

LABORATORY EVALUATION OF ORGANIC AND CHEMICAL WARM MIX
ASPHALT TECHNOLOGIES FOR SMA ASPHALTMartins Zaumanis¹✉, Eric Olesen², Viktors Haritonovs³, Guntis Brencis⁴, Juris Smirnovs⁵^{1, 3, 4, 5}Dept of Transportation, Riga Technical University, Āzenes street 16/20, LV-1048 Riga, Latvia²Danish Road Institute, Guldalderen 12, DK-2640 Hedehusene, DenmarkE-mails: ¹Martins.Zaumanis@rtu.lv; ²eol@vd.dk; ³viktors.haritonovs@rtu.lv;^{4, 5}smirnovs@rtu.lv

Abstract. Warm mix asphalt (WMA) technologies allow significant lowering of the production and paving temperature of the conventional hot mix asphalt (HMA), which promise various benefits, e.g. lowering the greenhouse gas emissions, reduction of energy consumption, improved working conditions, better workability and compaction, etc. However, in order to reach widespread implementation of WMA, it is necessary to prove that it has the same or better mechanical characteristics and long-term performance as HMA. This article presents a laboratory study that has been conducted to evaluate two different WMA technologies – chemical (using Rediset WMX) and organic (using Sasobit) for the use with stone matrix asphalt (SMA). The properties of two types of bitumen after modification with two different dosages of each WMA additive have been tested by traditional empirical test methods and with the Dynamic Shear Rheometer for a wide temperature range. Asphalt testing has been performed for SMA11 type mixture. At first, the necessary changes in testing conditions were determined by means of asphalt stiffness – the results suggested that for adequate comparison with reference HMA, at least two hour asphalt aging is essential before preparing test specimens. The properties of asphalt were determined for specimens that were prepared at four different compaction temperatures by means of two compaction methods – Marshall hammer and gyratory compactor. The test results show that it is possible to reduce the compaction temperature of 155 °C for HMA to at least 125 °C for both WMA products with maintaining similar density and mechanical characteristics at intermediate to high temperatures.

Keywords: warm mix asphalt, bitumen rheology, stiffness, aging, permanent deformations.

1. Introduction

The modern warm mix asphalt (WMA) technologies have the potential to reduce production temperature by 20 °C up to 40...50 °C from the conventional hot mix asphalt (HMA) and have a potential to do this without affecting the performance of asphalt (Čygas *et al.* 2009; Hurley, Prowell 2006). The different WMA production technologies are categorized in three groups (Zaumanis *et al.* 2012):

1. Foaming technologies;
2. Organic or wax technologies;
3. Chemical additives.

However, not all of the techniques provide similar asphalt performance as for HMA, therefore the WMA design process should involve not only empirical characterization of asphalt but also a careful analysis of bitumen and the performance properties of asphalt at different temperatures. The test methods and evaluation criteria may require adjustment in some cases. This laboratory study

has been conducted to evaluate Fischer-Tropsch wax and one of the available chemical additives.

Sasobit (Fig. 1a) is a Fischer-Tropsch process wax that reduces the viscosity of bitumen above the melting point of wax (~90 °C), thus improving the coating of aggregates and workability of the mix (Zaumanis 2011).

Rediset WMX (Fig. 1b) is a chemical additive in flaked form with a melting point of 110 °C. It is a combination



a) b)
Fig. 1. WMA additives: a – Sasobit; b – Rediset WMX

of cationic surfactants and rheology modifier, based on organic additives. It modifies the bitumen chemically and encourages active adhesion that improves the coating of the aggregates by binder. Other components of the additive reduce the viscosity of the binder at the production temperature (Zaumanis 2011).

