Asphalt production, paving and compaction techniques

Compactibility of asphalt mixtures with highly polymer modified bitumen (HiMA)

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Abstract

The paper presents the results of research on the compactibility of asphalt mixture with highly polymer modified bitumens (PMB HiMA or HiMA). HiMA is a new type of polymer modified bitumen and is characterised by reversed-phase of polymer-bitumen mixture i.e. polymer phase in the polymer-modified bitumen becomes continuous phase. The influence of temperature and bitumen content on compactibility of asphalt mixes is well known, however the use of such different type of bitumen like HiMA requires a different approach to this issue. In order to determine the effect of temperature and bitumen content on compactibility, some specific tests of SMA with PMB HiMA were carried out. In addition, some tests were performed with warm mix asphalt (WMA) additives. Each variant was analysed as a function of bitumen content and temperature. The mixes were produced at a laboratory and then were subjected to short-term ageing. After conditioning, the compactibility of the mixture was evaluated using Superpave Gyratory Compactor (SGC). The tests were carried out at several temperatures. The obtained results of compactibility show that SMA with HiMA behaves in a different way than mixtures with conventional bitumens. The test results allowed to determine the optimal compaction temperature as well as effectiveness of WMA additives in asphalt mixtures with HiMA. The results also showed that asphalt mixtures with HiMA should be operated in a different way than mixes with conventional bitumens.

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1. INTRODUCTION

The impact of temperature and bitumen content on compactability of asphalt mixtures produced with traditional bitumens is generally known, as are publications presenting analyses of the impact of asphalt components on the compaction resistance [1, 2]. In the standard approach for the determination of the optimum asphalt mixture compaction temperature, viscosity equivalent temperatures are used, e.g. according to the recommendations of the Asphalt Institute for unmodified bitumens, the laboratory mixing and compaction temperatures should be determined where the viscosity-temperature line crosses the viscosity ranges of 0.17 ± 0.02 Pa.s (mixing temperature range) and 0.28 ± 0.03 Pa.s (compaction temperature range), and the viscosity-temperature line is determined using the procedure described in [3]. In this case, the most popular method is the rotational viscosity procedure [4] at two test temperatures. It should be noted, that [3] was established for unmodified bitumens, which are Newtonian fluids at high temperatures. On the other hand, for polymer-modified bitumens, whose viscosity depends on shear rate (phenomenon known as pseudoplasticity), the application of the same procedures usually leads to an overestimation of the recommended mixing and compaction temperature [5]. Therefore, it is recommended to use either the bitumen manufacturer's recommendations or the method based on the measurements in Dynamic Shear Rheometer (DSR) [5].

Relatively new bitumens which contain a significantly higher amount of the SBS polymer, the so-called HiMA - Highly Modified Asphalts (the U.S. abbreviation) - with a reversed polymer-bitumen phase emphasise the problem of adequate temperature during application. This is affected not only by volumetric reversal of phases but also by properties of the special SBS polymer used in HiMA. A frequent mistake is to use the routine approach to the HiMA bitumens - the same as for the classic modified bitumens without reversed phases and with typical SBS. This usually leads to overheating of the bitumens and asphalt mixtures and significant problems with compaction on site.

2. HIGHLY POLYMER MODIFIED BITUMENS - HiMA

The HiMA bitumens are a relatively new type of binders which is modified with increased amount of SBS block copolymers exceeding 7% m/m. Achieving a certain limit of polymer content in the bitumen leads to a reversal of the volumetric proportions between bitumen and polymer after the modification process. As a result, the final PMB HiMA is a reversed polymer phase bitumen.

In October 2013, the first experimental sections of the road surface with highly modified bitumen in Poland (the sixth section in Europe), was made; PMB 65/105-80 HiMA was used for this purpose. Previous experience based on laboratory experiments and experimental sections indicate that PMB HiMA are characterised by above-standard properties. A continuous elastomer network markedly modifies properties of the bitumen and determines the performance of PMB HiMA. One of the main characteristics of the HiMA bitumens is the significant improvement of the flexibility and high tolerance resistance to increasing tensile strains. This, in turn, results in the other properties of these bitumens and then on properties of asphalt mixtures - fatigue performance, resistance to cracking, rutting resistance, etc. [6, 7].

