WARM MIX ASPHALTS RESEARCH, ANALYSIS AND EVALUATION

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Abstract. With increasing concerns of global warming and increasing exhaustion of greenhouse gases, the asphalt industry is looking for alternatives for hot mix asphalt (HMA). Reasonable solution for that is a use of warm mix asphalt (WMA) technologies which allow to lower the temperatures at which asphalt pavement material is mixed and placed on the road. The advantages of WMA are reduced energy consumption, reduced emissions and improved workability. WMA technologies can be used with regular HMA for easier compaction in extreme weather conditions and longer haul distances. This article presents the overview of different WMA production technologies, advantages and disadvantages of these technologies. It also represents experimental researches which were done in order to develop the optimal amount of chosen additives, their influence to physical mechanical asphalt mix properties and to determine the optimal additive for selected mixture. Water bearing, chemical and organic additives were used for WMA production and temperature of produced asphalt varied from 150 °C to 120 °C.

Keywords: Hot mix asphalt, warm mix asphalt, asphalt additives, Marshall stability, Marshall flow, indirect tensile strength.

1. Introduction

For many years, the asphalt industry has thought about energy savings and environmental benefits in asphalt production processes. Additionally, environmental awareness has been increasing rapidly over past ten years when air pollution reduction targets ratified by the European Union with the Kyoto Protocol have encouraged efforts to reduce pollution. HMA industry is exploring for technological improvements which will allow them to reduce high asphalt mix production temperatures but will not change asphalt mix workability and physical mechanical properties. HMA is produced at temperatures between 140 °C – 180 °C and compacted at temperatures between 120 °C – 160 °C (Cervarich 2003). These temperatures ensure that aggregate is dry, the asphalt binder coats the aggregate and HMA is workable. For asphalt mixes containing polymer modified binders even higher temperatures are used. Temperature of the asphalt mixture has a direct impact on binder’s viscosity as well as compaction. With the decreasing temperature of HMA mixture the binder of asphalt mixture becomes thicker, more resistant to deformation and more poorly compacted. Finally, the binder becomes so hard, that compaction is impossible. Production of warm mix asphalts and half-warm mix asphalts is one of those efforts to reduce pollution and to use other lower temperature asphalt mix benefits.

Asphalt mixes according to their mixing temperature and energy consumed for the heating process of materials are divided into (Vaitkus et al. 2009):

- Cold mix asphalt (CMA) – asphalt mixture produced at an ambient temperature using bitumen emulsion or foam;
- Half warm mix asphalt (HWMA) – asphalt mixture produced at a temperature below water vaporization;
- Warm mix asphalt (WMA) – asphalt mixture produced at a temperature range of 120 °C to 140 °C;
- Hot mix asphalt (HMA) – asphalt mixture produced at a temperature range of 150 °C to 180 °C in relation with the used binder.

WMA is a modified hot mix asphalt mixture that is produced, placed and compacted at a 10 °C – 40 °C lower temperature than the conventional hot mix asphalt mixture (Asphalt Institute, USA). WMA could be described as the asphalt mixture produced at 20 °C – 40 °C lower temperatures than the hot mix asphalt but at a higher temperature than the water boiling temperature (D’Angelo et al. 2008).

When asphalt is produced at lower temperatures, there are many potential benefits such as reduced energy consumption (fuel) in asphalt plant and reduced noxious gases emissions, increased workers’ safety due to reduce of smoke emissions, possibility to place asphalt mix in
cooler ambient temperatures and to haul farther distances without compromising workability (Kristjansdottir 2006).

WMA is fundamentally no different than HMA – it still consists of aggregates and asphalt binder that are heated to obtain proper mixing and workability – but the difference lies specifically in the temperature used to obtain proper mixing and workability (D’Angelo et al. 2008).

