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LOW-TEMPERATURE REQUIREMENTS FOR BITUMEN IN CENTRAL EAST EUROPEAN ROAD CONSTRUCTION

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Abstract. The paper presents the proposition of special assessment of low-temperature requirements for bitumens in the region of Central and Eastern Europe where there is a moderate transitional area from sea to the continental type of climate. The results of the research program conducted on the road neat bitumens, Styrene-Butadiene-Styrene polymer and polymer-rubber modified bitumen, and multigrade bitumen types were presented and discussed. Based on the Superior Performing Asphalt Pavements Performance Grade procedure for low temperatures, climatic zones in Poland were developed and compared to analogous zones for other countries from the Central and Eastern Europe region as Estonia and Belarus. The results of functional Performance Grade tests and European standard test of bituminous binders were analysed. It was concluded that some of the bitumens were not meet the performance requirements in the range of low temperatures by Superior Performing Asphalt Pavements Superpave specification and the low-temperature properties of those bitumens should be improved.

Keywords: asphalt binder, bitumen, low-temperature requirements, road construction.

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Introduction

In Central and Eastern Europe, encompassing Poland, there is a moderate transitional climate zone. It is a transition area from the sea to the continental climate. In recent years, depending on the air circulation, the dominance of sea or land influences is marked. During those years with the continental impact of air, circulation temperatures are very low during the winter and very high during the summer (Pszczoła, Judycki, & Ryś, 2016; Radziszewski, Sarnowski, Król, & Kowalski, 2017). Extreme recorded air temperatures in Poland reach values from approximately −40 °C to +40 °C. Similar low and high air temperatures are recorded in the countries located on the east from Poland, e.g. Estonia, Lithuania and Belarus. The specific climate conditions have an impact on road construction in various technologies, depending on the technical and functional class of each traffic load road.

Bituminous binders and asphalt mixtures are important materials used to build road pavements in Central and Eastern Europe (Radziszewski, Nazarko, Vilutienė, Dębkowska, Ejdys, Gudanowska, Halicka, Kilon, Kononiuk, Kowalski, Król, Nazarko, & Sarnowski, 2016). About 95% of the surface courses of pavement are built in this region contain in its composition neat or modified bitumens. Properties of the binder have a significant impact on the useful properties of the pavement layers and decide on its durability (Radziszewski, Sarnowski, Król, & Kowalski, 2017). One of the main problems related to ensuring long-term use of asphalt road pavement in a moderate transitional climate is to increase the resistance of bituminous mixtures to thermal induced cracking (Piłat & Radziszewski, 2010).

The properties of the bituminous binder significantly change in the function of temperature and time of loading. The asphalt binder as a thermoplastic material is, depending on the temperature conditions, in various rheological conditions (Gajewski, Sybilski, & Bańkowski, 2015). At a very low temperature, the binder may be in an unfavourable, brittle elastic state and becomes susceptible to cracking due to thermal contraction. In the field of operating temperatures, the binder in the road pavement should exhibit viscoelastic properties, i.e. both viscous and elastic properties. From the road user, it is preferred that the viscoelastic range of the bituminous binder is wide enough to match the climatic conditions of the region, determined by the lowest and highest temperature of the pavement layer in which the binder is used (Piłat & Radziszewski, 2010). In the climatic conditions of Central and Eastern Europe, this means keeping a viscoelastic state within the lowest temperature reaching around −40 °C (Kontson, Lill, Sillamate, Koit, Freiberg, & Aavik, 2016; Radziszewski, Sarnowski, Król, & Kowalski, 2017).

In the Central and Eastern Europe region, various bituminous binders are produced, from typical neat bitumens to those modified with various additives. Different low-temperature properties characterise these binders. It is crucial to choose an appropriate binder type for the asphalt mixture, taking into account the type of construction layer with this binder and the traffic load.

In European Union countries, road bitumens are classified by penetration at 25 °C, regardless of climatic conditions. In addition to penetration testing, road bitumens are classified based on tests of softening point temperature, flash point, solubility tests and assessment of resistance to technological ageing. It should be noted that the European standard requirements for bituminous binders are insufficient to assess the quality of bitumens, especially in the field of low temperatures (Król, Radziszewski, Kowalski, Sarnowski, & Czajkowski, 2014; Radziszewski, Kowalski, Krol, Sarnowski, & Piłat, 2014; Radziszewski, Sarnowski, Król, & Kowalski, 2017). The Fraass Braking Point temperature test is commonly used, which does not reflect the real phenomenon of fracture toughness temperature of asphalt layer in road pavement (Largeaud, Faucon-Dumon, Eckmann, Hung, Lapalu, & Gauthier, 2016; Li, & Marasteanu, 2004; Piłat & Radziszewski, 2010; Turk & Tusar, 2016).