2. Tasks of the research

The aim of the research is to investigate the changes in bitumen consistency after modification with WMA additives, to determine the physical-mechanical properties of asphalt after reduction of compaction temperature and to compare the characteristics of WMA with those of conventional HMA. To achieve this aim, the following tasks have been set:

1. Investigation of the changes in bitumen consistency at different temperatures after modification with WMA additives.
2. Determining the necessary adjustments in the mixture preparation, testing conditions and compaction method for evaluation of WMA properties and their adequate comparison with HMA.
3. Determining the physical and mechanical properties, including stiffness, resistance to deformations

and compactibility of asphalt modified with WMA additives and comparing the results with conventional HMA.

3. Bitumen testing

3.1. Methodology

In order to determine the visco-elastic behaviour of bitumen after modification with WMA additives, testing has been performed with conventional testing methods and the Dynamic Shear Rheometer (DSR) according to the testing plan provided at Fig. 2. Two different types of bitumen were tested – 50/70 and 40/60. To evaluate the effect of additives on bitumen's resistance to hardening, empirical tests were performed also after Rolling Thin Film Oven Test (RTFOT).

The stirring of additives with bitumen was performed at ~175 °C. Testing with traditional tests was performed by means of the test methods according to EN 12591 "Specifications for Paving Grade Bitumens". For the DSR, methodology from AASHTO TP5 was used at temperatures ranging from 100 °C to 30 °C with a 10 °C step, at frequencies within each temperature of 0.01, 0.0215, 0.0464, 0.1, 0.215, 0.464, 1, 1.59, 2.15, 4.65, and 10 Hz, for 25 mm diameter samples with 1 mm gap between parallel plates, at unaged state.

3.2. Testing with empirical test methods

The test results (Table 1) after addition of Rediset WMX show that this additive has small effect on the bitumen consistency characteristics at any temperature, suggesting that the difference in viscosity is not the explanation of the warm mix effect. The binder containing Sasobit compared to pure bitumen shows the tendency of consistency reduction at temperatures above the melting point of the additive and increases after crystallization of the wax. As expected, the degree of viscosity changes depends on the amount of the additive in bitumen. If different types

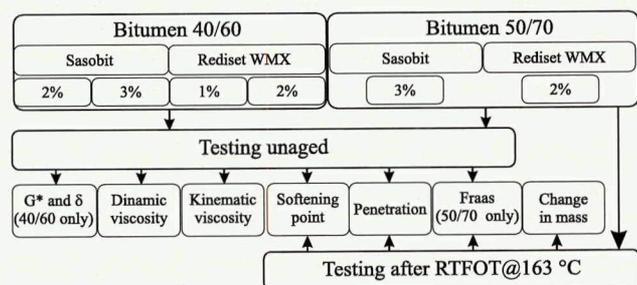


Fig. 2. Experimental plan for testing bitumen

Table 1. Traditional bitumen test results

Analysis	Bitumen 50/70			Bitumen 40/60				
	Ref. 50/70	+3% Sas.	+2% WMX	Ref. 40/60	+2% Sas.	+3% Sas.	+1% WMX	+2% WMX
Penetration at 25 °C,	65.0	45.2	55.4	48.0	33.3	32.6	43.0	37.3
Softening point, °C	50.4	78.4	58.1	50.4	64.0	78.8	51.4	52.2
Dynamic viscosity at 60 °C, Ps×2	340	2379	570	440	1148	2417	446	552
Kinematic viscosity at 135 °C, mm ² /s	607	485	529	545	468	422	508	448
Fraass breaking point, °C	-25	-20	-21	-	-	-	-	-
After RTFOT aging at 163 °C								
Change in mass, %	-0.10	-0.09	-0.12	-	-	-	-	-
Retained penetration, %	70.8	72.0	69.0	-	-	-	-	-
Softening point, °C (change)	56.8 (+6.4)	80.3 (+1.9)	63.7 (+5.6)	-	-	-	-	-
Fraass breaking point, °C (change)	-20 (-5)	-19 (-1)	-23 (+2)	-	-	-	-	-

of Sasobit modified binders are compared, the conclusion is that relatively to the pure bitumen the influence on the tested properties is similar, with the exception of dynamic viscosity. The results for initially softer bitumen (50/70) in this test show comparatively greater increase in viscosity than for harder bitumen (40/60). However, interpretation of the consistency results for determination of the optimum mixing temperature show that only about 5 °C reduction is attained. This suggests that the viscosity reduction is not the only property allowing reducing the temperature and that another parameter – bitumen lubricity (Hanz *et al.* 2010) – should be evaluated for describing the effects of these additives on the bitumen properties.