There are lots of WMA technologies around the world. However, the amount of testing has been done for the methods varies. From the main researches done so far and their findings, it seems safe to say that the quality of WMA is comparable to hot mix asphalt in most ways. However, it is only about 5 to 10 years (depending on method) since the earliest WMA field tests were started and therefore its long-term performance is still unproven.

A pavement life can be from 15 to 20 years or more and therefore its long-term performance is still unproven. However, it is only about 5 to 10 years (depending on method) since the earliest WMA field tests were started and therefore there is still quite some time before WMA’s affect on the pavement’s service life will be fully known.

WMA has been described as a group of technologies which allow a reduction in the temperatures at which asphalt mixtures are produced and placed. There are many different processes, and products, that can be used to achieve this reduction in temperature, but generally WMA technologies can be separated into four categories (Anderson et al. 2008; Button et al. 2007):

- Water based processes – non additive processes based on foaming. Bitumen foam is caused by spraying water into the heated bitumen (175 °C – 180 °C) or by adding moist sand (fine mineral particles) into asphalt mixture. Foam ensures sufficient coating of the asphalt binder and aggregate that makes asphalt mix workable; WAM-Foam, Terex WMA System, Double Barrel Green; LEA – Low Energy Asphalt, Ultrafoam GX;
- Water bearing additives – natural and synthetic zeolites, also based on foaming. Foam is caused by adding natural or synthetic zeolite into the asphalt mixture during asphalt production. When zeolite is added to the mix at the same time as the binder, water entrapped in this mineral structure is released. This water release creates a foaming of the asphalt binder and, thereby, temporarily increases workability and enhances aggregate coating at lower temperatures. Aspha Min – synthetic zeolite, Advera WMA Zeolite – synthetic zeolite, natural zeolite;
- Organic additives – wax additives such as Fischer Tropsch, Montan waxes, fatty acid amides. These organic waxes have longer chemical chain lengths so their melting point is at about 100 °C. The longer chains help keep the wax in solution and it reduces binder viscosity at typical asphalt production and compaction temperatures. The use of organic additives enables asphalt mix production and laying temperatures to be reduced by 20 °C – 30 °C. Sasobit, Ashphaltan B, Licomont BS 100;
- Chemical additives – change asphalt binder structure and reduce viscosity that allows to reduce asphalt mix producing and laying temperatures about 40 °C. Iterlow T, Cecabase.

In recent years large amount of experimental laboratory researches were carried out with different warm mix asphalt technologies. Gaufreyc et al. (2009) summarized information about the influence of total organic compounds emissions by using the low-emission asphalt LEA technology for WMA production. WMA with Cecabase temperature lowering technology were compared to traditional HMA by Gonzalez et al. (2009). Energy and emissions reduction, the possibility to use reclaimed asphalt, increased haul distances and cold weather paving benefits were summarized by him. Wax modified bitumen research was studied by Metzerk & Witsuba (2009). Silva et al. (2009) analyzed Sasobit and Cecabase use in WMA mixes. He summarized that temperature reductions used on site were overestimated, leaving some concerns about it, and that in order to obtain adequate results with WMA mixtures, it is essential to have a narrow control of the production temperature in the plant. Soenen et al. (2009) studied foamed bitumen in half-warm asphalt mixes. Su et al. (2009) determined that WMA mixtures produced with special temperature lowering wax (made by Japanese company) at the temperatures 30 °C lower than traditional HMA are suitable for use in airport pavement rehabilitation. However identical WMA mixture produced at 50 °C lower temperatures cannot be accepted due to poor tests results. Xiao et al. (2009) researched fatigue behavior of rubberized asphalt concrete mixtures containing WMA additives. He indicated that the addition of crumb rubber and WMA additive (Aspha Min and Sasobit) in asphalt mix reduce mixing and compacting temperatures and effectively extend the long-term performance of pavement compared to traditional HMA mixture. Midrange temperature rheological properties of WMA binders were investigated by Biro et al. (2009). This research summarized that asphalt mix temperature lowering additive Sasobit increases stiffness of binder, that makes mix more resistance to rutting, while another additive Aspha Min had no significant effect on different types of the binders.