In the evaluation of the road pavement behaviour at sub-zero temperatures, the speed of moving vehicles is less important than the stress from the load. Therefore, to assess the low-temperature properties of bituminous binders, it is reasonable to analyse stiffness of bitumen and asphalt mixture at low temperature under static load and ability to reduce the thermal stress in time as a relaxation (Pszczola, Jaczewski, Rys, Jaskula, & Szydlowski, 2018). The shape of the stiffness modulus curve as a function of the load time depends on the predominance of viscous or elastic properties at a given temperature. It is considered that improving the properties of low-temperature bituminous binders can be achieved by decreasing the elastic component and increasing the share of viscous components.

Already from the 1950s, the principle of determining asphalt stiffness at low temperatures in the creep test under static load was known, while design constraints made such measurement extremely difficult. In the years 80–90 of the 20th century, the Höppler consistometer was used to study the S under static load, which allowed creep measurements at sub-zero temperatures. It was only at the end of the 20th century that the SHRP project managed to develop a research device with sufficient accuracy and easy to use. The method developed in the USA is the measurement of creep stiffness performed on the asphalt binder bars in the BBR (Bending Beam Rheometer) at low temperatures (Asphalt Institute, 1997). This method is the basis for the low-temperature behaviour of bituminous binders in Superior Performing Asphalt Pavements (Superpave) Performance Grade (PG) specification. In the Superpave assumptions, the stiffness of the bitumen after long-term ageing is one of the leading parameters when it comes to low-temperature cracks, while the ability to stress relaxation was to eliminate the use of deeply oxidised bitumen. Superpave system adopted the PG criteria for old, aged pavements. It was assumed that bitumen in the pavement layer after 12–15 years of service operation will be aged and will become stiffer and susceptible to cracks (McGennis, Shuler, & Bahia, 1994).

However, the Superpave specification was developed when modifications of bitumens were used occasionally and sparingly, today the situation is different. Most of the binders are somehow modified, e.g. air is blown, Styrene-Butadiene-Styrene (SBS) -polymer modified, gelled, wax modified, bio-modified, bio-fluxed (Hesp, Soleimani, Subramani, Phillips, Smith, Marks, & Tam 2009). In research of Hesp & Subramani, 2009), it is proved that some modifications of bitumens can improve parameters obtained from an original BBR test but can increase the number of low-temperature cracks. Otherwise, some modified bitumen can exhibit weak properties in BBR test, but the application can reduce the number of low-temperature cracks. It is, therefore, Hesp & Subramani (2009) suggested improving the procedure of BBR test for assessing temperature properties than those proposed in the Superpave. Nevertheless, any modification of existing criteria in *EN-12591:2009 Bitumen and Bituminous Binders – Specifications for Paving Grade Bitumens* and *EN-14023:2010 Bitumen and Bituminous Binders – Specification Framework for Polymer Modified Bitumens* standards should be proceeded by a full investigation of the bitumens available in the market.

1. Objectives

The main objective of the paper is the proposition of low-temperature requirements for bitumens in the region of Central and Eastern Europe by Superpave specification. The analysis was conducted based on the research project "*Road Bitumen and Modified Bitumen in the Polish Climatic Conditions*" (research grant from the National Centre for Research and Development and the General Directorate of National Roads and Motorways in Poland for 2016–2018). In that research project, the full research plan of neat bitumens, SBS-polymer and polymer-rubber modified bitumen and multigrade bitumen types were performed. All binders were produced by Polish refineries. Based on the research, by the principles of Superpave for low temperatures, climate zones in Poland were shown (Pszczoła, Judycki, & Ryś, 2016; Pszczoła, Ryś, & Jaskuła, 2017). Analogous zones for other countries from the Central and Eastern Europe region as Estonia and Belarus (Kontson, Lill, Sillamate, Koit, Freiberg, & Aavik, 2016) In the second part of the paper, the results of functional PG tests and *EN* standard test of bituminous binders are presented and discussed. This allowed the selection of suitable binders that meet the low-temperature requirements for specified climate zones.

2. Performance grade of bitumens in Middle Europe

2.1. Performance grade resulting from climatic conditions

The analysis of climatic data in Poland from the period of 30 years was carried out (Pszczoła, Ryś, & Jaskuła, 2017). The methodology adopted to determine the functional type of bitumen based on climatic data in Poland by the original Superpave method (Asphalt Institute, 1997, 2011; Solaimanian, 1994) and its subsequent modification of LTPP-SMP (Long-Term Pavement Performance Program (U.S.), 1998; Mohseni, 1998) was as follows:

1. Adoption of the data analysis period of 30 years (years 1986 to 2015) and acquisition of temperature data for this period from meteorological stations located on the territory of Poland. The period of available data could not be shorter than 20 years;
2. Qualitative analysis of the obtained air temperature data from individual meteorological stations;
3. Determination of minimum air temperatures during each analysed year and maximum values of the 7-day average of the highest daily air temperatures occurring for 7 consecutive days during each analysed year;
4. Accepting different levels of probability in depending on the road rank: 95% for motorways, 80% for main national roads, 50% for other roads;
5. Determination of occurrence of minimum and maximum annual air temperatures over the entire analysis period (minimum 20 years);
6. Verification whether air temperature distributions are normal distributions;
7. Determination of the depth of analysis for a given asphalt layer in the pavement construction. The depth at which the upper surface

of the given asphalt layer is assumed to determine the minimum temperature;
8. Determining the value of the lower PG temperature in a given layer in the pavement using the computational relationships by Superpave;
9. Based on the temperature values obtained, classify bitumens in intervals of 6 ºC, by the requirements of *AASHTO M 320-05 Standard Specification for Performance-Graded Asphalt Binder*.