The Fraass breaking point temperature is significantly increased by using WMA additives. However in general, the properties of original bitumen are irrelevant because during the production process it oxidizes. It is more important to evaluate bitumen in the state in which it occurs in mixture. The aging process was simulated by the RTFOT and the influence of this procedure on Fraass temperature is significantly different for pure and modified bitumen. The breaking point temperature of the reference bitumen increased by a notable 5 °C after the RTFOT. That of the Sasobit modified binder increased only by 1 °C and it even dropped by 2 °C for bitumen modified with Rediset WMX which suggests some anti-aging effect on bitumen of the chemical additive. This shows that the general concern that wax technology significantly worsens the low temperature behaviour may not be true for all types of bitumen and has to be verified. It must be also taken in consideration that the effect of oxidative hardening in actual production process would be smaller for bitumen in WMA than for HMA because lower temperatures would be applied, therefore possibly even greater flexibility of bitumen in WMA is attained.

The analysis of the consistency results after RTFOT suggests that aging has similar effect on the change of mass and retained penetration for both WMA modified

binders and pure bitumen. The changes in softening point for Sasobit are relatively smaller than for other binders but this is logical considering that already initially it had a significantly higher value in this test.

3.3. Performance-related testing

The DSR was used to measure the rheological properties of binder. The test parameters (complex shear modulus (G^*) and the phase angle (δ)) are used to characterize both the viscous and elastic behaviour at intermediate to high temperatures which are the main ranges that are affected by the WMA additives.

The relative comparison of G^* for modified and unmodified binders (Fig. 3) show that after crystallization Sasobit increases the stiffness of binder and improves the resistance to deformation. The relative comparison between two Sasobit modified bitumens show a logarithmical increase when the wax content changes from 2% to 3% which indicates that 3% is the best alternative for further testing. The illustration (Fig. 3) also demonstrates the crystallization range of wax, which is between 80 °C and 90 °C, meaning that in construction object the compaction should be finalized before this temperature is reached. At this temperature the additive creates a shear sensitive binder, of which the consistency depends both on the temperature and the frequency of loading. The evaluation of G^* for Rediset WMX, however, suggests that this chemical additive has almost no effect on this property.

The summary of changes in phase angle, in comparison with pure bitumen, provided at Fig. 4 shows that binders containing Sasobit have improved elasticity, however addition of Rediset WMX, like with G^* , shows almost no effect on δ at any given temperature. The large phase angle variations within 80 °C and 70 °C compared to other temperature ranges for 3% Sasobit may be attributed to the process of wax crystallization while the test was being performed.

