

# Research on Properties of Warm Mix Asphalt

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**Abstract:** Warm Mix Asphalt (WMA) is a technology that allows significant lowering of the production and paving temperature of conventional Hot Mix Asphalt (HMA). A laboratory study was conducted to evaluate two different WMA technologies – Sasobit and Rediset WMX. The testing consisted of two parts – determination of changes in rheological properties of bitumen at intermediate to high temperatures and mixture testing. The properties of bitumen were tested with traditional EN test methods and with the Dynamic Shear Rheometer (DSR). Testing of asphalt was performed for SMA mixture at four different temperatures. The compactibility characteristics, density, stiffness modulus and resistance to permanent deformations as a measure of Marshall test and dynamic creep were determined. The results show that it is possible to reduce the compaction temperature of 155°C for HMA to 125°C for WMA.

**Key words:** Warm Mix Asphalt, WMA, Viscosity, Temperature, Rheology, Permanent deformations, Stiffness, Asphalt Ageing

## INTRODUCTION

The potential temperature reduction ranges of WMA are presented in Figure 1. By reducing the viscosity of bitumen and/or increasing the workability of mixture, WMA technologies have the potential to significantly reduce the temperature without compromising the performance of asphalt. The existing WMA production technologies can be categorised in three groups:

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

All of the existing products use at least one of these technologies, but there may be combination of them as well.

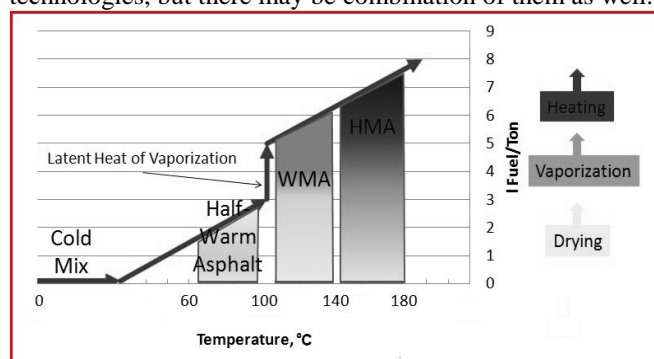


Fig. 1. Classification of asphalt by production temperature

A laboratory study was conducted to evaluate two different WMA technologies – Sasobit and Rediset WMX.

Sasobit is an organic technology that uses wax to reduce the viscosity of bitumen above the melting point of the wax therefore improving coating of aggregates and workability of the mix. After crystallisation, Sasobit forms a lattice structure that increases the stiffness of the binder which gives the mixture stability and increases the resistance to deformations.

Rediset WMX is a chemical additive that uses a combination of cationic surfactants and organic additive based rheology modifier. It chemically modifies the bitumen and encourages active adhesion that improves coating of aggregates by binder. Other components of the additive reduce the viscosity of the binder at production temperature.

## AIMS AND TASKS OF THE RESEARCH

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

1. Investigation of the changes in bitumen consistency at intermediate and high temperatures after modification with WMA additives.
2. Determining necessary adjustments in mixture preparation and testing conditions for evaluation of WMA properties and adequate comparison with HMA.
3. Determining the mechanical properties of stiffness, resistance to deformations and compactibility for asphalt, modified with WMA additives and comparing the results with conventional HMA.
4. Determining the suitability of different compaction methods for densification of WMA in laboratory circumstances.

## METHODOLOGY

The testing consisted of two parts – at first the properties of bitumen were determined with the traditional test methods. Then asphalt mixture was tested at different compaction temperatures to determine the mechanical properties.

### Bitumen

The response of bitumen to stress is dependent on both temperature and loading time and the degree to which their behaviour is viscous and elastic is a function of both temperature and loading time. In order to determine the visco-elastic behaviour of bitumen after modification with WMA

additives the testing was performed with the traditional testing methods and with the DSR equipment according to testing plan in Figure 2.

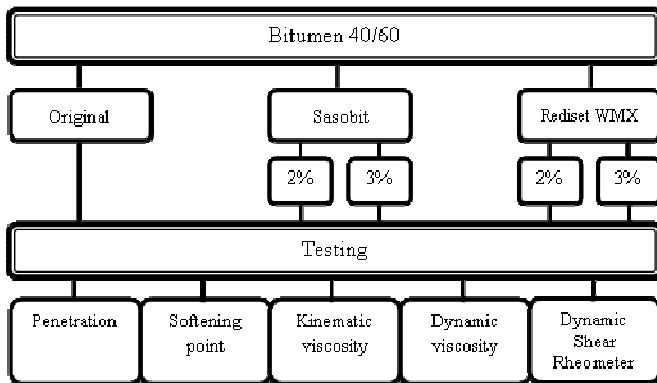


Fig. 2. Experimental plan for bitumen testing

The initial stirring of additives with bitumen was performed at ~175°C. All the binder cans were stirred thoroughly prior to pouring the sample to ensure the test specimen was homogeneous.