Climatic zones were determined for particular probability levels, and separately for individual asphalt layers: wearing course, binder course and base course. Figure 1 presents zones of PG grade in Poland for the level of probability of . The level for motorways was assumed as a temporary value, and it is recommended to increase the level of probability to 98% in a few years. When the value of the maximum PG grade for wearing course increase to +58 and the minimum PG decrease to −34 in certain areas (Pszczoła, Ryś, & Jaskuła, 2017).

Some European countries also developed climatic zones by the Superpave method from this part of Central and Eastern Europe as part of their research and development (Błażejowski, & Wójcik-Wiśniewska, 2018; Leonovich, & Melnikova, 2012). The division of the country into climate zones by the PG system, to which the authors obtained access, was performed in addition to Poland, Estonia and Belarus (Table 1).

Table 1. Climatic zones by the Performance Grade system for wearing courses in Central Eastern European countries

Probability level	Belarus			Estonia		Poland		
	Zone							
	1	2	3	1	2	1	2	3
	N-E	C, W	S–E	E	N–E, W, S	E, N–E	C, S, W	Coast
98%	52–34	52–28	58–28	58–34 58–40	58–28 58–34	52–34 58–34	52–28 58–28	52–22
95%	–	–	–	–	–	52–28	52–28	52–22
80%	–	–	–	–	–	52–28	52–22	46–22 46–16
50%	–	–	–	–	–	46–22	46–22 46–16	46–16

Note: *N, E, S, W* – the area of the country respectively located in the North, East, South and West of the country; *C* – the area in the centre of the country.