WMA mixtures have been also investigated in Lithuania recently. Vaitkus et al. (2008) summarized the use of warm mix asphalt mixes in Lithuania roads. Compaction properties of WMA were investigated by Vaitkus et al. (2009) also. He determined that optimal reduction of hot mix asphalt working temperature, when using synthetic additive – Iterlow T is 30 °C and that warm mix asphalt concrete with Iterlow T compaction level of 97 % was reached after 4 – 5 passes of roller with static load. With increasing HMA mixture output in Lithuania the possibility on the use of WMA also increases. According to Sivilevicius and Sukevicius (2009) HMA mixture output in Lithuania has increased twice (from 0.8 million tons in 1998–2001 to 1.7 million tons in 2006–2008). Lots of lower temperature asphalt mix benefits can be attained by using WMA instead of HMA. So there is demand on more warm mix asphalt researches in Lithuania.
nia in order to determine optimal WMA technology or additive most suitable for this region.

2. Advantages and disadvantages of WMA

Emissions of hazardous materials (greenhouse gases) during WMA production are significantly lower than during hot asphalt mix production. According to Gonzalez et al. (2009) WMA with Cecabase RT additive production reduces different pollutants emissions from 14 % to 36 % compared to traditional HMA. A reduction of about one third of the CO produced was obtained with the reduction of 40 °C in asphalt mix production. Field tests showed that virtually no fumes have been seen coming from the asphalt mixture near the paver using WMA with Cecabase RT additive (Gonzalez et al. 2009). Gaudefroy et al. (2009) determined that total organic compounds emissions provided by half-warm bitumen mixes are lower than HMA according to the manufacturing temperature difference. Emissions reduction advantage of WMA has been already cited in several occasions (D’Angelo et al. 2008; Anderson et al. 2008). Laying of asphalt pavements in half or fully – closed sites, e.g. in tunnels, makes a negative impact on the road workers’ health since the exhausted smoke and fumes are cleared away much slower than in an open area. In these cases, lower emissions of WMA mixtures would be a considerable advantage.

The reduced energy consumption is another benefit of WMA. Energy consumption for a WMA production is 60 % – 80 % of that for HMA production, depending on how much the production temperature is lowered. Gonzalez et al. (2009) determined that a reduction of energy (gas) in asphalt plant is from 20 % to 24 % during production of WMA with Cecabase RT additive. Reduction depended on asphalt mix type used. The importance of this benefit depends on what sort of energy is used for the production process and how polluting and expensive it is. In Lithuania the energy cost is relatively high and has been continuously rising, therefore this benefit can be very important for the asphalt producers. On the basis of the review of scientific investigations it could be stated that lower fuel consumption in the production of WMA mixtures has not been estimated as one of the main advantages of these mixtures.

Major advantages of WMA are related to the lower viscosity of the asphalt mix. Generally, improved workability can have various effects throughout the production and placement process. Improved workability has following advantages (Kristjansdottir 2006):

1. Lower working temperatures:
   - Energy savings during production;
   - Reduced emissions;
   - Decreased cooling rate due to smaller difference between ambient and compaction temperatures.
2. Increased temperature gap between mixing and compaction (by using regular HMA mixing temperatures):
   - Increased haul distances;
   - Increased time available for compaction, thereby for example extended paving season into the colder months of the year.
3. Easier compaction (by using regular HMA mixing temperatures), which are beneficial:
   - During extreme weather conditions;
   - For reducing amount of roller passes to reach necessary compaction.
4. The possibility to use 50 % and more of reclaimed asphalt in warm mix asphalt.

