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Influence of warm mix asphalt technology on asphalt physical and mechanical properties

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HIGHLIGHTS

- WMA technologies allows to lower the HMA mixing and working temperature by 30 °C.
- The physical and mechanical properties of WMA reach the same level as HMA.
- Required amount of additive vary from 0.3 to 2.0 of amount of binder.

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ABSTRACT

With increasing concerns of global warming and increasing exhaustion of greenhouse gases, the asphalt industry is looking for alternatives of hot mix asphalt (HMA). Reasonable solution is a use of warm mix asphalt (WMA) technologies, which allows to reduce asphalt mixing and working temperatures. The advantages of WMA are reduced energy consumption, reduced emissions and improved workability. This article presents the overview of different WMA production technologies, advantages and disadvantages of these technologies. Water bearing, chemical and organic additives were used for WMA production and temperature of produced asphalt varied from 150 °C to 120 °C. Results of experiment for selection of optimal amount of temperature lowering additives and their influence to physical mechanical characteristics of asphalt mix are presented too.

1. Introduction

The technological improvements are being explored in the asphalt industry for the last years. It will allow to reduce high asphalt mix production temperatures. However, it does not change asphalt mix workability and physical mechanical properties [1–3]. The production of warm mix asphalts and half-warm mix asphalts is one of the attempts to reduce pollution and to use another lower temperature asphalt mix benefits [1,4–5].

Asphalt mixtures, according to their mixing temperature and energy consumed for the heating process of materials, are divided into [6]:

– Cold mix asphalt (CMA), asphalt mixture produced at 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 from 120 °C to 140 °C;
– Hot mix asphalt (HMA), asphalt mixture produced at a temperature range from 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 10–40 °C lower temperature than the conventional hot mix asphalt mixture. WMA is described as the asphalt mixture produced at 20–40 °C lower temperatures than the hot mix asphalt but at a higher temperature than the water boiling temperature [1,7–8].

When asphalt is produced at lower temperatures, there are many potential benefits as: reduced energy consumption (fuel) in

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asphalt plant and reduced noxious gases emissions; increased safety of workers due to reduction of smoke emissions; possibility to place asphalt mix in cooler ambient temperatures and to haul further distances without compromising workability [9].

WMA fundamentally does not differ from HMA. It still comprises of aggregates and asphalt binder that are heated to obtain the proper mixing and workability. However, the difference specifically lies in the temperature used to obtain proper mixing and workability.

There are numerous of WMA technologies around the world. However, the number of tests has been done using various methods. On the basis of the main researches done so far and their findings, it appears secure to state that the quality of WMA is comparable to hot mix asphalt in most of the ways. However, it is only about from five to ten years (depending on method) since the earliest WMA field tests were started. Therefore, this long-term performance is still unproven. A pavement can exist from fifteen to twenty years or longer. Hence, there is still some time before effect of WMA on the pavement's service life will be fully known [10].

2. Warm mix asphalt technologies

WMA has been described as a group of technologies that allows reduction in the temperatures at which asphalt mixtures are produced and placed. There are many different processes and products that could be used to achieve this reduction in temperature, but, generally, WMA technologies are separated into four categories [11]:

1. Water based processes, the non-additive processes based on foaming. Bitumen foam is caused by spraying water into the heated bitumen (175–180 °C) or by adding moist sand (fine mineral particles) into asphalt mixture. The 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;
2. Water bearing additives are natural and synthetic zeolites also based on foaming. The 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 foaming of the asphalt binder. Thereby, it temporarily increases workability and enhances aggregate coating at lower temperatures. Aspha Min is synthetic zeolite. Advera WMA Zeolite is synthetic zeolite and natural zeolite;
3. Organic additives are wax additives as Fischer Tropsch, Montan waxes and fatty acid amides. These organic waxes have longer chemical chain lengths, thus, their melting point is at about 100 °C. The longer chains help to keep the wax in solution and they reduce binder viscosity at typical asphalt production and compaction temperatures. The use of organic additives allows asphalt mix production and laying temperatures to be reduced by 20–30 °C. Sasobit®, Ashphaltan B, Licomont BS 100;
4. Chemical additives change asphalt binder structure and reduce viscosity that allow to reduce asphalt mix producing and laying temperatures about 40 °C. Iterlow T, Cecabase.