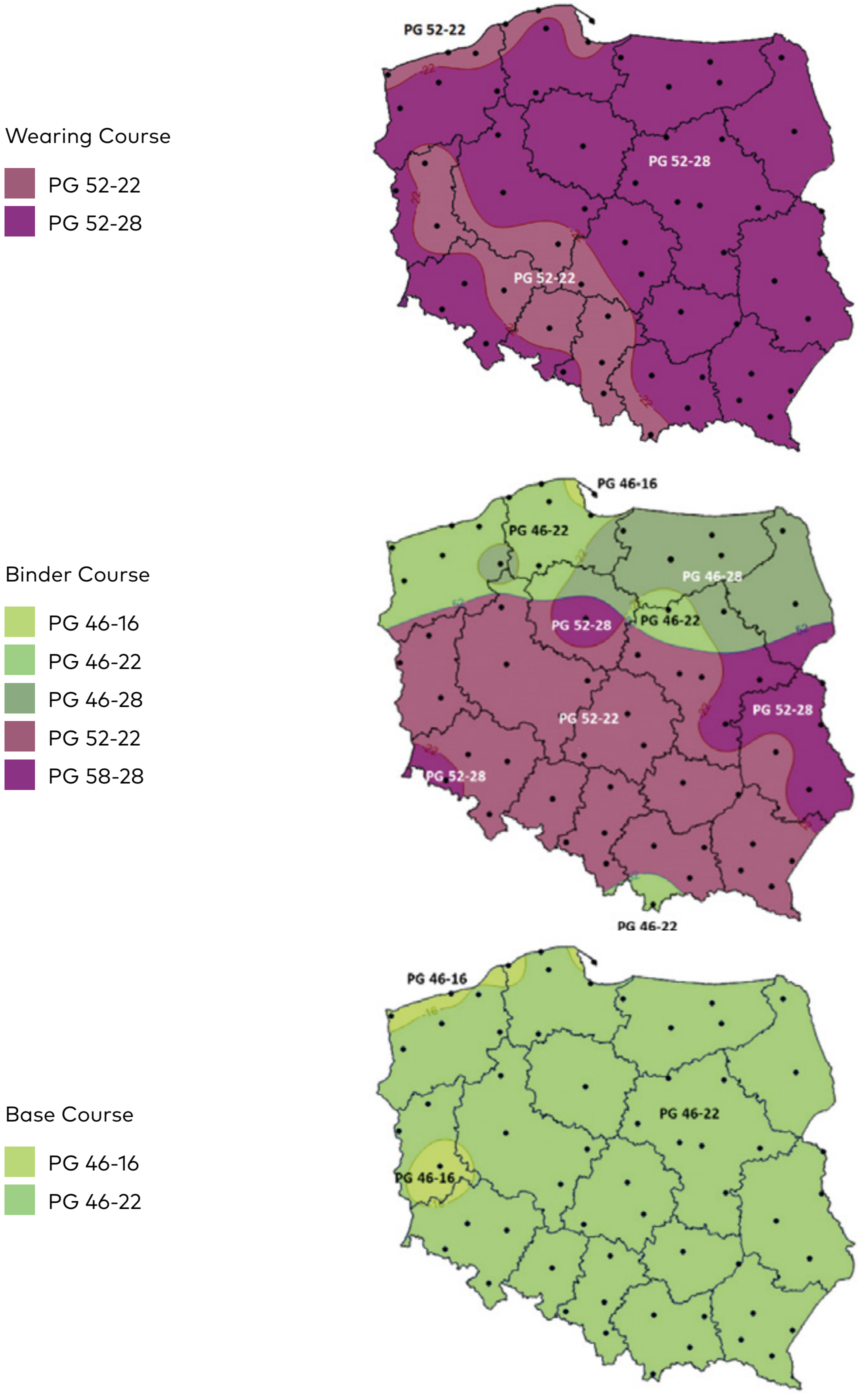


Figure 1. Climatic zones for the Polish area for the Performance Grade

Figure 1 and Table 1 show that in Central and Eastern Europe, depending on the assumed level of probability, the lowest temperatures of the required functional type PG vary from −16 °C to −40 °C.

2.2. Performance grade and basic properties of bitumens

Various types of bitumens available in the Polish market, including neat, SBS-polymer modified, polymer-rubber-modified and multigrade were tested. A similar type of bitumen especially neat bitumen is used in the rest part of Europe (Błażejowski, & Wójcik-Wiśniewska, 2018; Delfosse, Drouadaine, Faucon-Dumont, Largeaud, Eckmann, Planche, Turner, & Glaser, 2016; Kontson, Lill, Sillamate, Koit, Freiberg, & Aavik, 2016). The properties of bitumens performed by the European classification system and PG (by Superpave) system are shown in Table 2.

European standards produce all of the evaluated bitumens. There were only tested by PG specification. As can be concluded from the comparison of Table 2 with Figure 1 and Table 1, tested bitumens meet PG performance requirements in the range of high temperatures.

Table 2. Properties of tested bitumens

Binder classification by *EN* standard	Binder classification by PG standard	Penetration at 25°C, 0.1 mm		Softening point by R&B, °C		Fraass Breaking Point, °C		Elastic recovery at 25°C, %	
		Measured	Required	Measured	Required	Measured	Required	Measured	Required
20/30	82–10	26	20–30	62	55–63	−7	NR	–	–
35/50	70–10	41	35–50	55	50–58	−15	≤ −5	–	–
50/70	64–16	62	50–70	49	46–54	−9	≤ −8	–	–
70/100	64–22	82	70–100	46	43–51	−14	≤ −10	–	–
MG 35/50-57/69	82–*	43	35–50	65	57–69	−20	≤ −15	–	–
MG 50/70-54/64	82–*	52	50–70	63	54–64	−20	≤ −17	–	–
PMB 10/40-65	82–10	32	10–40	65	≥ 60	−16	≤ −5	71	≥ 60
PMB 25/55-60	88–10	31	25–55	69	≥ 60	−14	≤ −10	82	≥ 60
PMB 25/55-60 CR	82–22	41	25–55	61	≥ 60	−18	≤ −10	80	≥ 60
PMB 45/80-55	76–22	59	45–80	60	≥ 55	−17	≤ −15	85	≥ 70
PMB 45/80-55 CR	82–22	49	45–80	62	≥ 55	−21	≤ −15	98	≥ 70
PMB 45/80-65	82–22	47	45–80	76	≥ 65	−17	≤ −15	84	≥ 80

Note: *MG* – multigrade; *PMB* – SBS-polymer modified bitumen; *CR* – crumb rubber; * – beyond classification in the range of low temperatures, higher than 0°C.

Otherwise, in low temperatures, the performance properties of bitumens are unsatisfactory; thus, the detailed analysis of low-temperature properties of the bitumens was performed.

3. Evaluation of low-temperature properties of bituminous binders

The basis of the analysis was an extended static load creep test carried out in the BBR. The prismatic specimen was prepared with dimensions of 125/12.5/6.25 mm. Binder was first aged by the Rolling Thin Film Oven Test (RTFOT) method and then aged by Pressure Aging Vessel (PAV) method. Flexural creep tests are performed at five temperatures: −6 °C, −12 °C, −18 °C, −24 °C, and −30 °C. The specimen was preloaded by 30±5 mN, and then a constant test load of 980±50 mN was applied in the centre of the beam span. During the test, the beam deflection was continuously recorded. Based on geometry and deflection value, the flexural creep stiffness characteristic was calculated.