3. THE GOAL OF THE PROJECT

The project's goal was to determine the optimum compaction temperature for asphalt mixtures contained PMB HiMA bitumens, examine the impact of high production temperature of the asphalt mixtures, and consequently the overheating of bitumen (190°C). The second goal was to examine the impact of WMA additives on the PMB HiMA bitumens.

4. EXPERIMENTAL PROCEDURES AND MATERIALS

4.1. Materials

The SMA 8 surf asphalt mixture for wearing course was used in the project. The composition is presented in Table 1 and the grading curve in Figure 1.

Table 1. Composition of SMA 8 surf

Material	Type	Content in mineral mixture	Content in bitumen
Coarse aggregate	Gabbro 5/8	64.5%	function of bitumen content
Coarse aggregate	Gabbro 2/5	7.0%	function of bitumen content
Fine aggregate	Glacial 0/2	18.0%	function of bitumen content
Filler	Limestone	10.5%	function of bitumen content
		Final density of the mineral mixture: $\rho_a = 2.90\ Mg/m^3$	
Bitumen	PMB 65/105-80 HiMA		6.4% 6.7% 7.0%
Adhesion promoter			0.3% of bitumen mass
Cellulose fibres			0.3%

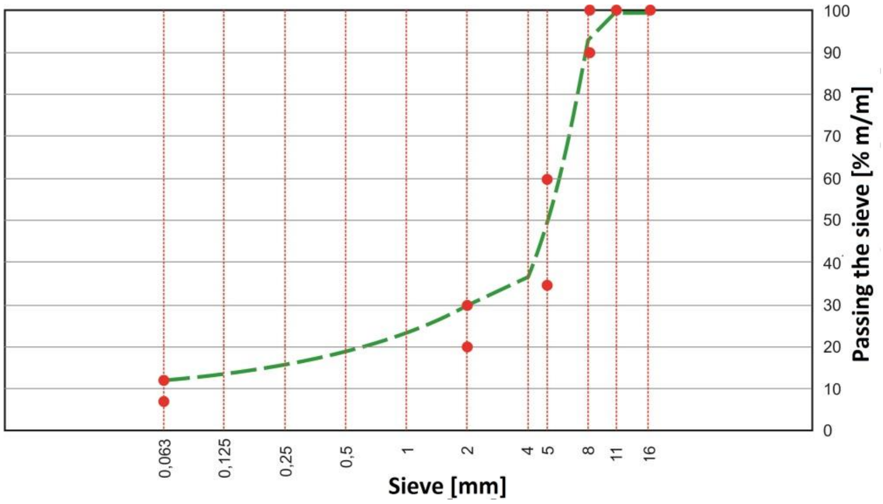

Figure 1. SMA 8 surf - Grading curve

The variable in the asphalt mixtures composition was the content of PMB 65/105-80 HiMA.

In addition, SMA 8 surf with 6.4% content (m/m) of PMB 65/105-80 HiMA was tested with WMA additives. The WMA content is presented below:

- Fischer-Tropsch wax-based additive, 2% of the bitumen weight;
- Fatty amine derivative-based additive, 0.4% of the bitumen weight.

The WMA additives were added to the bitumen according to the manufacturers' recommendations. They were used to improve the compactability, not to reduce the mixing temperature.

The compactability tests were conducted on such prepared asphalt mixtures.

Table 2 present properties of highly modified bitumen - PMB 65/105-80 HiMA.

