 litres reactor, semi pilot productions were conducted to see the difficulties that can be encountered in pilot scale production and the designs and modifications of the pilot plant were made with the experience gained. In the pilot plant (Figure-3), 4 tons of the additive were sythesized and 3 kg packages were prepared to be used in asphalt plant.

Figure-3: Pilot Plant at ICT Institute, TUBITAK MAM, Turkey

In June 2015, pilot asphalt laying by using WMA additives was performed at Ankara Highway, Karapürçek intersection region (Figure-4). Pilot asphalt laying consists of 800 m, in which 400 m is applied with additives produced in TUBITAK MAM and 400 m is applied with a commercial zeolitic base additive. Also, hot mix asphalt without additive was layed to compare with the ones with additives layed at lower temperatures.

The rutting performance of three asphalt core specimens were measured by the wheel-tracking test. This test measures the rut depth produced by the repeated rolling of a loaded wheel for 20,000 loading

Figure-4: Pilot Asphalt Laying at Ankara Highway, Karapürçek Intersection Region

cycles. The results shows that TUBITAK MAM WMA additive performed the best wheel tracking results, whereas the commercial one had the highest rut depth.

The TSR (Tensile strength ratio) testing was used to evaluate the moisture susceptibility of the asphalt mixture. The moisture susceptibility was evaluated by comparing the tensile strength of asphalt mixtures in the dry and wet conditions. From the results, it was found that all the specimens made passed the minimum TSR value required by the General Directorate of Highways Technical specifications (TSR=0.80). In addition, the domestic WMA samples exhibited higher TSR value compared to commercial product.

According to unit weight, compaction percentage and air void of core speciments, WMA compressed better. Air voids are less and unit weights are bigger when compared to HMA. The field performance evaluations are more realistic as they simulate the real application. The results show that the performance of the additive produced in TUBITAK MAM has more dominant features than commercial additive.

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REFERENCES

- Asphalt, 2013. The Smooth Quiet Ride, 2013. Available at: http://www.apa-mi.org/docs/2013LRW-WarmMixAsphalt.pdf (Accessed Dec 27, 2015).
- D'Angelo, J., Harm, E., Bartoszek, J., Baumgardner, G., Corrigan, M., Cowsert, J., Harman, T., Jamshidi, M., Jones, W., Newcomb, D., Prowell, B., Sines, R. and Yeaton, B., 2008. Warm-Mix Asphalt: European Practice. Report No. FHWA-PL-08-007. U.S. Department of Transportation. Washington, D.C.
- EAPA, 2014. Asphalt in Figures 2014, European Asphalt Pavement Association.
- EAPA, 2014a. The use of warm mix asphalt. Available at: http://www.eapa.org/userfiles/2/Publications/EAPA%20paper%20 %20Warm%20Mix%20 Asphalt%20-%20version%202014.pdf (accessed Dec 28, 2015).
- Hill, B., 2011. Performance Evaluation of Warm Mix Asphalt Mixtures Incorporating Reclaimed Asphalt Pavement, University of Illinois at Urbana-Champaign.
- Jones, W. 2004. Warm mix asphalt-a state of art review; Australian Asphalt Pavement Association Advisory Note 17. KEW Victoria; Australia.
- Koenders, B.G., Stoker, D.A., Brown, P., Groot, P.C., Larsen, O., Hardy, D., and Wilms, K.P., 2000. Innovative Process in asphalt production and application to obtain lower operating temperatures. 2nd Eurasphalt & Eurobitumen Congress Spain, Barcelona.
- Rubio, M.C., Martinez, G., Baena, L., and Moreno, F., 2012. Warm mix asphalt: an overview, Journal of Cleaner Production, 24, 76-84.
- Sampath, A., 2010. Comprehensive evaluation of four warm asphalt mixture regarding viscosity, tensile strength, moisture sensitivity, dynamic modulus and flow number. Master Thesis, University of Iowa.
- Silva, H.M.R.D., Oliveria, J.R.M., Peralta, J., Zoorob, S.E., 2010. Optimization of warm mix asphalts using different blends of binders and synthetic paraffin wax contents, Construction and Building Materials, 24(9), 1621-1631.
- Sutton, C.L., 2002. Hot mix blue smoke emissions. Technical Paper T-143: Astec Industries, Inc.
- You, Z., Goh, S.W., and Dair, Q., 2011. Laboratory Evaluation of Warm Mix Asphalt. Michigan Department of Transpiration Construction Paving Unit.
- Zaumanis, M., 2010. Warm mixasphalt investigation. PhD Thesis, Riga Technical University.