The S of the bitumen depends on the time and the load amount. Due to the resistance of bitumen to low temperatures, it is essential to decreasing S and increasing the ability to the stresses relaxation of the bitumen. An isotherm of the bitumens S was plotted in function of the load time to evaluate the temperature properties. In Figures 2–4 the function of S in loading time for bitumens with high, medium and low penetration are presented successively. For the comparison of all bituminous binders, the

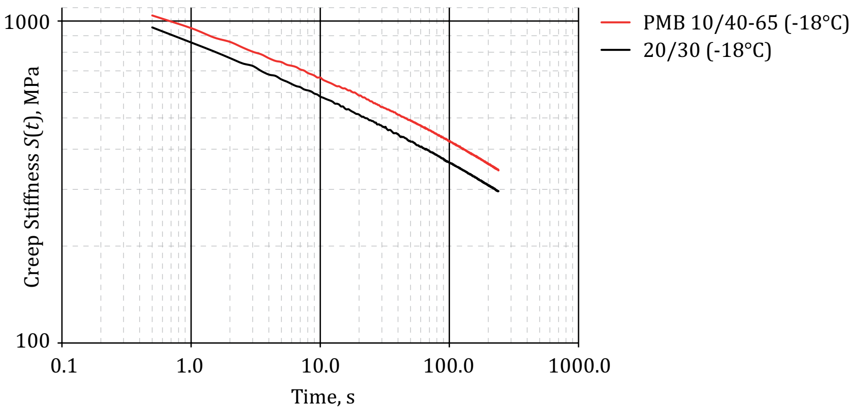


Figure 2. Curves of the creep stiffness modulus versus time for hard consistency bitumens

stiffness test results were taken at −18 °C, whereas for the multigrade bitumen results are also shown for test temperatures −24 °C and −30 °C.

By analysing the *S* of bitumen at low temperatures, it can be said that for the harder binders, the less slope of the function of *S* in loading time was observed. The less change in the *S* of the bitumen in the function of the constant load time occurs reduced ability to stress relaxation. Based on the obtained results, it is seen that at −18 °C the highest stiffness level and the least stresses relaxation show bitumen 20/30, 35/50 and SBS-polymer modified bitumen 10/40-65 (Figures 2 and 3). It was shown that the neat bitumens: 20/30, 35/50 and SBS-polymer modified bitumen 10/40-65 exhibit high stiffness level and reduced ability to stress relaxation. Such behaviour is typical for deeply oxidised bitumen, which was to be eliminated in the Superpave specification by both criteria *m*-value and *S* – stiffness (McGennis, Shuler, & Bahia, 1994).

The properties of soft and medium hardness binders are very diverse (Figures 3 and 4). In the case of neat bitumen, it can be noted that the 50/70 and 70/100 bitumen at short load times show a comparable *S*. On the other hand, the bitumen 70/100 with a longer load time exhibits reduced stiffness, which increases relaxation of stresses (higher slope of isotherms). In contrast to neat bitumen, SBS-polymer modified bitumen exhibits, in most cases, comparable or reduced stress relaxation. This behaviour is mainly due to the introduction into the bitumen the SBS modifier, which is the elastomer. The SBS polymer stiffening the bitumen and decreases it is Fraass Breaking Point, which can imply indirectly at the increase of tensile strength. The SBS modified bitumen with crumb rubber additive (PMB CR) are exhibited different properties. It is noted that the isotherms of *S* are much more inclined compared to the counterparts that are modified only by the SBS polymer. During the modification of the bitumen with the addition of crumb rubber from used car tires, there is a partial melting process (devulcanized) of rubber (Gaweł, Piłat, Radziszewski, Kowalski, & Król, 2011; Radziszewski, Piłat, Sarnowski, Zborowski, & Ruttmar, 2015). These rubbers modify the bitumen binder as the polymer SBS and the antioxidants contained in rubber improve resistance to the ageing of the binders. The remaining unvulcanised part of the rubber works in bitumen as flexible filler. Due to the use of soft bitumen for rubber modification, such binders show both the characteristics of elastomer-modified bitumen and typical soft road bitumen. This behaviour is reflected in reduced stiffness at low temperatures and increased stress relaxation.