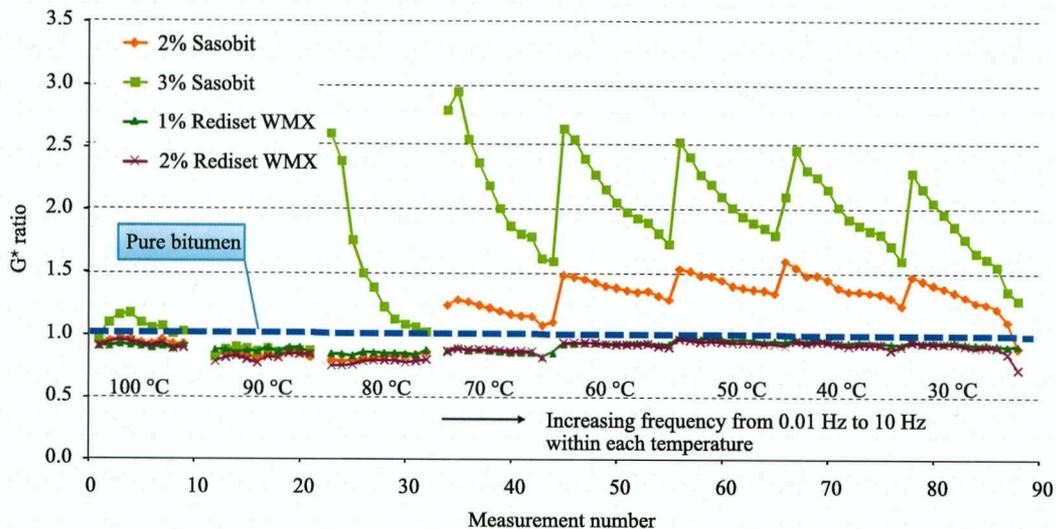


Fig. 3. Ratio of G^* for the modified binders relative to pure bitumen

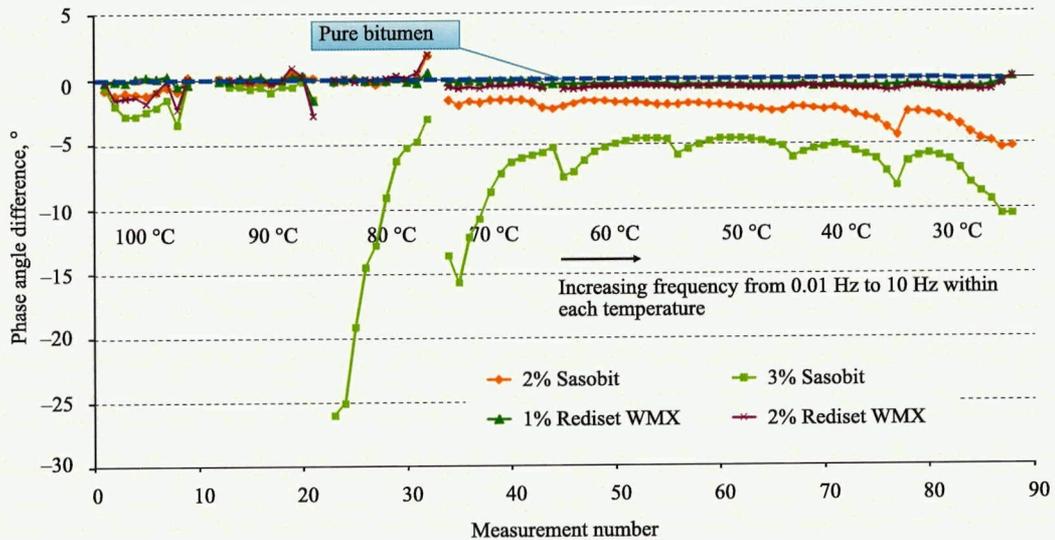


Fig. 4. Difference in phase angle of WMA binders relative to pure bitumen

Both of the results (G^* and δ) somewhat explain the reports of increased resistance to rutting for the Sasobit modified bitumen, which is especially important for high in-service temperatures (~60 °C) and short loading times that are typical for traffic.

4. Asphalt mixture testing

4.1. Methodology

Testing of the mixture has been performed on SMA-11 mixture with granite course aggregates according to testing plan at Fig. 5. Based on bitumen testing results 2% Rediset WMX and 3% Sasobit was used for mixing WMA. Three different WMA compaction temperatures were compared with the reference HMA temperature which was deducted according to EN 12697-35 Laboratory Mixing for the 40/60

grade bitumen. All of the testing was performed according to respective EN standard procedures listed in Fig. 5.