Testing was performed with test methods according to EN 12591 and with Dynamic Shear Rheometer (DSR) according to AASHTO TP5 [1] at temperatures 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, 10 Hz, for 25 mm diameter samples with 1 mm gap between parallel plates, at unaged state.

### Asphalt

The traditional empirical requirements for bituminous mixtures are based on long term knowledge about the combination of requirements for composition and component materials together with performance-related (e.g. Marshall properties) requirements for bituminous mixtures and asphalt layer. Because WMA is a relatively new technology, the knowledge of empirical properties for this type of asphalt is significantly smaller than for HMA and application of HMA specifications can be misleading in characterising the asphalt properties. The differences in WMA temperature and production technology include modification of bitumen and aggregate interaction and changes in the binder consistency in short and long term. This may indicate the need for modification of methodology for performing tests and differences in characterisation and specification requirements of WMA. Therefore a part of the testing plan is to determine necessary changes in test conditions, like short term ageing for asphalt mixtures.

According to different research [2; 3] consistency changes and different properties for binder used in WMA production may result in different strength gain of the WMA compared to HMA in short period of time. Therefore, while there are no requirements for asphalt ageing for conventional HMA, adequate comparison of WMA and HMA may require mix

ageing in forced draft oven at compaction temperature. This simulates the initial strength gain processes that would occur in actual asphalt storage in the silo and transportation of the mix to paving site. Short term ageing was performed according to AASHTO PP2 [4]. The mechanical effect of asphalt ageing was examined by means of the indirect tensile test for gyratory specimens. It is a measure of stiffness of asphalt and is proven to be sensitive to stiffness of binder.

Compaction with two methods – Marshall hammer and gyratory compactor – was performed in order to establish the possible advantages of using each of these compaction methods for evaluation of WMA. Gyratory compactor simulates field compaction more closely and allows to evaluate the densification parameters of mixture. However there are concerns that it is insensitive to temperature changes [5]. Compaction was performed according to the following conditions:

- Marshall (impact) compaction according to EN 12697-30. Compaction at desired temperature with 50 blows from each side;
- Gyratory compaction according to EN 12697-31. Compaction at desired temperature with 200 gyrations at 600kN for 1.25° angle. Moulds of 100mm diameter were used.

The mixture testing was performed according to experimental plan in Figure 3.

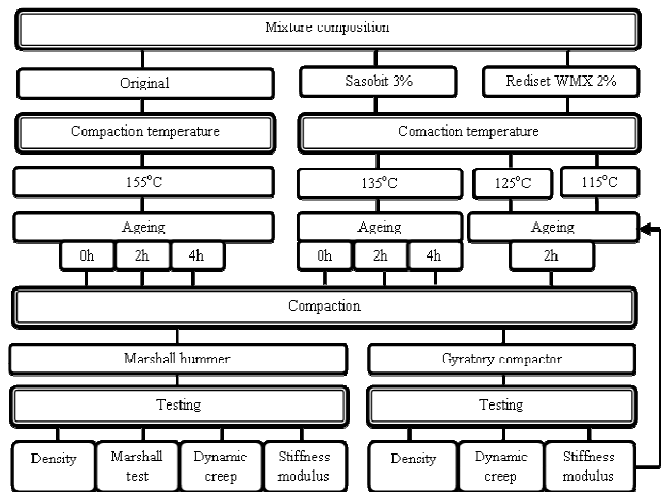


Fig. 3. Experimental plan for asphalt mixture testing

### COMPOSITION OF ASPHALT MIXTURES

A composition of Stone Mastic Asphalt with max particle size of 11 mm (SMA11) was designed for the purpose of this research (see Table 1).

Mixing was performed according to EN 12697-35. All materials were prepared by heating them to constant mass at the respective mixing temperature before introducing them to the mixer. Additives, when used, were stirred with bitumen before mixing with other aggregates so that no problems with inhomogeneous distribution can occur. The mineral materials

were pre-mixed for 1 min before adding the bitumen so that a homogeneous particle distribution was secured.