Table 2. Properties of the highly modified bitumen PMB 65/105-80 HiMA

Property	Test method	Unit	Data
Penetration @ 25°C	EN 1426	0.1 mm	91
Softening Point R&B	EN 1427	°C	91.4
Fraass Breaking Point	EN 12593	°C	-20
Elastic Recovery @25°C	EN 13998	%	95
Elastic Recovery @25°C after RTFOT	EN 13998	%	95
Cohesion (Force ductility method) @ 10°C	EN 13589	J/cm^2	4.9
Viscosity (Brookfield) @ 90°C	EN 13302	Pa·s	474
Viscosity (Brookfield) @ 135°C	EN 13302	Pa·s	1.54
Viscosity (Brookfield) @ 160°C	EN 13302	Pa·s	0.52
PG designation	AASHTO M332	-	70E-28
MSCR test @ 64°C (after RTFOT) - Jnr 3200 - Recovery	ASTM D 6405	 kPa^{-1} %	 <0.1 97.3

4.2. Experimental procedures

The following activities were performed in order to determine the optimum compaction temperature and the impact of WMA additives on SMA 8 surf with PMB 65/105-80 HiMA:

- asphalt mixture mixing acc. to [8] - in two variants:
  - 170°C - simulation of recommended production conditions in the mixing plant (with and without WMA additive),
  - 190°C - overheating simulation (without WMA additive);
- Process ageing simulation of the asphalt mixture acc. to [9] for 2 h, with mixing every 0.5 h, in two temperature variants:
  - 165°C - for asphalt mixtures mixed at 170°C - simulation of recommended production conditions in the mixing plant (with and without WMA additive),
  - 185°C - for asphalt mixtures mixed at 190°C - overheating simulation (without WMA);
- Asphalt compaction in a gyratory compactor acc. to [10] (Figure 2) at the following temperatures:
  - mixed at 170°C: 115°C, 145°C, 165°C - 3 specimens for each temperature and each bitumen content;
  - mixed at 190°C: 115°C, 145°C, 165°C, 185°C - 3 specimens for each temperature and each bitumen content.

	Bitumen content	WMA additive		Mixing temp./ conditioning temp. [°C]		Compaction temp. [°C]			
		2% F-T wax	0.4% Fatty amine derivative	170/ 165	190/ 185	115	145	165	185
SMA8 PMB 65/105-80 HiMA	6.4%			●		●	●	●	
					●	●	●	●	●
		●		●		●	●		
			●	●		●	●		
	6.7%			●		●	●	●	
	7.0%			●		●	●	●	

Table 3. Tested variants of SMA 8 surf with PMB 65/105-80 HiMA

1370 g specimens were compacted in dia φ = 100 mm moulds of gyratory compactor.

Compaction parameters in a gyratory compactor:

- working pressure - 600 kPa,
- revolutions: 150, acc. to [11] the compaction should be made to 200 revolutions but the initial tests showed that mastic is pressed out from the mould after 150 revolutions; in the case of SMA asphalt mixtures with a strong coarse aggregate skeleton, the number of revolutions was limited to 150,
- angle of rotation – 0,82°,
- rotational speed ~ 30 rpm

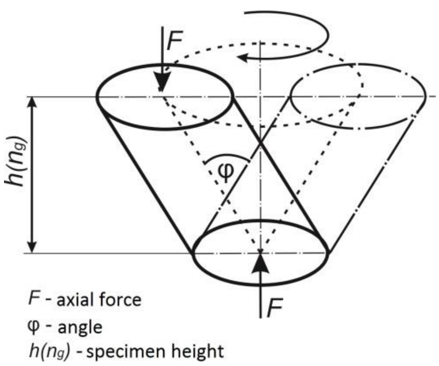

Figure 2. Diagram of asphalt mixture specimen compaction in a gyratory compactor [10]

The compactability tests results of SMA 8 asphalt mixtures with various bitumen content at various temperatures were compared using two methods.
First one is based on [11]. It consists in determining the parameters v (1) and compactability ratio K, based on data from the gyratory compactor:

$$v(ng) = v(1) - (K \times \ln(ng))$$

where:

- ng – number of gyrations,
- v(ng) – voids content after the number of gyrations ng,
- v(1) – voids content after 1st gyration,
- K – compactability coefficient.