The differences in WMA production temperature and technology include modification of bitumen consistency, different bitumen and aggregate interaction and changes in the binder aging processes (Bueche, Dumont 2011). This may result in different strength gain of the WMA compared to HMA during a short period of time (Chowdhury, Button 2008); therefore, a part of the testing plan was to determine whether short-term aging is necessary before performing tests. Short-term hardening simulates the initial strength gain processes that would occur during actual asphalt storage in the silo and transportation of the mix to paving site (Perkins 2009). Asphalt aging was performed according to AASHTO PP2-2001:Standard Practise for Short and Long Term Aging of Hot Mix Asphalt, in a forced draft oven at the proposed compaction temperature. The mechanical effect of asphalt aging was examined by means of the indirect tensile test, which characterizes the stiffness of asphalt and is proven to be sensitive to stiffness of binder, length of short-term ageing, compaction temperature, and anti-stripping treatments (Aschenbrenner 1995).

Compaction was performed by means of two different methods – Marshall hammer and gyratory compactor. Impact (Marshall) compaction was performed according to EN 12697-30 Specimen Preparation by Impact Compactor at the desired temperature with 50 blows from each side. Gyratory compactor allows evaluating the compaction of mixture in all of the densification range which is especially important for assessment of WMA properties. However, there are concerns that it is insensitive to temperature changes (Hurley, Prowell 2006). To evaluate wide range of compaction force, 200 gyrations at 600 kN for 1.25° external angle were applied. Moulds of 100 mm diameter were used.

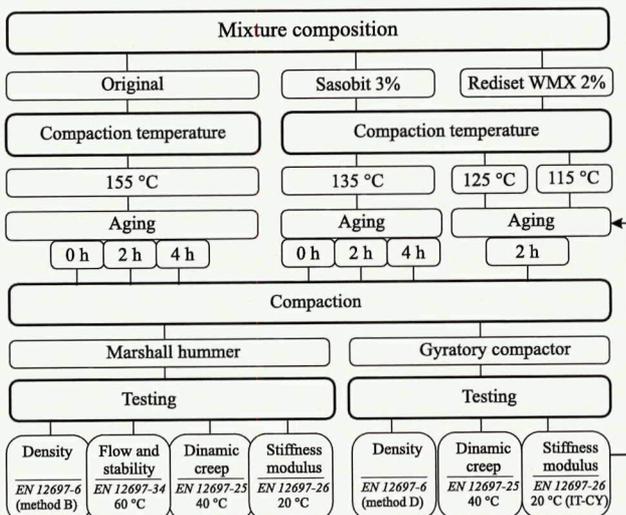


Fig. 5. Experimental plan for testing asphalt mixture

Max density of the mixture was determined for unaged reference samples according to EN 12697-5 Determination of the Maximum Density procedure A (volumetric) by using water.

4.2. Asphalt aging

The densification data from gyratory compactor was expressed as a function of density at particular number of gyrations with a reference max density of 2532.2 kg/m³. The results show significant changes in densification at different times of aging. The compactibility data for specimens with no aging confirm that the compaction requires less energy for both WMA compared to HMA. However, after hardening for two and four hours, the compaction characteristics level out and are very similar for both WMA and HMA.

The stiffness modulus and the number of air voids at different aging times are presented at Fig. 6. The results show an increase in stiffness after extending the aging time for all specimens, except for Sasobit at 4 h which is probably due to the excessive density of this core. The strength gain however is different for WMA products compared to the reference HMA. Whereas specimens initially have a similar stiffness modulus, already after two hours of aging the stiffness has a variation of 2089 MPa between the lowest (Rediset WMX) and the highest (Sasobit) of the obtained results.

The stiffness test results suggest that initial aging is essential for adequate comparison of mixes, however further research is required to determine the optimum oxidation time. All subsequent samples for the purposes of this research were compacted after two hour aging, because this is considered as an average time for mixture storing and transportation.

4.3. Density

The results of bulk density for both compaction methods that are shown at Figs 7 and 8 do not correlate. The density of the reference HMA at 155 °C for gyratory specimens was lower than for WMA, whilst for Marshall specimens it was higher in all cases. This is probably due to different compaction energies used but the different temperature sensitivity of each compaction method is another explanation. However, numerically the difference between all the WMA specimens and HMA, except for Marshall at 115 °C, is minor and the cores are attributed as having a similar density.