Numerous of experimental laboratory researches have been carried out using different warm mix asphalt technologies in recent years. Gaudefroy et al. [12] 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 was compared to traditional HMA by Gonzalez et al. [13]. Energy and reduction of emission, the possibility to use reclaimed asphalt (RAP), increased haul distances and cold weather paving benefits were summarized by him. Nejad et al. [4] determined that rutting properties of the asphalt mixtures replacing up to 60% of the virgin aggregate with RAP could be improved, but too much RAP in asphalt mixtures could increase moisture sensitivity. It was found that the optimal replacement of RAP level is 50%. Zelelew et al. [1] analyzed Sasobit® additive impact on WMA rutting and fatigue cracking parameters. It was found that the asphalt binder containing Sasobit® increase the high-temperature binder grade by 6 °C. Equally, WMA with Sasobit® demonstrate better resistance to rutting and moisture damage comparing to traditional HMA. Wax modified bitumen research has been studied by Metzker and Witsuba [14]. Silva et al. (2009) [15] analyzed Sasobit® and Cecabase usage in WMA mixes. It has been summarized that temperature reductions, used on site, have been overestimated, leaving some concerns about it. In order to obtain the adequate results with WMA mixtures, it is essential to have narrow control of the production temperature in the plant. China experience using WMA with Sasobit® and Rediset has showed relatively best performances in areas, where rutting and stripping are the main failures of asphalt pavements [2]. Soenen et al. [16] studied foamed bitumen in half-warm asphalt mixes. Su et al. [17] 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 pavement rehabilitation of an airport. However, the identical WMA mixture produced at 50 °C lower temperatures cannot be accepted due to poor tests results. Liu et al. [3] analyzed the performance of WMA with polyphosphoric acid (PPA). It has been found that WMA containing 1.5% PPA achieves good intermediate and high temperature rheological properties. Xiao et al. [18] 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 it effectively extends the long-term performance of pavement compared to traditional HMA mixture. Midrange temperature rheological properties of WMA binders were investigated by Biro et al. [19].

WMA mixtures have also been investigated in Lithuania recently. Vaitkus et al. [6,20] summarized the use of warm mix asphalt mixes in Lithuania roads. Compaction properties of WMA were investigated by Vaitkus et al. [21] also. It has been determined that the optimal reduction of hot mix asphalt working temperature, when using synthetic additive Iterlow T, is 30 °C. In addition, that warm mix asphalt concrete with Iterlow T compaction level of 97% has been reached after four–five passes of roller with static load. With increasing HMA mixture output in Lithuania the possibility on the use of WMA increases as well. According to Sivilevicius and Sukevicius [22], HMA mixture output in Lithuania has increased twice (from 0.8 million tons in 1998–2001 to 1.7 million tons in 2006–2008). Numerous of temperature asphalt mix benefits can be attained by using WMA instead of HMA. Thus, there is a demand on more warm mix asphalt researches in Lithuania in order to determine the optimal WMA technology or additive that is the most suitable for this region.

3. Advantages and disadvantages of WMA

The major advantages of WMA are related to the lower viscosity of the asphalt mix. Generally, the improved workability could have various effects throughout the production and placement processes. Improved workability has the following advantages [9]:

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) that is beneficial:
   – During extreme weather conditions;
   – For reducing the amount of roller passes to reach the necessary compaction.
4. The possibility to use 50% and much of reclaimed asphalt in warm mix asphalt.

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

1. According to the most of researches, physical and mechanical characteristics of warm mix asphalt are worse than hot mix asphalt. Warm mix asphalt characteristics vary depending on the used technology;
2. Drying temperature of lower aggregates 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).

4. Experimental research of warm mix asphalt

The research has been carried out in Road Research Laboratory of Vilnius Gediminas Technical University. Two asphalt mix temperature lowering technologies have been selected at first stage: Iterlene T and Cecabase, represented technology of chemical additives; Aspha Min and natural zeolite, water bearing technology. Asphalt mix with chemical additives has been produced from dolomite aggregates and asphalt mix with water bearing additives, gravel aggregates. The amount of additives varied from 0.1% to 0.4% by weight of bitumen (Iterlow T and Cecabase) and from 1.0% to −2.5% by total weight of asphalt mix (Aspha Min and natural zeolite).