Due to the fact that the comparison of two-parameter equations is troublesome (which can be seen in Figure 4), the further analysis used the indicator v(50) - the calculated void content after 50th gyration.
Second method used to compare compactability of the mixes is Construction Energy Index (CEI) based on [12].
The CEI is calculated by measuring the area below the graph between n = 8th compaction cycle (which represents the works performed by a typical paver during the placement of pavement and before the use of a roller for further compaction) and the amount of voids equal to 4.8% (v/v), as shown in Figure 3.
The amount of voids equal to 4.8% (v/v) was determined according to European specifications in which the compactability ratio for SMA should be 98% of the density of asphalt mixtures compacted according to Marshall i.e. about 4.8% (v/v) of voids determined according to [13].

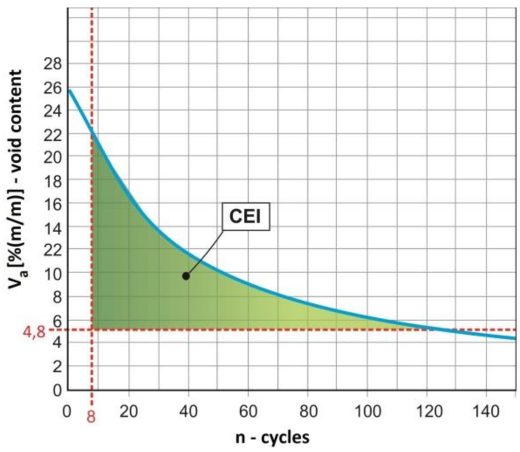

Figure 3. CEI Index as a function of n and void content (based on [14])

5. RESULTS

5.1. The results obtained at: mixing temperature 170°C, conditioning temperature 165°C

5.2. Asphalt mixtures without WMA additives

The results of compactability ratio K of SMA 8 surf asphalt mixtures with PMB 65/105-80 HiMA produced and conditioned in recommended conditions (170°C, 165°C) are presented in Figure 4.a. Figure 4.b shows the calculated void content after 1st gyration of SMA 8 surf depending on the PMB 65/105-80 HiMA content, respectively for 6.4 - 6.7 - 7.0% of bitumen in the asphalt mixture.
As it has been written previously, comparing compactability of the mixes on base of two-parameters equation is not clear, thus Figure 4.c shows the voids content calculated after 50th gyration. The results show that the compaction increases as the compaction temperature increases as well as the asphalt content increases.