The compaction data from gyratory compactor in percent to max density for both WMA products and the control mix at different temperatures is illustrated at Fig. 9. It is obvious that compactibility at temperatures of 125 °C and 135 °C is similar to the reference mix for both WMA products. WMA at 115 °C, however, has noticeably different compaction characteristics for both products. Density at the first part of the compaction is significantly higher than for other samples and reaches its final compaction level at about 100 gyrations for Sasobit and 70 gyrations for Rediset WMX. The compaction energy of about

70 gyrations is considered to relate to the actual field compaction, meaning that with this compaction effort, higher in-situ density than for HMA would be achieved. This behaviour is attributed to the reduced hardening of binder, due to the lower aging temperature.

4.4. Stiffness

The comparison between the stiffness modulus of Marshall and gyratory cores has shown not a good correlation (Fig. 10) in relation to control mix at 155 °C. Therefore, the evaluation of the stiffness modulus of WMA depends not only on the type of additive used and the compaction temperature, but also on the compaction method and/or

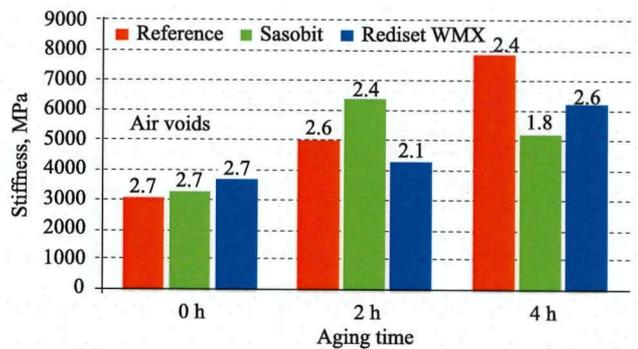


Fig. 6. Stiffness modulus after different aging times

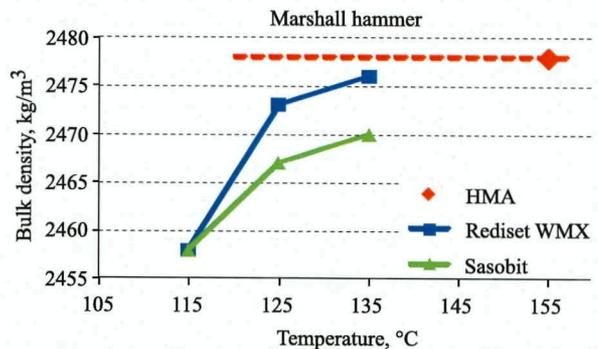


Fig. 7. Bulk density at different compaction temperatures for the Marshall specimens