TABLE 1  
Mix compositions

Material	Ref	Sasobit	Rediset
Bitumen 40/60	6.5%	6.5%	6.5%
Lime powder	4.7%	4.7%	4.7%
Granite 0/2	23.3%	23.3%	23.3%
Granite 2/5	9.3%	9.3%	9.3%
Granite 5/8	14.0%	14.0%	14.0%
Granite 8/11	42.0%	42.0%	42.0%
Fibre	0.2%	0.2%	0.2%
WMA additive	-	Sasobit 3% of bit. mass	Rediset WMX 2% of bit. mass

## RESULTS AND DISCUSSION - BITUMEN.

### Traditional test methods

The test results (Table 2) show the expected tendency of consistency reduction at high temperatures and increase at intermediate for the wax technology of Sasobit. As expected, the degree of viscosity changes depends on the amount of the additive in the bitumen. The addition of Rediset WMX, however, has only minor effect on the bitumen characteristics, because it is a chemical additive and modification of bitumen viscosity is only one of the properties of this additive. Other characteristics involve interaction of bitumen and aggregates and therefore the assesment of these properties requires for testing of mixture.

The test results for bitumen with 3% of Sasobit resulted very high variance between the test results (25.8%) therefore the test was repeated, but it still resulted in 21.9% difference. However three out of four samples showed a very high correlation coefficient (0.99-1.00) within one capillary viscometer meaning that the tests were performed accurately.

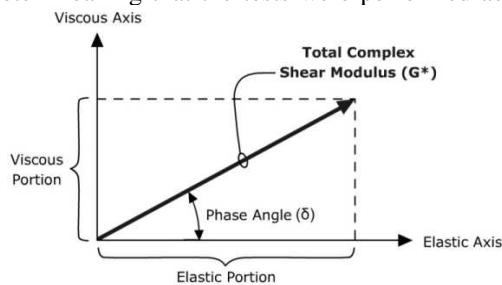


Fig. 4. Relationship between  $G^*$  and  $\delta$

The relative comparison of complex modulus ( $G^*$ ) for modified and unmodified binders (Figure 5) show that addition of Sasobit improves the total resistance to deformation after crystallisation of wax. The improvement is larger when low frequencies within the same temperature are applied and the difference becomes smaller with temperature reduction. The relative comparison between two Sasobit

Although visually no such evidence was found, the poor comparison between the results is attributed to inhomogeneous mixing of the additive with the binder or to “structure” in the binder. This suggests that when WMA modified bitumen is tested, extra care should be given to stirring the bitumen before testing is performed.

TABLE 2  
Traditional bitumen test results

Bitumen type	Pen at 25°C	Soft. point	Dyn. visc. 60°C	Kin. visc. 135°C	Pen Index, $I_p$
	EN 1426	EN 1427	EN 12596	EN 12595	EN 12591
	1/10 mm	°C	Pa s	mm <sup>2</sup> /s	-
Ref.	48.0	50.4	440.0	544.8	-1.2
3% Sas	32.6	78.8	2416.6	421.7	3.1
2% Sas	33.3	64.0	1147.7	467.8	0.8
2% Red	37.3	52.2	551.5	477.5	-1.3
1% Red	43.0	51.4	445.5	507.6	-1.2

## RHEOLOGICAL MEASUREMENTS WITH DSR

The DSR is used to measure the rheological properties of binder, including complex shear modulus ( $G^*$ ) and phase angle ( $\delta$ ) at intermediate to high temperatures. These parameters are used to characterise both viscous and elastic behaviour of bitumens, where the two components are linked by the phase angle to the complex modulus. The complex modulus is a measure of the total resistance of material to deformation when exposed to a sinusoidal shear stress load. The graphical illustration of DSR measurement is in Figure 4.

modified bitumens shows a logarithmical increase when switching from 2% to 3%.

The illustration also shows the crystallisation range of wax which is between 80°C and 90°C. After this point the additive creates a shear sensitive binder, where the consistency is dependent both on temperature and the frequency of loading.

Chemical additive of Rediset WMX, however, suggests that Rediset WMX has almost no effect on this property.

The summary of changes in phase angle ( $\delta$ ) in comparison with pure bitumen in Figure 6 shows that binders containing Sasobit have improved elasticity, but addition of Rediset WMX, again, shows almost no change at any given temperature. The large differences in the 80°C and 70°C ranges for 3% Sasobit are attributed to the process of crystallisation of wax.

Both of these results explain the increased resistance to rutting for Sasobit modified bitumens, which is especially important for high in-service temperatures (~60°C) and at short loading times, that are typical for traffic.