The multigrade (MG) bitumens exhibit different properties from other binders. In the production process, these binders are composed to show a low-temperature sensitivity (positive Penetration Index). This can be achieved by oxidation of the part bitumen, which results in

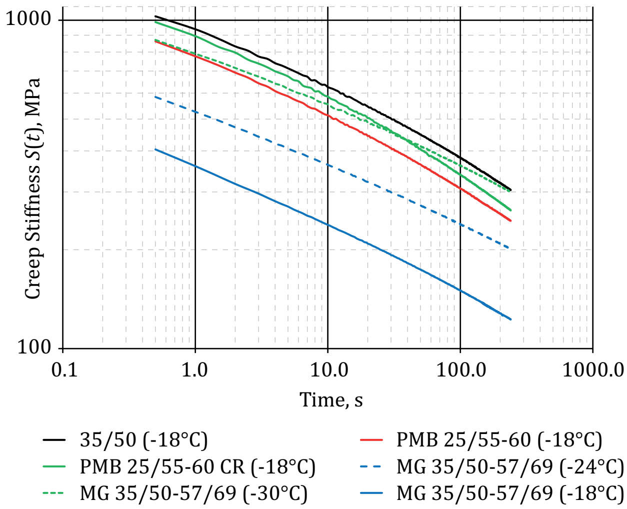


Figure 3. Curves of the creep stiffness modulus versus time for medium consistency bitumens

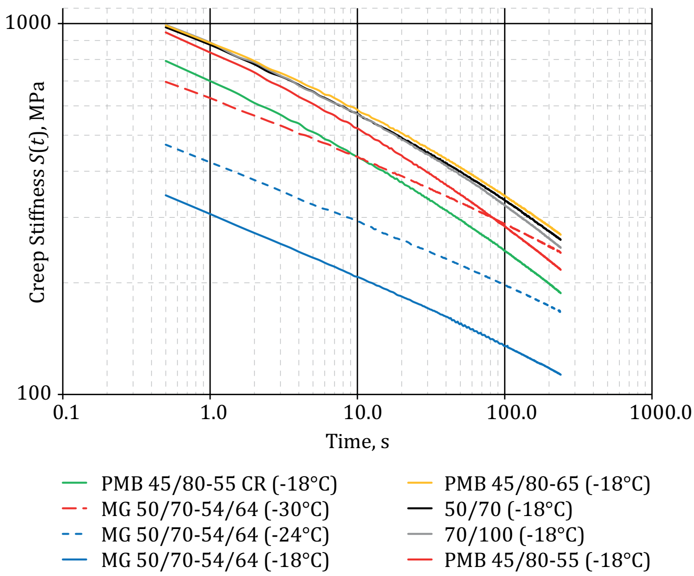


Figure 4. Curves of the creep stiffness modulus versus time for soft consistency bitumens

increased asphaltenes content and subsequent mixing of lighter fractions, which affect the reduction of consistency. As a result, the stiffer binder is obtained at a higher temperature, while with reduced stiffness at low temperatures. In Figures 3 and 4 it can be noted that the multigrade bitumen show comparable stiffness with their counterparts' binders at an average temperature lower of –12 °C. However, the slope of the creep stiffness curve is much lesser than in the case of reminder bitumens what indicates that MG bitumens have much less ability to stress relaxation.

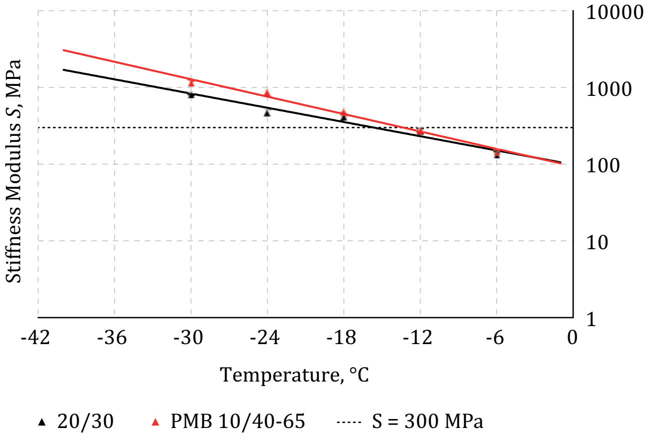
To determine the temperature of the less PG (by Superpave) the flexural creep stiffness test is conducted in the BBR rheometer. In BBR test the flexural creep *S* and *m*-value is determined for binders after the PAV ageing. The creep *S* in 60 seconds of the load (creep) of the binders should be no more than 300 MPa, and the stiffness change expressed as *m*-value should be above than 0.300. At present, in Superpave, the lesser PG is determined by taking a temperature at which the *S* equals 300 MPa, and the *m*-value equal 0.300 and is reduced by –10 °C. Of the above two specified temperatures, the higher is selected as a critical one. Figures 5–7 show the dependencies of the *S* and the *m*-value parameter in the function of temperature. The horizontal dotted line plots the Superpave criteria.

The difference between limiting temperatures obtained from *S* and *m*-value at 60 seconds loading can be a parameter to estimate the resistance to cracking. Bitumens with the diminished value of results in better low-temperature performance. The summary of parameter for analysed bitumens is given in Figure 8, and the summary of low-temperature performance grade is shown in Table 3.