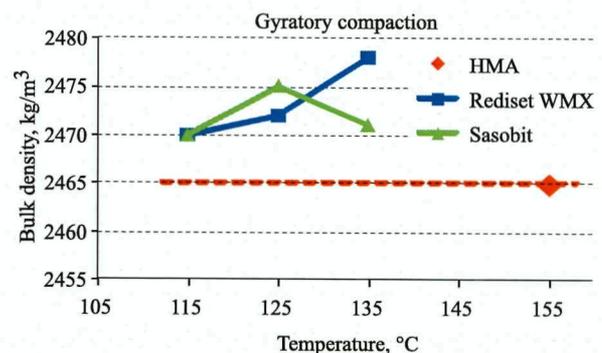


Fig. 8. Bulk density at different compaction temperatures for gyratory specimens

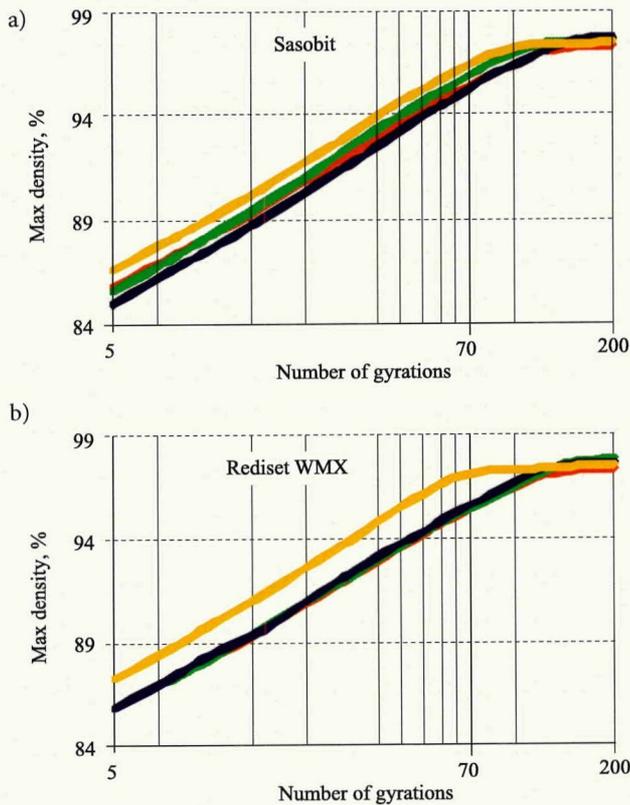


Fig. 9. Compaction characteristics at different temperatures: a – Sasobit; b – Rediset WMX: ■ Ref(155C); ■ Ref(135C); ■ Ref(125C); ■ Ref(115C)

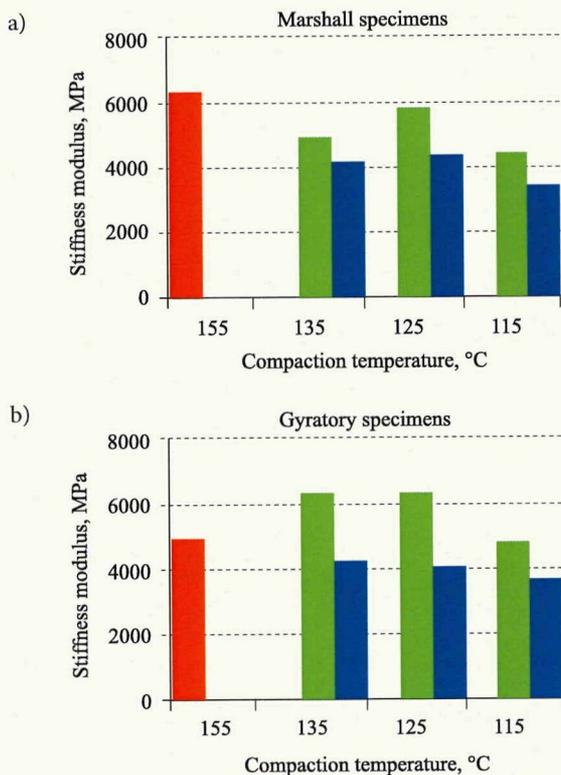


Fig. 10. Stiffness modulus test results: a – Marshall specimens; b – Gyrotory specimens: ■ Reference; ■ Sasobit; ■ Rediset WMX

the applied compaction force. Nonetheless, the results show that the stiffness of Sasobit is higher than for Rediset WMX at all compaction temperatures for both compaction methods. It is also clear that the difference between stiffness of both WMA at 135 °C and 125 °C is not significant, thus allowing to assume that it is possible to lower temperature to at least 125 °C while maintaining the relatively highest possible stiffness modulus for both WMA products. Further lowering of the temperature is considered to reduce stiffness of the mixture.

4.5. Permanent deformations

The Marshall test results are presented in Table 2. The Marshall stability results show a tendency to decrease with the reduced temperature and are generally lower than for the control mix at 155 °C, meaning that the rutting resistance is worse than for the reference mix at 155 °C. The results of Marshall flow also show the tendency of decreasing with lowering the temperature. This means less deformation in the pavement under the critical stability load. The Marshall quotient values are calculated as the ratio of stability to flow and represent an approximation of the load ratio to deformation under the particular test conditions. Therefore, the results could be used as a measure of the resistance of materials in service to shear stresses, permanent deformation and, hence, rutting. The results show that the WMA at 125 °C has approximately the same value as the reference.