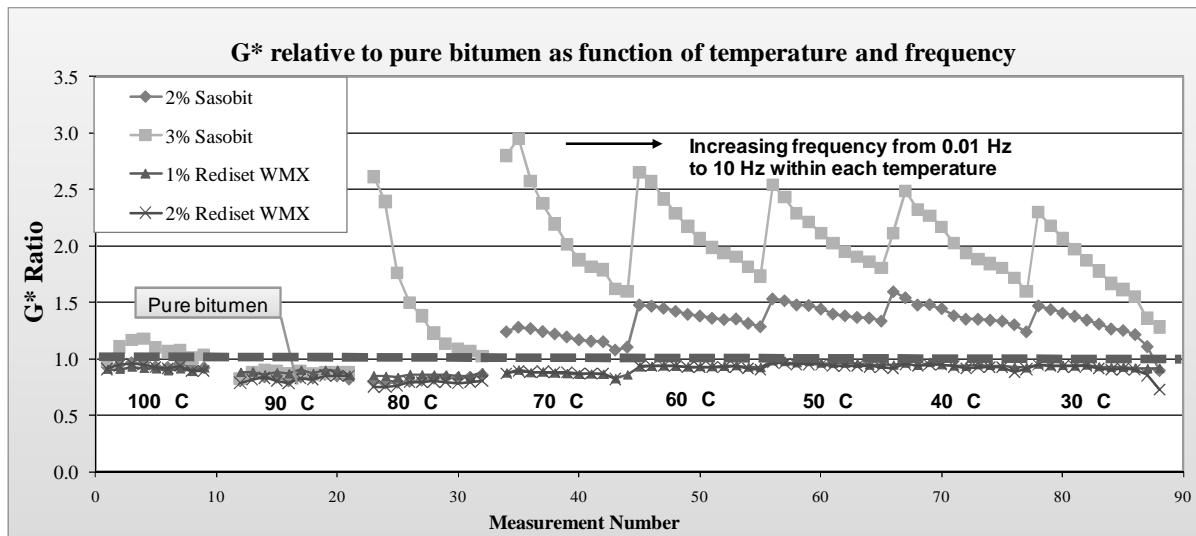


Fig. 5. Complex modulus  $G^*$  for modified binders relative to pure bitumen

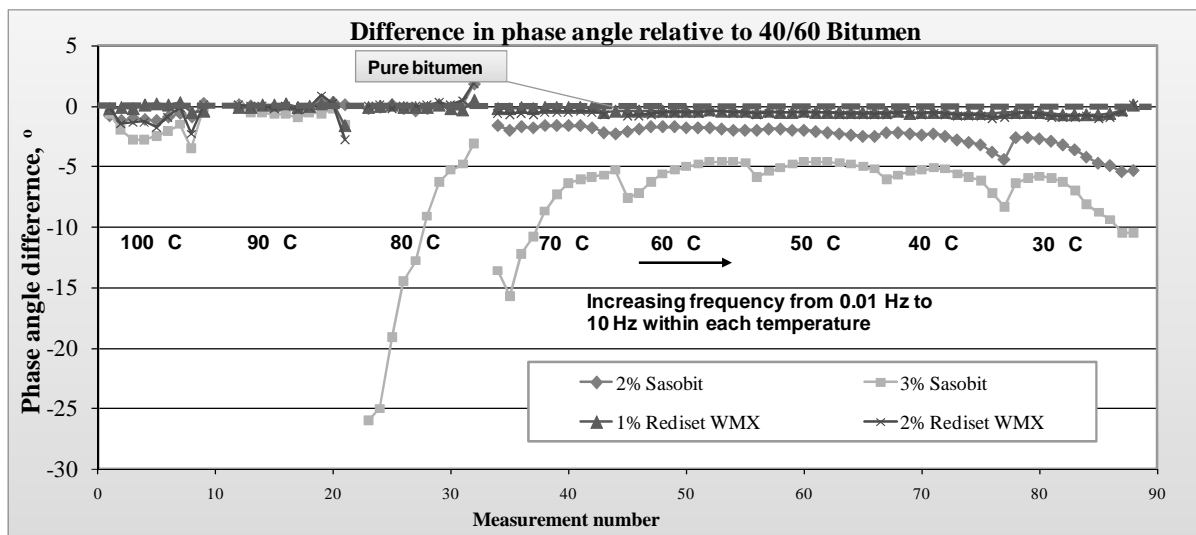


Fig. 6. Difference in phase angle of WMA binders to pure bitumen

## RESULTS AND DISCUSSION - ASPHALT

### Asphalt ageing

The compactibility data for 200 gyrations allows evaluating the processes of densification through wide range of compaction force. The densification data as a function of number of gyrations and ageing time is presented in Figure 7. The results show significant changes in densification at different ageing times. The compactibility data in Figure 7 with no ageing show that although the final density is similar, both WMA products reached this level significantly faster – already at 100 gyrations, while HMA continued to compact

until 170 gyrations. This is probably due to modifications in binder viscosity from WMA additives. After hardening for two hours, the compaction characteristics level out with the difference that HMA reached final density again at 170 gyrations while both WMA continued to compact after this point therefore reaching a higher final density. After four hours of ageing, HMA had hardened further while WMA had similar characteristics as for two hour ageing. It must be noted that HMA was aged in higher temperature therefore the hardening probably had higher effect than for WMA which explains the further hardening of HMA from 2 to 4 hours.