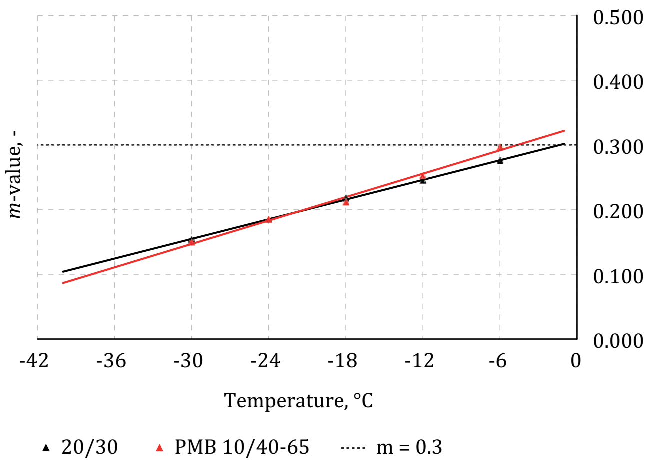
Table 3. Low-temperature performance grade of bitumens tested

Binder	BBR critical temperature for		Superpave PG grade
	S = 300 MPa	*m* = 0.300	
	t = 60 s		
20/30	–14	–1	–10
35/50	–15	–6	–10
50/70	–15	–11	–16
70/100	–15	–14	–22
PMB 10/40-65	–15	–5	–10
PMB 25/55-60	–14	–4	–10
PMB 45/80-55	–14	–14	–22
PMB 45/80-65	–15	–12	–22
PMB 25/55-60 CR	–15	–13	–22
PMB 45/80-55 CR	–21	–12	–22
MG 35/50-57/69	–20	beyond classification	beyond classification
MG 50/70-54/64	–29	beyond classification	beyond classification

Analysing the results of binder properties determined on the basis of tests in the BBR (at S = 300 MPa and m = 0.300, PG by Superpave), it should be noted that the tested neat bitumens show unfavourable low-temperature values, too high in relation to the minimum temperatures required for application in climatic conditions of Central and Eastern Europe. In the case of bitumen type 20/30, 35/50, PMB 10/40-65, PMB



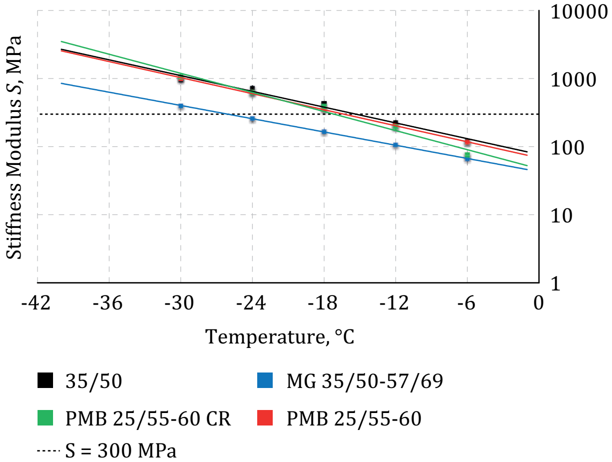
Stiffness modulus



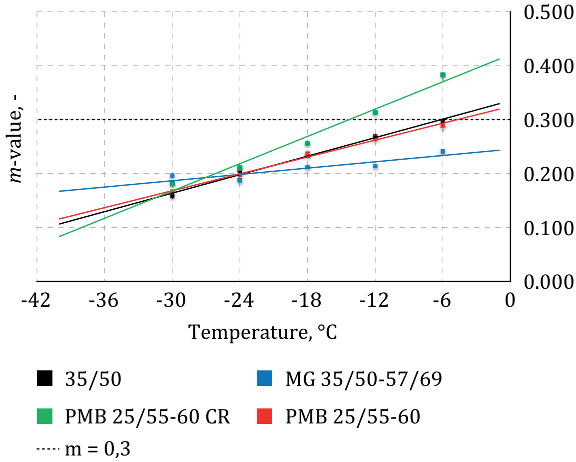
m-value

Figure 5. Stiffness modulus and the *m*-value parameter at 60 seconds loading from the Bending Beam Rheometer test versus temperature for hard consistency bitumens

25/55-60 the low-temperature performance grade is below −10 °C, and it mainly results from slower relaxation of the material expressed by *m*-value. It is also visible in the relatively wide differences between limiting temperatures obtained from *S* and *m*-value is highest for this group of bitumens. It can result from the adverse influence of the oxidation process during the production of this bitumen on the rheological properties. Modification by SBS elastomers has a minor