However, although the Marshall test is widely used for mix design, it is important to recognize its limitations. The research (Brown 1993) for conventional HMA shows that the Marshall test is a poor measure of permanent deformations of asphalt, especially for SMA which was evaluated in this research.

The dynamic creep test has been performed only for the WMA samples that according to previous test results were considered to have the best ratio of temperature reduction versus performance. Consequently, samples compacted at 125 °C were used. The max strain results at the end of test (3600 s) are presented in Fig. 11 and show similar levels of WMA for specimens compacted with both compaction methods, but the results of the reference sample differ by 30%. These differences for the HMA specimens are attributed to different compaction levels because of changed compaction methods and densification force. Nonetheless, in general, the results are considered to show good resistance to rutting, proving that reduction in the compaction temperature by 30 °C for both WMA products

Table 2. Marshall test results

Temp.	Stability, kN			Flow, mm		
	Ref	Sas	Red	Ref	Sas	Red
155 °C	9.3			5.4		
125 °C		8.0	7.2	4.5	4.3	
115 °C		6.2	7.4	3.9	5.5	

is possible without having an increased susceptibility to permanent deformations.

Elastic behaviour, which is measured as the recovery after the relaxation period, has proportionally shown almost identical data for WMA and HMA, meaning that both WMA products are capable of recovering after the applied stress, as well as the control mix.

5. Conclusions

1. Addition of Sasobit reduces viscosity of bitumen at high temperatures and increases it at intermediate temperatures. At in-service temperatures, Sasobit provides higher resistance to deformations and improved elasticity of bitumen. Addition of Rediset WMX has relatively minor effect on the viscosity properties of bitumen.

2. The low temperature properties after RTFOT aging are similar for pure and modified bitumen. The use of Rediset WMX reduced oxidative hardening compared to other samples and decreased the Fraass breaking point temperature after RTFOT.

3. Oxidative hardening has different effects on WMA and HMA. Therefore, for the laboratory mixed samples the changes in mix preparation method should be considered by performing asphalt aging before carrying out compaction.

4. The use of both tested WMA products allows reducing the compaction temperature by at least 25 °C with the density remaining similar to HMA. The compactibility at this temperature is similar to that of HMA.

5. The analysis of mechanical properties of asphalt showed that reduction of compaction temperature by at least 25 °C for both WMA products is possible while maintaining similar stiffness and without having an increased susceptibility to permanent deformations.

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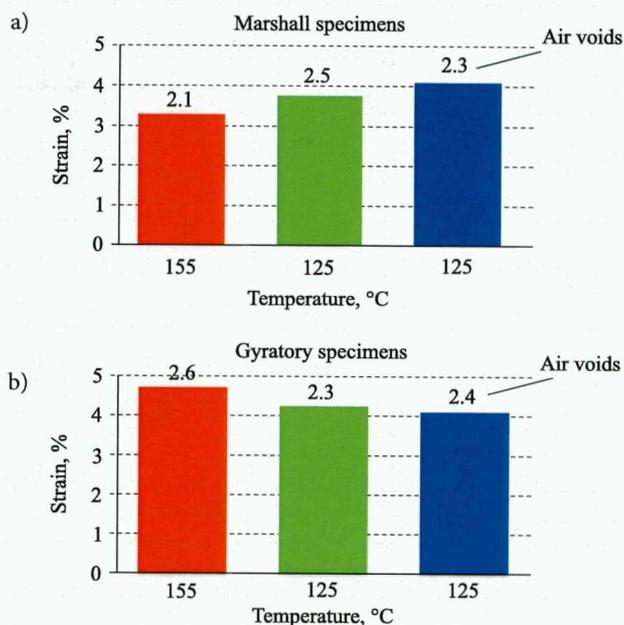


Fig. 11. Max strain for dynamic creep test: a – Marshall specimens; b – Gyratory specimens: ■ Reference; ■ Sasobit; ■ Rediset WMX

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