The use of WMA technologies in reclaimed asphalt pavement (RAP) has been investigated by Lee et al. (2009), Gonzalez et al. (2009) during past years. Mucinis et al. (2009) defined that the greatest values of RAP that can be used in recycled asphalt mix vary depending on the type of its homogeneity (content of bitumen or mineral aggregates). Asphalt pavement durability depends not only from RAP homogeneity, properties of the binder are very important also. Lee et al. (2009) investigated characteristics of WMA binders (with zeolite Aspha Min and wax Sasobit) containing aged binders. He summarized that Aspha Min and Sasobit along with virgin and aged bitumen increases binders’ resistance to rutting. It was also determined that recycled binders with WMA additives have significantly lower resistance on low temperature cracking.

Warm mix asphalt production disadvantages are bound to lack of the research on these mixes and conditionally with short usage of time. Warm mix asphalt production and consumption weaknesses are as follows:

1. According to the most researches warm mix asphalt physical and mechanical characteristics are worse than hot mix asphalt. Warm mix asphalt characteristics vary depending on used technology;
2. Lower aggregates drying temperature requires to use cohesion properties between mineral materials and bitumen improving additive;
3. The incensement in price for the asphalt using warm mix asphalt technology because of additional additive price or asphalt plant modification;
4. The prolongation of asphalt mixing cycle due to addition of additives (not all technologies).

3. Experimental research of warm mix asphalt

3.1 Laboratory research

Two experimental researches were done in order to develop the optimal amount of chosen additives, their influence to physical mechanical properties of asphalt mix and to determine the best suitable additive for selected mixture. AC 16 PD asphalt mixture was selected. It is typically used one layer bituminous mixture in Lithuania roads with light load. AC 11 VS asphalt mixture was studied in the first experimental research also, for more about this mixture research analysis read (Vaitkus et al. 2009).

First experimental research was carried out in July of 2008 by the Road Research Laboratory of Department
of Roads of Vilnius Gediminas Technical University. Two asphalt mix temperature lowering technologies were selected: Iterlene T and Cecabase represented chemical additives technology; Aspha Min and natural zeolite – water bearing technology. Asphalt mix with chemical additives was produced from dolomite aggregates and asphalt mix with water bearing additives – gravel aggregates. Amount of additives varied from 0.1 % to 0.6 % (Iterlow T and Cecabase RT by total weight of asphalt mix; Aspha Min and natural zeolite by total weight of asphalt binder).

For each additive 8 mixtures were mixed, two control mixtures in 150 °C and 120 °C temperatures without additive and six mixtures in 120 °C with different amount of selected additives. All mixtures were produced from the bitumen 70/100. Chemical additives Iterlene IN/400L (for chemical technologies) and Gripper L (for water bearing technologies) were added to improve cohesion properties between mineral materials and bitumen. These asphalt mixtures were then compacted using a Marshall compactor and tested for stability, flow, bulk density and air voids in a standard way. Stability of Marshall specimens represents the greatest asphalt pavement resistance to deformation, flow of Marshall specimens – deformation with maximum load.

However warm asphalt mixes with water bearing additives Aspha Min and natural zeolite did not show expected results so they became difficult to analyze. At that moment asphalt mixes with Cecabase and Rediset could only be compared to each other, so the demand on the use of other type of additives in AC 16 PD asphalt mixture occurred. Therefore the second experimental research was carried out in August of 2009. Identical type of bituminous mixture was selected (AC 16 PD) and made with dolomite aggregates. Organic additives technology was now chosen. Sasobit and Rediset were used to produce WMA. Amount of additives varied from 1.0 % to 2.5 % by total weight of asphalt binder. Two control mixtures in 150 °C and 120 °C temperatures were produced and four with different amount of Sasobit and Rediset additives in 120 °C. Cohesion properties between mineral materials and bitumen improver Iterlene IN/400L were used for asphalt mixes with Sasobit. Rediset itself had that type of improver.