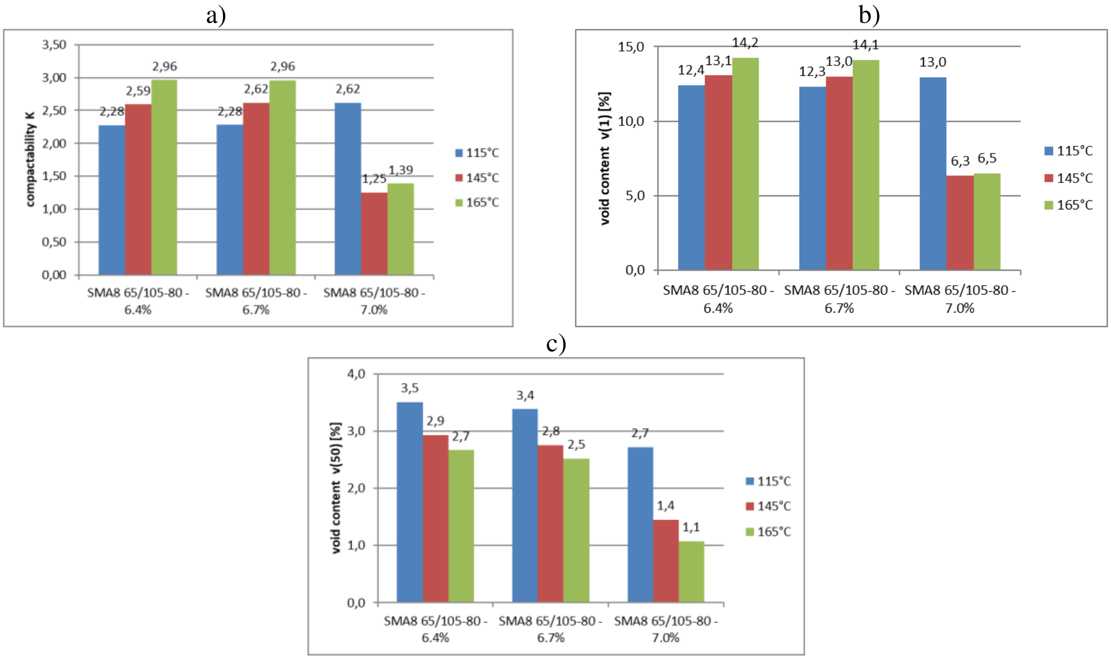

Figure 4. SMA8 surf with various PMB 65/105-80 HiMA bitumen content and various compaction temperatures a) compactability ratio K, b) calculated void content after 1st gyration, c) calculated void content after 50th gyration

The CEI results are presented in Figure 5. They coincide with the results of the v(50) indicator. The graph indicates that already above the compaction temperature of 115°C, all SMA 8 asphalt mixtures with PMB 65/105-80 HiMA compact well, with the best CEI result was observed for the highest bitumen content 7.0%. At 115°C, the compaction effectiveness is clearly less and the asphalt mixtures gives more resistance. In addition, a positive impact of higher bitumen contents - that is 7.0% - can be observed at each compaction temperature, even at 115°C.

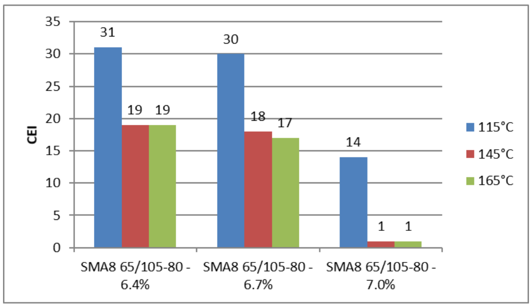

Figure 5. CEI SMA 8 surf with PMB 65/105-80 HiMA at various bitumen content and various compaction temperatures

5.3. Asphalt mixtures with WMA additives

The compactability results of SMA 8 surf asphalt mixtures with 6.4% (m/m) of PMB 65/105-80 HiMA with WMA additives are presented in Figure 6. Void content after 50th gyration are shown in Figure 6.a and the CEI in Figure 6.b. This test was performed using the asphalt mixture with the least bitumen content (6.4% (m/m)) as it was assumed that such asphalt mixture would have the greatest compaction resistance.

The effectiveness of the used additives evaluated with both methods lead to the same conclusions. At 115°C, no asphalt mixture compactability improvement was observed for fatty amine derivative - based additives in comparison with the reference asphalt mixture without WMA additives (Fig. 6.a-b). The effectiveness of compaction was improved for asphalt mixture with the F-T wax. At 145°C, both additives improved the compactability. The effectiveness of compaction was much higher with the F-T wax.

a) b)