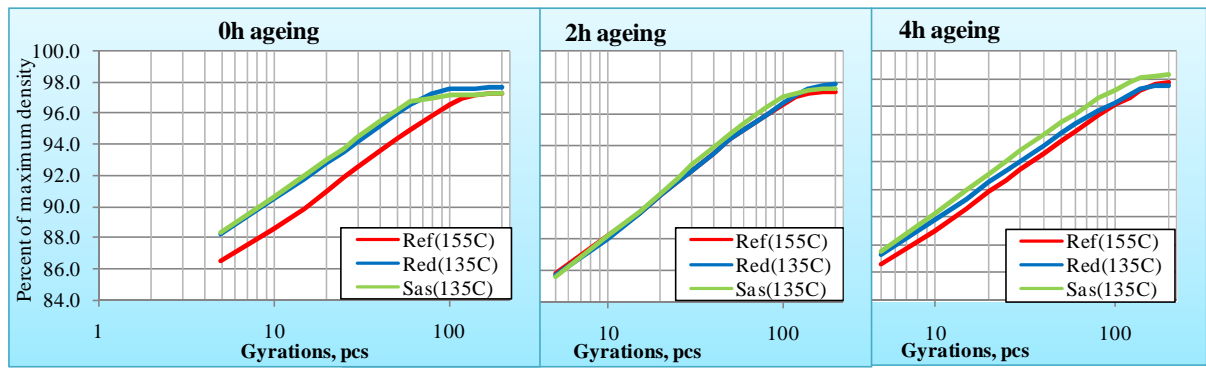


Fig. 7. Compaction characteristics for different ageing times

The stiffness modulus and number of air voids at different ageing times are presented in Figure 8. The results show an increase of the stiffness with increased ageing time for all specimens except Sasobit at 4 hours. This is considered to be connected with the excessive density and not to the mechanical properties of the product.

Results show that the strength gain is different for WMA products compared to reference HMA. While specimens initially have similar stiffness modulus, already after two hour ageing the stiffness has a variation of 2089 MPa between lowest (Rediset WMX) and highest (Sasobit) of the obtained results. This proves that ageing is essential for adequate mix comparison.

Based on the analysis of these results all further samples of WMA were compacted after two hour ageing.

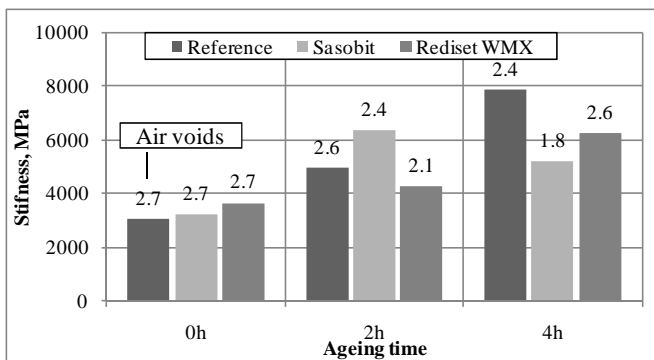


Fig. 8. Stiffness modulus after different ageing times

### Density

The results of bulk density (according to EN 12697-6) for specimens compacted at different temperatures with Marshall hammer and gyratory compactor are shown in Figure 9 and Figure 10 respectively.

The results between the compaction methods do not correlate which is probably due to different compaction energies used. 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. Different temperature sensitivity of each compaction method could be another explanation. However, numerically the difference

between all of the WMA specimens and HMA, except Marshall at 115°C, is minor and the cores can be attributed to have similar density.