Asphalt mixtures were compacted using a Marshall compactor and tested for stability, bulk density, air voids. Indirect tensile strength test was carried out also to measure the tensile strength of compacted asphalt mix.

3.2 Analysis and evaluation of research results

Asphalt mix specimens density results were scattered and depended on technology (Fig 1). Water bearing Aspha Min and zeolite technologies with gravel aggregates showed the lowest asphalt mix density results. Asphalt mix produced in 120 °C temperature with different amount of Iterlow T and Cecabase chemical additives density results were not scattered and varied from 2453 kg/m³ to 2462 kg/m³, however they were lower than control mixture results. By increasing amount of Rediset in asphalt mixture, asphalt mix specimens density results increases. Asphalt mixes with different amount of Rediset or Sasobit did not reach control mixture density. However density results difference between asphalt mixes with organic and chemical additives and control mixture were very small. Therefore the use of optimal amount of Iterlow T, Cecabase, Sasobit and Rediset allows to reduce asphalt mix production and compaction temperatures from 150 °C to 120°C without major asphalt pavement density reduction.

0.1 % (1 %) in Figs 1 – 4 represents the dosage of additives in asphalt mix. 0.1 % shows amount of natural zeolite, Aspha Min (by the mass of the mix) and Cecabase, Iterlow T (by the mass of the binder) dozed in the mixture. (1 %) represents amount of Sasobit and Rediset (by the mass of the binder) dozed in asphalt mix. All asphalt mixtures with additives were compacted in 120 °C temperature.

![Fig 1. Distribution of asphalt mix specimens density with different temperature lowering additives and different amounts of them](image-url)
Marshall specimens compacted from asphalt mixes with natural zeolite and Aspha Min stability results showed that optimal amount of these additives is 0.3% (by the mass of the mix) as then the greatest stability values were reached (Fig 2). However asphalt mix with 0.3% amount of natural zeolite stability results were scattered and did not reach control mixture stability. The same amount of Iterlow T and Cecabase additives (0.3% by the mass of binder) is optimal in asphalt mixes because of the highest Marshall stability values then.

By increasing Rediset amount in asphalt mixture (by the mass of the binder) Marshall stability results increases and the highest value is reached at 10.7 kN with 2.5% amount of Rediset. Highest stability results for asphalt specimens with Sasobit were determined with 2.0% (by the mass of binder) of this additive in the mix, as then a very similar to asphalt specimens with Rediset stability value was reached (10.8 kN). Marshall specimens compacted from the mix with these amounts of Rediset and Sasobit additives stability results were higher compared to control mixtures compacted in 150 °C temperature. As the amount of Sasobit in mixture increases to 2.5%, Marshall stability value decreases.

Generally asphalt mixes with organic additives Rediset and Sasobit Marshall stability values were highest compared to other four temperature lowering additives. It is possible to compare only asphalt mixes produced with Iterlow T, Cecabase, Sasobit and Rediset additives as they all were produced according to identical asphalt mix project. Marshall specimens compacted from asphalt mix with Sasobit and Rediset additives stability values is about 20% higher than specimens with Iterlow T and Cecabase. According to these results it is clear that the use of organic additives in asphalt mixes increases their stability.

Flow values of Marshall specimens compacted from asphalt mix with natural zeolite, Aspha Min, Iterlow T and Cecabase were scattered and depended on technology (Fig 3). However the less scattered flow values were reached with the use of 0.2% amount of these additives. It was determined that the use of Sasobit in asphalt mixes reduces flow of Marshall specimens. The greatest flow reduction was reached with 2.5% amount of Sasobit and was about 16% lower compared to the flow of specimens of control mixture. Asphalt mix specimens with different amount of Rediset flow values were not scattered and varied from 4.8 mm to 5.3 mm.