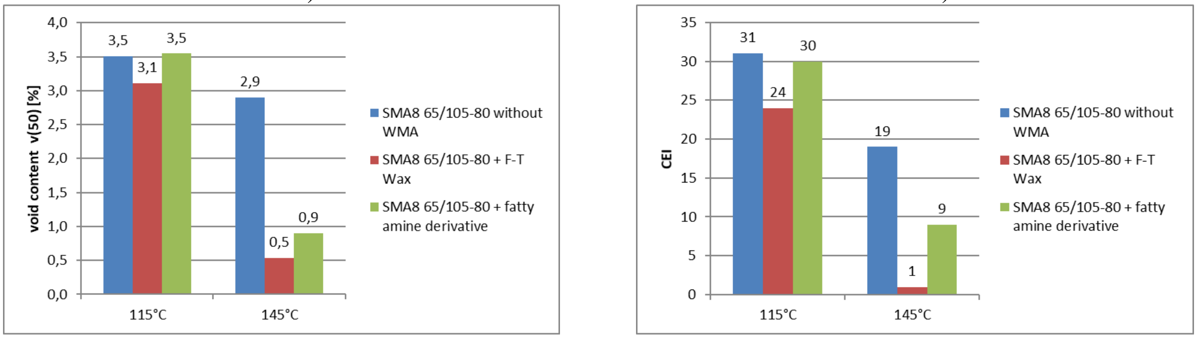

Figure 6. SMA 8 surf with PMB 65/105-80 HiMA with WMA additives at various compaction temperatures a) calculated void content after 50th gyration, b) CEI

5.4. The results obtained at: mixing temperature 190°C, conditioning temperature 185°C

The goal of this project stage was to verify the impact of overheating on the asphalt mixture compactability. The PMB HiMA reverse phase bitumens, with predominance of polymer phase, are susceptible to a significant viscosity increase if the asphalt mixture or bitumen is heated above 180°C. Such high production temperatures are often used for asphalt mixtures with standard polymer modified bitumens, the reason being a routine approach of road construction contractors to the PMB application. The observations made in Poland between 2013 and 2018 with PMB HiMA bitumens, indicate that asphalt mixture of such high temperature on site does not compact better, but poses bigger problems.
The compactability results of SMA 8 surf asphalt mixture with 6.4% (m/m) of PMB 65/105-80 HiMA, produced and conditioned at elevated temperature, and then compacted at various temperatures are presented in Figure 7.
The results indicate that the asphalt mixture produced at 190°C and then conditioned for 2 hours at 185°C shows good compactability only in the 165 - 185°C range which is untypical for such soft bitumen (about 90 pen).

a) b)

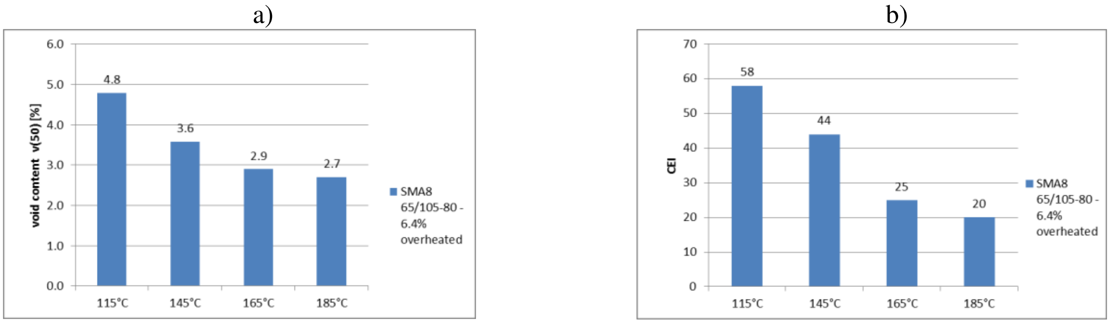

Figure 7. Asphalt mixture SMA 8 surf with PMB 65/105-80 HiMA 6.4% (m/m), overheated asphalt mix, various compaction temperatures a) calculated void content after 50th gyration, b) CEI

5.5. Comparison of overheating impact on compactability

Figures 8.a-b present the comparison of compactability of asphalt mixture produced and conditioned at recommended conditions (175°C/170°C) and of asphalt mixture produced and conditioned at elevated temperature (190°C/185°C), for the same bitumen content (6.4% (m/m)) and compaction temperature. Both compactability factors, the calculated void content after 50th gyration and CEI, indicate a significant compaction effectiveness deterioration of the overheated asphalt mixture in comparison with the asphalt mixture produced at recommended temperature, especially in temperatures 115°C and 145°C. Only at 165°C compactability of overheated mixture is close to compactability of mix produced at recommended conditions.