Asphalt mixtures have been mixed in different temperature: at 150 °C and 120 °C temperatures without additives and with different quantity of additives at 120 °C. Bitumen 70/100 (penetration 7–10 mm) has been used for all asphalt mixtures. The plan of experiment and amount of different additives are presented in Table 1. Adhesion additives Iterlene IN/400L (for chemical technologies) and Gripper L (for water bearing technologies) have been added to improve adhesion properties between aggregates and bitumen. These asphalt mixtures were, then, compacted using a Marshall compactor (2 × 50 blows) and tested for stability, flow, bulk density and air voids in a standard way.

However, warm asphalt mixes with water bearing additives Aspha Min and natural zeolite have not showed the expected results, so it has become difficult to analyze. At that moment the asphalt mixes with Cecabase and Rediset could only be compared to one another. Therefore, the demand on the use of another type of additives in AC 16 PD asphalt mixture has occurred. The identical type of bituminous mixture has been selected (AC 16 PD) and made with dolomite aggregates in second experimental research. The technology of organic additives has been chosen. Sasobit® and Rediset were used to produce WMA. The 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 control mixtures were made with different amount of Sasobit® and Rediset additives in 120 °C. Adhesion additive Iterlene IN/400L has been used for asphalt mixes with Sasobit®. Rediset has itself that type of adhesion improver.

Asphalt mixtures were compacted using a Marshall compactor (2 × 50 blows) and tested for stability, bulk density, and air voids. The indirect tensile strength test was carried out also to measure the tensile strength of compacted asphalt mix.

5. Analysis and evaluation of research results

Asphalt mix specimens density results have been scattered and depended on technology (Figs. 1 and 2). Water bearing Aspha Min and zeolite technologies with gravel aggregates showed the lowest asphalt mix density results. Asphalt mix mixed in 120 °C temperature with different amount of Iterlow T and Cecabase chemical additives density results were not scattered and varied from 2.453 Mg/m^3 to 2.462 Mg/m^3. However, they were lower than HMA results. By increasing amount of Rediset in asphalt mixture, asphalt mix specimens density results increases. Asphalt mixes with different amount of Rediset or Sasobit® have not reached control mixture density. However, density results difference between asphalt mixes with organic and chemical additives and control mixture were very low. Therefore, the usage 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. 1–7 represents the dosage of additives in asphalt mix. 0.1% shows the amount of natural zeolite, Aspha Min (by the mass of the mix) and Cecabase, Iterlow T (by the mass of the bitumen) dozed in the mixture. 1% represents the amount of Sasobit® and Rediset (by the mass of the bitumen) dozed in asphalt mix. All asphalt mixtures with additives have been compacted in 120 °C temperature. Marshall specimens, compacted from asphalt mixes with natural zeolite and Aspha Min stability results, showed that the 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 it did not reach control mixture stability. The same amount of Iterlow T and Cecabase additives (0.3% by the mass of bitumen) 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 bitumen) Marshall stability results increases and the highest value is reached at 10.7 kN with 2.5% amount of Rediset. The highest stability results for asphalt specimens with Sasobit® have been determined with 2.0% (by the mass of bitumen) 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%, the value of Marshall stability decreases. Zhang et al. [23] have found that Sasobit® additive improves both, the high temperature property in serve stage and workability during construction, but it worsens the properties of low temperature.

Generally, asphalt mixes with organic additives Rediset and Sasobit® Marshall stability values were highest compared to another four temperature lowering additives. It is only possible to compare 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, are about 20% higher than specimens with Iterlow T and Cecabase. With reference 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 it

Table 1
Plan of experiment and amount of different additives.

Asphalt mix type	Bitumen type	Adhesiveness promoter	Additive type	Amount of additive in bitumen (in asphalt mixture) by mass, %				Mixing temperature, °C	
AC 11 VS (granite)	70/100	Iterlene IN/400L	Iterlow T	0.0				150	120
				0.1	0.2	0.3	0.4	120	
			Cecabase	0.0				150	120
				0.1	0.2	0.3	0.4	120	
AC 16 PD (dolomite)			Iterlow T	0.0				150	120
				0.1	0.2	0.3	0.4	120	
			Cecabase	0.0				150	120
				0.1	0.2	0.3	0.4	120	
AC 16 PD (gravel)		Gripper L	Aspha-min	(0.0)				150	120
				(1.0)	(1.5)	(2.0)	(2.5)	120	
			Natural zeolite	0.0				150	120
				(1.0)	(1.5)	(2.0)	(2.5)	120	