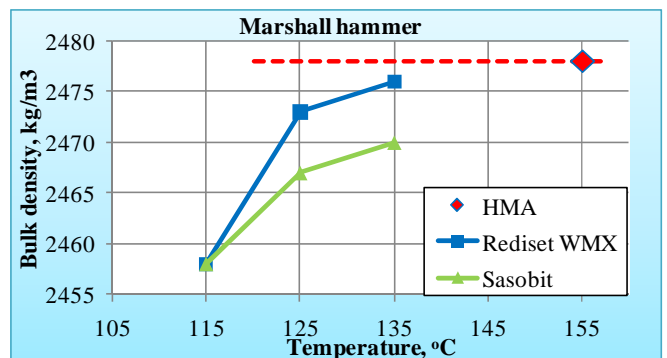


Fig. 9. Bulk density at different compaction temperatures for Marshall specimens

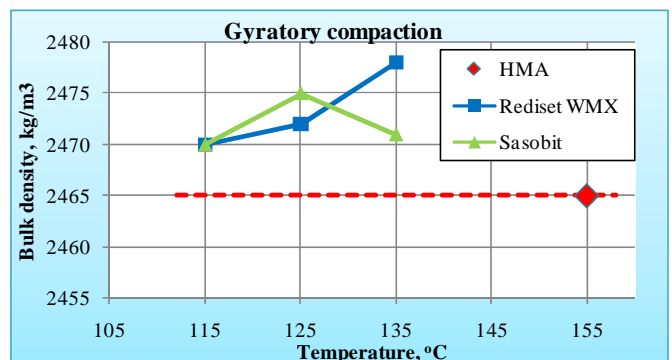


Fig. 10. Bulk density for different compaction temperatures for gyratory specimens

The compaction in percent of maximum density for both WMA products and the control mix at different temperatures is illustrated in Figure 11 and Figure 12. It is visible, that compactibility for temperatures of 125°C and 135°C are similar to reference mix for both WMA products. WMA at 115°C, however, has noticeably different compaction characteristics for both products. The density at the first part of compaction is significantly higher than for other samples and reaches its final bulk density at about 100 gyrations for

Sasobit and 70 gyrations for Rediset WMX. It is considered that compaction energy of about 70 gyrations simulates the actual field compaction, meaning that with this compaction effort, higher in-situ density than for HMA would be achieved. This behaviour could be attributed to the reduced hardening of binder, because of a lower ageing temperature.

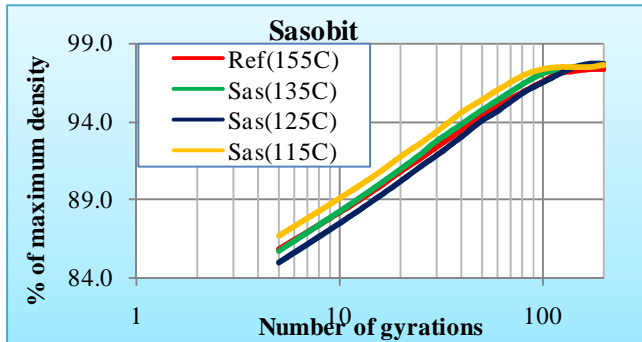


Fig. 11. Compaction characteristics of Sasobit at different temperatures

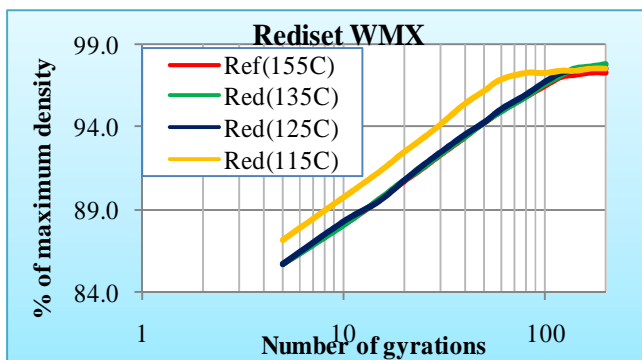


Fig. 12. Compaction characteristics of Rediset WMX at different temperatures

### Stiffness

The stiffness was measured in accordance with the EN 12697-26 at 20°C. The results of testing are presented in Figure 13 for gyratory specimens and in Figure 14 for Marshall cores.

A comparison between stiffness modulus of Marshall and gyratory cores did not show good correlation as the control mix at 155°C had a different relative value in comparison with WMA mixtures. Therefore, the judgement of stiffness modulus against reference mix depends not only on the type of additive used and the compaction temperature, but also on the compaction method and/or the applied compaction force.

Nonetheless, the results showed that the stiffness of Sasobit was higher than for Rediset WMX at all compaction temperatures for both methods. It is also clear that the difference between stiffness of both WMA at 135°C and 125°C is not significant and therefore it can be assumed that lowering the temperature to at least 125°C is possible with maintaining the highest possible stiffness modulus for both WMA products. A further temperature reduction is considered to lower the stiffness of mixture.