a) b)

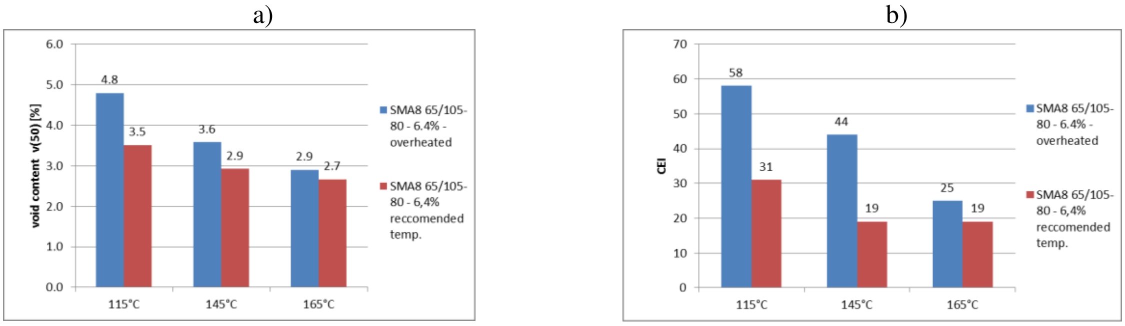

Figure 8. Compactability comparison: overheated and not-overheated SMA 8 surf
a) calculated void content for 50th gyration, b) CEI

6. CONCLUSIONS

Compactability of the SMA 8 with PMB 65/105-80 HiMA was determined with two methods: based on the standard EN 12697-10 and based on Construction Energy Index. Direct comparison of the parameters given in the standard EN 12697-10 (voids content after the first gyration v(1) and compaction coefficient K) is quite troublesome, so for the purposes of the presented analyses, voids content after 50th gyration was determined.
The research confirmed the impact of temperature and the content of PMB HiMA bitumen on the SMA 8 asphalt mixture compactability. The aforementioned asphalt mixture is characterised by the best compactability in the 145 - 165°C temperature range and compacts clearly better at the 7.0% content (m/m).
The tests of asphalt mixtures with WMA additives: F-T wax-based and fatty amine derivatives, indicated a compactability improvement when 2% (m/m) of F-T wax was added to the bitumen, but the use of a fatty amine derivative-based additive did not improve the compactability at the compaction temperature of 115°C. In addition, a significant compactability improvement can be observed for asphalt mixture with F-T waxes at 145°C, and a noticeable improvement took place for asphalt mixture with fatty amines in comparison with the energy necessary to compact the SMA 8 surf without additives.
The tests performed on asphalt mixture subjected to elevated production and conditioning temperatures (overheated) indicated a compactability deterioration at temperatures below 145°C in comparison with the asphalt mixture produced and conditioned in optimum conditions. It was proven that the SMA 8 surf with PMB HiMA should not be produced and conditioned above 175°C. The deteriorated compactability is a result of an excessive viscosity increase of PMB HiMA if stored or conditioned at temperatures above 180°C. Excessive temperature of mixing the aggregate with the HiMA bitumen leads to the workability deterioration.

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REFERENCES

[1] Renken P., The compaction energy required for optimum compacted asphalt, The East-West European Road Conference, 1993, Warsaw, Poland
[2] Renken P., The compaction resistance of asphalt mixes – a comprehensive performance related property, Proceedings of the 3rd Euroasphalt & Eurobitume Conference, 2004, Vienna
[3] ASTM D2493 Standard Practice for Viscosity-Temperature Chart for Asphalt Binders
[4] ASTM D4402 Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer
[5] West R., Watson, D. E. NCHRP Report 648, Mixing and Compaction Temperatures of Asphalt Binders in Hot-Mix Asphalt. 2010
[6] Błażejowski K., Wójcik-Wiśniewska M., Peciakowski H., Olszacki J. ,The performance of a highly modified asphalt for long-lasting asphalt pavements, Transportation Research Procedia, 14, 2016, pp. 679 – 684, Transport Research Arena, Warsaw, Poland
[7] Błażejowski K., Wójcik-Wiśniewska M. Baranowska W., Ostrowski P., Highly modified binders ORBITON HiMA – Application Guide 2019, ORLEN Asfalt, Poland