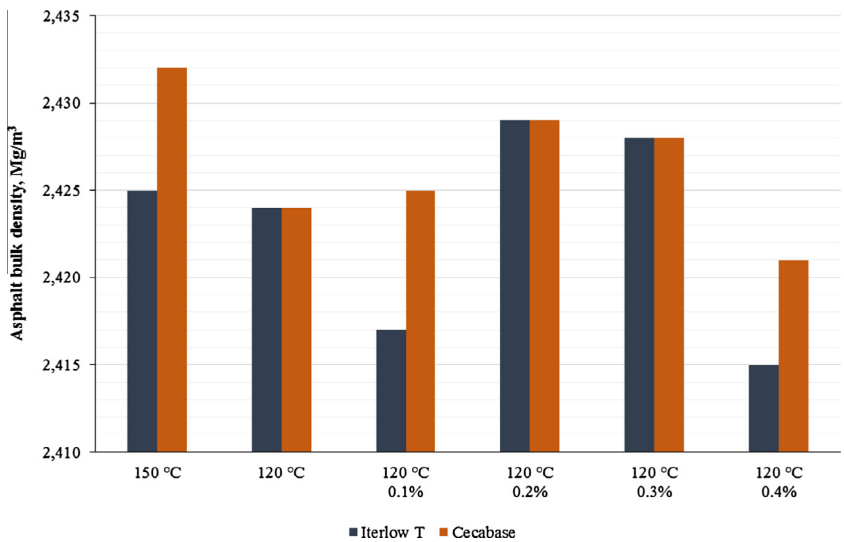

Fig. 1. Distribution of AC 11 VS asphalt bulk density dependent on different amount of additives and mixing temperature.

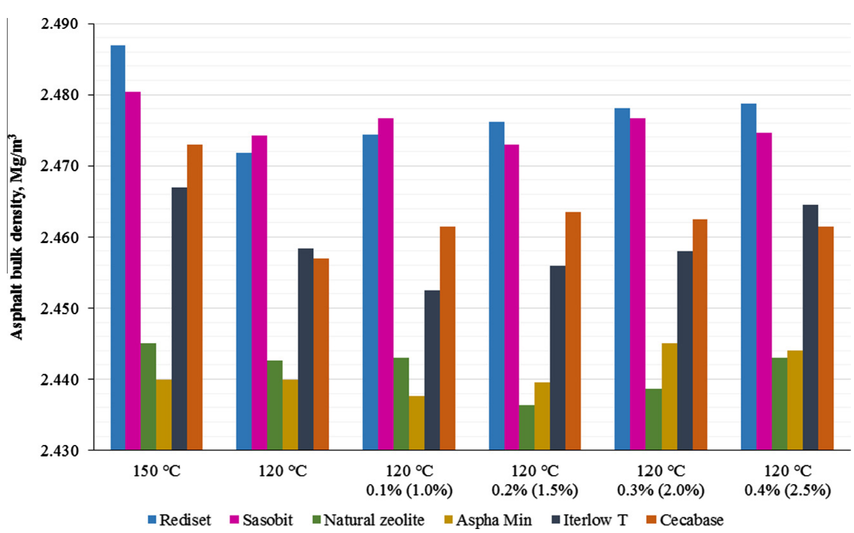

Fig. 2. Distribution of AC 16 PD asphalt bulk density dependent on different amount of additives and mixing temperature.

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. The research of Vargas-Nordbeck and Timm [24] showed that the use of WMA technologies could increase permanent deformation while addition of high RAP content results is less rutting.

The indirect tensile strength test was made to Marshall specimens, compacted from asphalt mix with Rediset and Sasobit®