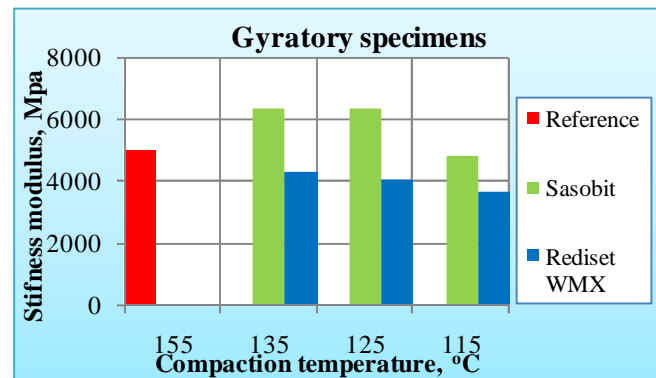


Fig. 13. Stiffness modulus test results for gyratory specimens

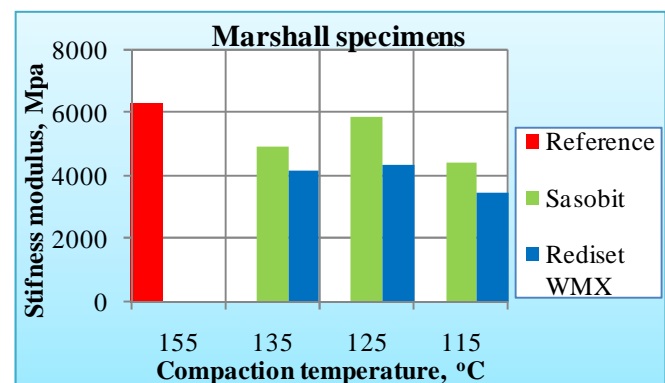


Fig. 14. Stiffness modulus test results for Marshall specimens

### Permanent deformations

Resistance to permanent deformations was measured by two methods:

- Marshall test for specimens prepared with impact compactor according to EN 12697-34 at 60°C;
- Dynamic creep test for two types of cores – compacted with the Marshall hammer and the gyratory compactor according to EN 12697-25 at temperature of 40°C for 3600 pulses with a test stress of 100 kPa and a relaxation period of 900 seconds. Preconditioning was performed with stress of 10 kPa and duration of 120 seconds.

The results of Marshall test are presented in Table 3. The Marshall stability results are a measure of maximum load carried out by the specimen before failure. They show a tendency to decrease with reduced temperature and generally are lower than for the control mix at 155°C meaning that the rutting resistance is lower than for the reference mix at 155°C. However, although the Marshall test is widely used, it is important to recognise its limitations. Research [6; 7] for conventional HMA shows that the Marshall test is poor measure of permanent deformations of asphalt, especially for open graded mixes like SMA where the changes in binder consistency or binder and aggregate interaction has minor effect on the test results. Repeated load tests give more realistic results on actual performance of asphalt.

The Marshall flow can be considered as an opposite property to stability. It is the amount of deformation of the specimen before failure occurs. The results again show tendency to decrease with lower temperature with exception of Rediset WMX at 155°C. This means less deformation in the pavement under a critical stability load.

The values of Marshall quotient are calculated as the ratio of stability to flow and represent an approximation of the ratio of load to deformation under a particular test condition. Therefore it can be used as a measure of materials in service resistance to shear stresses, permanent deformation and hence rutting. The results here show that WMA at 125°C has approximately the same value as reference. Therefore, from the Marshall test it can be concluded that both WMA products compacted at 125°C in terms of rutting would perform approximately the same as control HMA compacted at 155°C.

TABLE 3  
Marshall test results

Param.	Mix	Temperature, °C			
		155 °C	135 °C	125 °C	115 °C
Stability	Ref	9.30			
	Sas			8.00	6.20
	Red		7.90	7.20	7.40
Flow	Ref	5.35			
	Sas			4.45	3.95
	Red		5.05	4.25	5.45
Quotient	Ref	1.74			
	Sas			1.79	1.58
	Red		1.57	1.69	1.36

The dynamic creep test was performed only for the samples that according to all other results were considered to have the best ratio of temperature reduction versus performance. WMA at 125°C complied with this demand. The results are presented in Table 4. The results show similar levels of maximum strain of WMA for both compaction methods, but the results of the reference sample differ by 30%. Therefore, the differences in the results are attributed to the different relative compaction levels and hence – different comparative level of air voids. Nonetheless, in general the results are considered to show a good resistance to rutting and are similar for all specimens, proving that reduction of compaction temperature by 30°C for both WMA products is possible without having an increased susceptibility to permanent deformations.

Elastic behaviour, which is measured as the recovery after relaxation period, proportionally showed almost identical data for WMA in comparison to control mixture for both compaction methods, meaning that both WMA products are capable to recover after applied stress as good as control mix.