Fig 2. Distribution of asphalt mix stability with different temperature lowering additives and amounts of them

Fig 3. Distribution of asphalt mix flow with different temperature lowering additives and amounts of them
Indirect tensile strength test was made to Marshall specimens compacted from asphalt mix with Rediset and Sasobit additives. Research results show that by increasing amount of these additives indirect tensile strength increases (Fig 4). The greatest values were reached with 2.5 % (by amount of the binder) for each of additive. Asphalt mix with Rediset in all senses showed higher indirect tensile strength values compared to asphalt mix with Sasobit. Marshall specimens compacted from the mix with these amounts of Rediset and Sasobit additives indirect tensile strength results were higher compared to the control mixture compacted in 150 °C temperature. Indirect tensile strength of control asphalt mixture produced in 120°C temperature decreases about 17 % compared to control mixture produced in 150 °C and WMA mixes with 2 % of Rediset and Sasobit.  

Optimal amount of Sasobit and Rediset additives is 2.0 % by the mass of the binder according to stability, flow and indirect tensile strength results. Highest asphalt mixes with Sasobit stability results were reached with this amount of additive. In order to avoid great reduction in asphalt pavement resistance on low temperature cracking more than 2.0 % of Sasobit (by the mass of the binder) should not be used. Decrease in flow values confirms that. Same notice could be applied to asphalt mixes with Rediset.

3.3 Experimental research conclusion

According to laboratory research analysis it was determined that:

- Natural zeolite and Aspha Min could not be tested properly under laboratory conditions, therefore much greater amounts of mixtures in asphalt plant should be tested;
- The use of organic additives in asphalt mixes increases asphalt pavement stability;
- Asphalt mixes with Zeolite, Iterlow T and Cecabase additives stability values did not matched to traditional HMA stability values;
- The use of Sasobit in asphalt mixes decreases asphalt pavement deformation (flow);
- By increasing amount of Rediset and Sasobit additives indirect tensile strength increases;
- Rediset showed the best Marshall stability, flow and indirect tensile strength results compared to other studied additives.

Conclusion

Based on the results presented in this paper and on their analysis, the main conclusions that can be drawn from this study are the following:

1. Field and laboratory researches carried out by the scientists of various countries show that the values of the properties of WMA mixtures are scattered and inconstant if compared to that of HMA mixtures.

2. When asphalt is produced at lower temperatures, there are many potential benefits such as reduced energy consumption (fuel) in asphalt plant and reduced noxious gases emissions, increased workers’ safety due to reduce of smoke emissions, possibility to place asphalt mix in cooler ambient temperatures and to haul farther distances without compromising workability; possibility to use 50 % and more of reclaimed asphalt in warm mix asphalt.

3. Optimal amount of asphalt mix temperature lowering additives, determined by this research, is 0.3 % (by the mass of the mix) for natural zeolite and Aspha Min; 0.3 % (by the mass of the binder) for Iterlow T and Cecabase. At these amounts of additives the greatest Marshall stability values were reached;

- The use of optimal amount of Iterlow T, Cecabase, Sasobit and Rediset allows to reduce asphalt mix production and compaction temperatures from 150 °C to 120 °C without major compacted asphalt pavement density reduction;
4. The use of organic additives in asphalt mixes increases asphalt pavement stability. The use of Sasobit in asphalt mixes decreases asphalt pavement flow.

5. Sasobit and Rediset additives increase asphalt pavement tensile strength, however more than 2.0% of Sasobit and Rediset (by the mass of the binder) should not be used in order to avoid great reduction in asphalt pavement resistance on low temperature cracking.

6. The properties of WMA mixture produced in 120 °C by the Rediset technology showed best results compared to other studied technologies. Stability, flow and indirect tensile strength values were less scattered compared to other selected additives and similar to control mixture produced in 150 °C temperature. Therefore Rediset is most suitable for lowering temperature for AC 16 PD asphalt mix.

7. It is recommended to extend the research and to construct asphalt pavement section using Rediset technology. During and after construction evaluation of asphalt pavement physical and mechanical properties should be done.

References