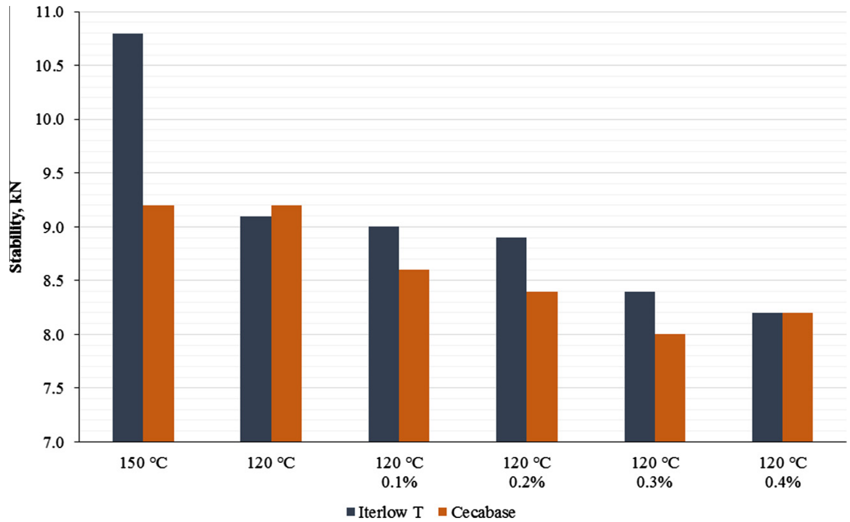

Fig. 3. Distribution of AC 11 VS asphalt Marshall stability dependent on different amount of additives and mixing temperature.

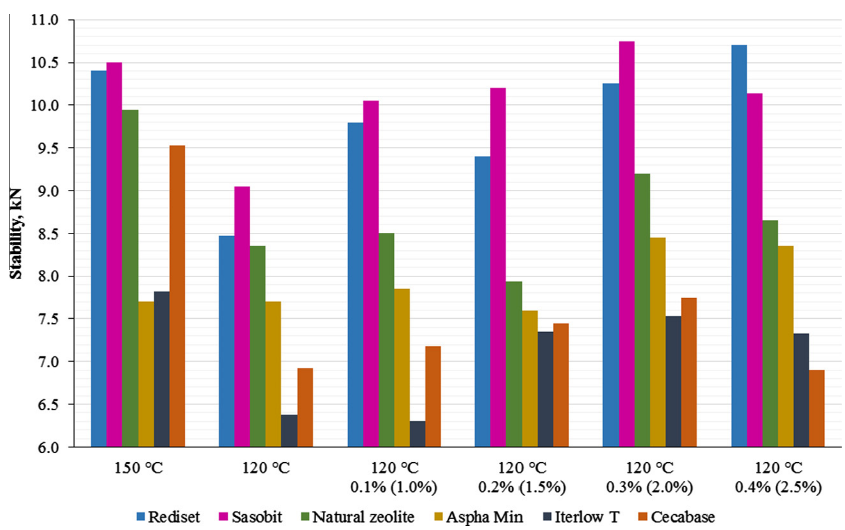

Fig. 4. Distribution of AC 16 PD asphalt Marshall stability dependent on different amount of additives and mixing temperature.

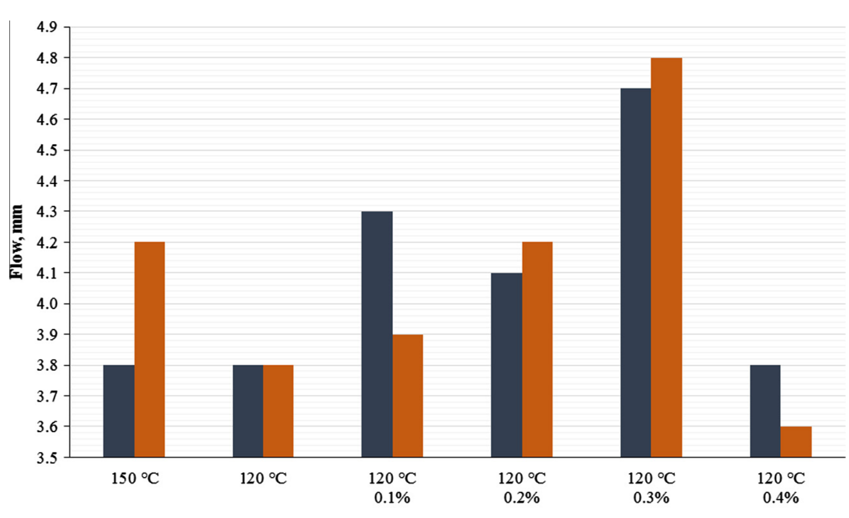

Fig. 5. Distribution of AC 11 VS asphalt Marshall flow dependent on different amount of additives and mixing temperature.