TABLE 4  
Dynamic creep test results

Mix	Temp °C	Air voids, %	Strain at 3600 sec, %	Strain after relax, %	Strain recovery, %
Gyratory sample					
Ref	155	2.6	4.71	3.48	1.23
Sas	125	2.3	4.24	3.12	1.13
Red	125	2.4	4.11	2.85	1.26
Marshall sample					
Ref	155	2.1	3.28	2.31	0.97
Sas	125	2.5	3.74	2.71	1.03
Red	125	2.3	4.06	2.97	1.09

### CONCLUSIONS

1. Addition of Sasobit lowers the viscosity of bitumen at high temperatures and increases at intermediate. At in service temperatures Sasobit provides higher resistance to deformations and improved elasticity of bitumen. Addition of Rediset WMX has minor effect on bitumen properties.
2. Oxidative hardening due to different production and compaction temperatures and use of additives had different effect on WMA and HMA. Therefore asphalt ageing before carrying out the compaction is essential to provide adequate test results of WMA. The ageing time simulates the initial strength gain that would occur in actual field conditions.
3. Use of both tested WMA products allows a reduction of the compaction temperature to at least 125°C, with having a similar density as HMA. Even more – analysis of gyratory compaction data suggests that less compaction force may be required to reach the same density and with application of further compaction higher density may be attained than for HMA.
4. The analysis of mechanical properties of asphalt showed that reduction of compaction temperature to at least to 125°C for both WMA products is possible with maintaining similar stiffness and without having increased susceptibility to permanent deformations.

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#### **Mārtiņš Zaumanis, Viktors Haritonovs. Silto asfalta maisījumu īpašību izpēte**

Tehnoloģijas, kas būtiski ļauj samazināt karsto asfalta maisījumu ražošanas un iekļāšanas temperatūru, tiek sauktas par siltajiem asfalta maisījumiem. Tas rada dažādas priekšrocības pār karsto asfaltu, piemēram, samazina atmosfēras piesārņojumu, zemāku enerģijas patēriņu, uzlabo darba apstākļus, padara vieglāku ietradājamību un sablīvējamību, u.c. Tomēr, lai panāktu plašu ieviešanu komerciālajā ražošanā, ir nepieciešams pierādīt, ka WMA nodrošina tādas pašas vai labākas asfalta īpašības un ilgmūžību nekā tradicionālie karstie asfalta maisījumi. Lai izanalizētu divas WMA tehnoloģijas – Sasobit un Rediset WMX, tika veikts pētnieciskais darbs laboratorijā. Testēšana sastāvēja no divām daļām – bitumena reoloģijas noteikšana pie vidējas līdz augstai temperatūrai. Bitumena īpašības tika testētas pie divām dažādām WMA piedevu dozācijām ar tradicionālajām EN testa metodēm un ar DSR iekārtu. Maisījuma testēšana tika veikta SMA asfaltam pie četrām dažādām temperatūrām. Vispirms tika noteiktas nepieciešamās izmaiņas testēšanas procedūrās, lai nodrošinātu adekvātu salīdzinājumu ar karsto maisījumu. Mehānisko īpašību testēšana tika veikta pēc divu dažādu sablīvēšanas metožu lietošanas – rotācijas un Māršala blīvētāja. Tika noteiktas sablīvējamības, blīvuma, stinguma moduļa īpašības un pretestība deformācijām, kā Māršala testa un cikliskās slogošanas rezultāts. Iegūtie rezultāti parāda, ka asfalta sablīvēšanas temperatūru WMA maisījumiem, salīdzinot ar HMA, var samazināt no 155°C līdz 135°C, turklāt saglabājot mehāniskās īpašības.

#### **Мартинш Зауманис, Виктор Харитонов. Исследование свойств теплых асфальтовых смесей**

Тёплые асфальтобетонные смеси (WMA) позволяют существенно снизить температуру производства и укладки асфальта. Это даёт большие преимущества по сравнению с горячими смесями асфальта - меньшие затраты энергии, уменьшение вредных выбросов в атмосферу, улучшенные условия труда и удобоукладываемости смеси. Однако для широкого практического применения необходимо доказать, что свойства и долговечность WMA не уступает традиционным асфальтобетонам. Испытание вяжущего производилось согласно требований Европейских стандартов (EN) и используя прибор DSR. Реологические свойства битума определены при средних и высоких эксплуатационных температурах. Тёплые асфальтобетонные смеси изготовлены, используя битумный модификатор Sasobit и адгезивную добавку Rediset. Для исследования механических свойств был изготовлен SMA асфальт. Образцы уплотнялись, используя метод Маршала и ротационный уплотнитель. Изготовленным образцам экспериментально были определены модули жесткости, уплотнение, плотность и сопротивление образованию колеи. Полученные результаты показывают, что температуру уплотнения смесей WMA по сравнению с HMA можно уменьшить с 155°C до 135°C, сохранив при этом механические свойства.