[8] PN-EN 12697-35: Asphalt mixtures –Test method – Part 35: Laboratory Mixing
[9] AASHTO R 30 Standard Practice for Mixture Conditioning of Hot Mix Asphalt (HMA)
[10] PN-EN 12697-31: Bituminous mixtures. Test methods for hot mix asphalt. Specimen preparation by gyratory compactor
[11] PN-EN 12697-10: Asphalt mixtures –Test method – Part 10: Compactability
[12] Mahmoud A.F.F., Bahia H., Using gyratory compactor to measure mechanical stability of asphalt mixtures, Report WHRP 02/5 (0092- 01-02),Wisconsin Highway Research Program, 2004, USA
[13] PN-EN 12697-8: Asphalt mixtures –Test method – Part 8: Determination of void characteristics of bituminous specimens
[14] KucińskaM., Asphalt samples compaction in gyratory compactor, Drogownictwo, 7-8, 2013, pp. 236 – 240
[15] Asphalt Institute Inc. and European Bitumen Association–Eurobitume: The Bitumen Industry – A Global Perspective, Information Series No. 230 (IS-230), 2011
[16] Kluttz R., Jellema E., Woldekidan M.F., Huurman M., Highly Modified Bitumen for Prevention of Winter Damage in OGFCs, American Society of Civil Engeenering, 2013
[17] Kluttz, R., Molenaar A., Van de Ven M., Poot M., Liu X., Scarpas A., Scholten E., Modified Base Courses for Reduced Pavement Thickness and Improved Longevity, Proceedings of the International Conference on Perpetual Pavement, 2009, Columbus, OH, USA
[18] Kluttz R., Willis J.R., Molenaar A., Scarpas T. and Scholten E., Fatigue Performance of Highly Modified Asphalt Mixtures in Laboratory and Field Environment, 7th RILEM International Conference on Cracking in Pavements, 2012
[19] Morgan P., Mulder A., The Shell bitumen industrial handbook. Surrey: Shell Bitumen; 1995
[20] Polacco G., Stastna J., Biondi D., Zanzotto L., Relation between polymer architecture and nonlinear viscoelastic behavior of modified asphalts, Current Opinion in Colloid & Interface Science, 11(4), 2006, pp. 230-245
[21] Sanchez-Alonso E., Vega-Zamanillo A., et al., Evaluation of compactability and mechanical properties of bituminous mixes with warm additives, Construction and Building Materials, 25, 2010
[22] Timm, D., Powell, R., Willis, J. and Kluttz, R., Pavement Rehabilitation Using High Polymer Asphalt Mix, submitted for the Proc. 91st Annual Transportation Research Board, 2012, Washington D.C., USA
[23] Timm, D., Robbins M., Kluttz R., Full-Scale Structural Characterization of a Highly Polymer-Modified Asphalt Pavement. Proceedings of the 90th Annual Transportation Research Board, 2011, Washington, D.C., USA
[24] Timm, D.H., Robbins M., Willis J.R., Tran N., Taylor A.J., Field and Laboratory Study of High-Polymer Mixtures at the NCAT Test Track. Draft Report, National Center for Asphalt Technology, 2013, Auburn University, USA
[25] Willis J., Timm D., Kluttz R., Taylor A., Tran N., Laboratory Evaluation of a High Polymer Plant- Produced Mixture, submitted for the Association of Asphalt Paving Technology Annual Meeting, 2012, Austin, TX, USA
[26] Zhu, J., Birgisson, B., Kringos, N. Polymer modification of bitumen: Advances and challenges. European Polymer Journal, 54, 2014, pp. 18-38, http://dx.doi.org/10.1016/j.eurpolymj.2014.02.05