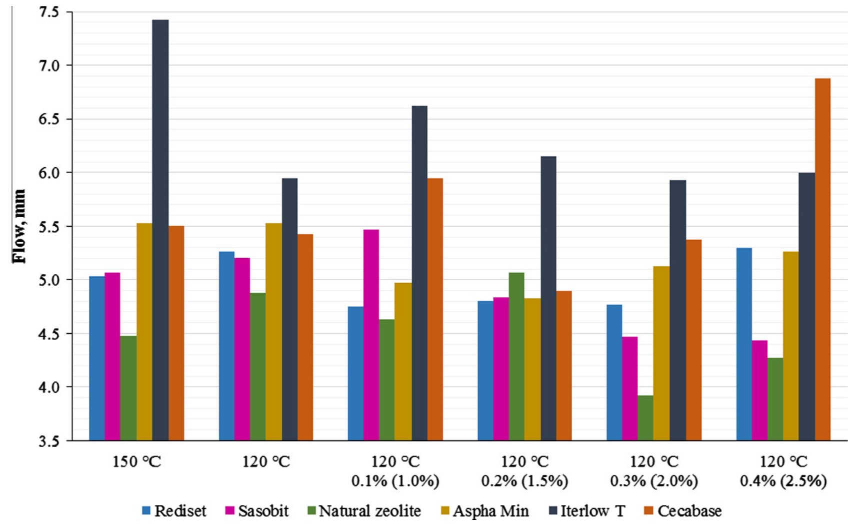

Fig. 6. Distribution of AC 16 PD asphalt Marshall flow dependent on different amount of additives and mixing temperature.

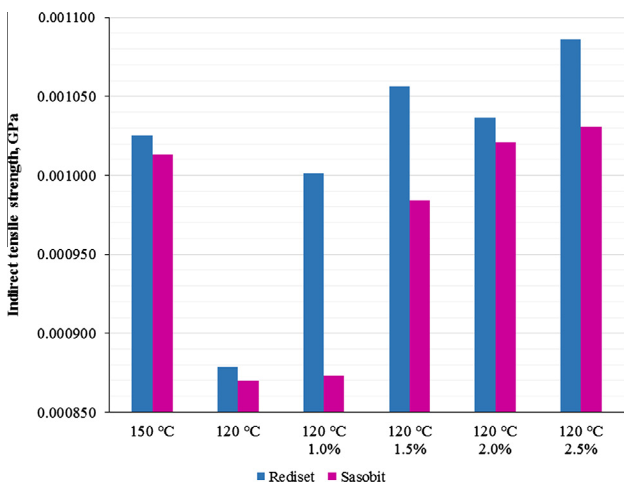

Fig. 7. Distribution of AC 16 PD with dolomite aggregates indirect tensile strength with different amount of Rediset and Sasobit® additives.

additives. The results of research show that by increasing amount of these additives, indirect tensile strength increases (Fig. 4). The greatest values were achieved with 2.5% (by amount of the bitumen) for each of the additive. Asphalt mix with Rediset, in all senses, have 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®. Otherwise, Zaumanis et al. [8] determined that the compaction temperature of 155 °C for HMA could be reduced to at least 125 °C for WMA with Rediset or Sasobit® maintaining similar density and mechanical properties.

The optimal amount of Sasobit® and Rediset additives is 2.0% by the mass of the bitumen according to stability, flow and indirect tensile strength results. The highest asphalt mixes with Sasobit® stability results were reached with this amount of additives. 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 bitumen) should not be used. Decrease in flow values confirms that. The same notice could be applied to asphalt mixes with Rediset.

6. Conclusions

Based on the results, presented in this paper and on their analysis, the main conclusions of this study are the following:

1. When asphalt is produced at lower temperatures, there are many potential benefits, as reduced energy consumption (fuel) in asphalt plant and reduced noxious gases emissions, increased safety of workers due to reduce of fume emissions, possibility to place asphalt mix in cooler ambient temperatures and to haul further distances without compromising workability; possibility to use 50% and more of reclaimed asphalt in warm mix asphalt.
2. The 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 bitumen) for Iterlow T and Cecabase; 2.0% (by the mass of the bitumen) for Sasobit® and Rediset.
3. The use of organic additives in asphalt mixes increases asphalt pavement stability. The use of Sasobit® in asphalt mixes decreases asphalt pavement flow.
4. Sasobit® and Rediset additives increases asphalt pavement tensile strength. However, more than 2.0% of Sasobit® and Rediset (by the mass of the bitumen) should not be used in order to avoid great reduction in asphalt pavement resistance on low temperature cracking.
5. The properties of WMA mixture produced in 120 °C by the Rediset technology showed best results compared to another studied technologies. Stability, flow and values of indirect tensile strength were less scattered comparing to another selected additives and similar to control mixture produced in 150 °C temperature. Therefore, Rediset is the most suitable for lowering temperature for AC 16 PD asphalt mix.

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