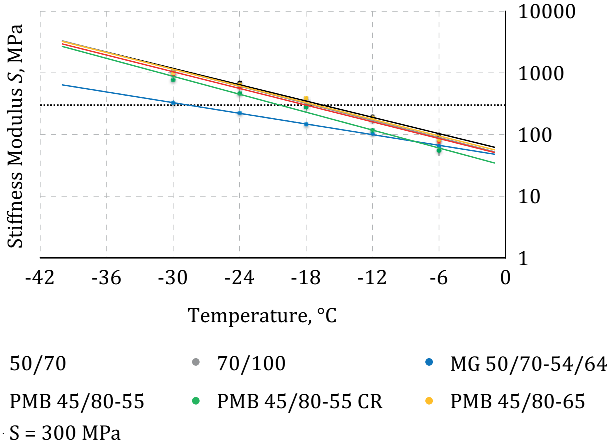
Stiffness modulus



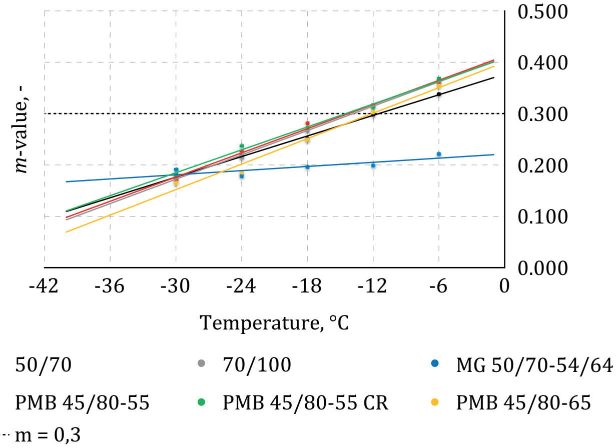
m-value

Figure 6. Stiffness modulus and *m*-value parameter at 60 seconds loading from the Bending Beam Rheometer test versus temperature for medium consistency bitumens

influence on rheological properties of bitumens. For example, bitumens, PMB 45/80-55 and PMB 45/80-65 did not obtain significant differences in low-temperature properties. Modification by crumb rubber can reduce the bitumen stiffness at low temperatures and increase the ability to stress relaxation. Both elastomers SBS and crumb rubber decrease Fraass Braking Point (Table 2) what result in improvement of the resistance on low-temperature cracking in compare to neat bitumens.



Stiffness modulus



m-value

Figure 7. Stiffness modulus and *m*-value parameter at 60 seconds loading from the Bending Beam Rheometer test versus temperature for soft consistency bitumens

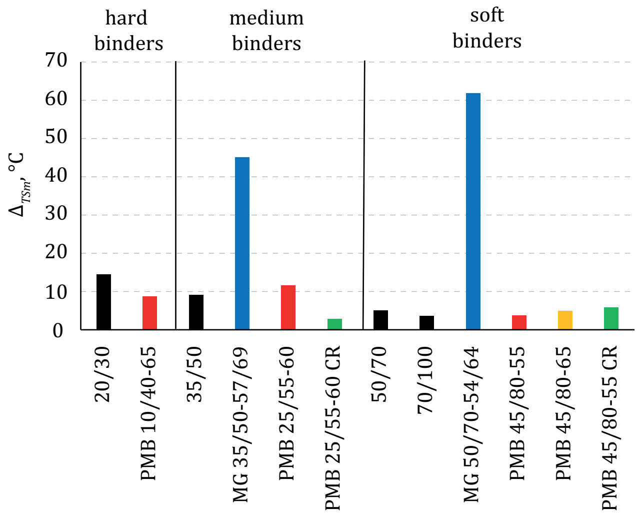


Figure 8. Differences between limiting temperatures obtained from stiffness modulus and *m*-value parameter

Particular bitumen types are the multigrade bitumens MG 35/50 and MG 50/70, which are characterised by a favourable less value of *S* at very low operating temperatures and very less value of Fraass Breaking Point. However, these bitumens obtain the stress relaxation much less than in the case of reminded bitumens so their application can be tricky and can result in a considerable amount of low-temperature cracks in the future.

4. Proposal for functional classification of bitumens available on the market of Central and Eastern Europe

The assignment of bitumens for asphalt pavement in Poland is proposed in Table 4. The proposal takes into account the climatic conditions in Poland and performance properties of tested bitumens. The choice of the type of bituminous binders for the construction layers of road pavements was made by assuming different levels of probability of the lowest pavement temperatures in Central and Eastern Europe. It was made by concerning the rank of a road defined by the technical class. For motorways, the risk of low-temperature cracking should be as low as possible. Therefore, a probability of 95% was assumed that means that the minimum or maximum air temperature may occur every 20 years.

Table 4. Proposal of bitumens assignment regarding performance properties and climatic conditions

Asphalt layer	**Bitumen type by traffic load, type and location of the road**				
	Low traffic load (below 500 000 ESALs)	**Medium and high traffic load (above 500 000 ESALs)**			
		Other roads		**Motorways**	
	Bitumen type by European standards Performance Grade climatic zone (*p* = 50%)	**Bitumen type by European standards**	**Performance Grade climatic zone (*p* = 80%)**	**Bitumen type by European standards**	**Performance Grade climatic zone (*p* = 95%)**
Asphalt base course	50/70[1)] PG52-22	20/30[1)] PMB 10/45-60 [1)] 35/50[1)] PMB 25/55-60[1)] PMB 25/55-80[2)] 50/70 PMB 45/80-60[3)] PMB 45/80-80[2)] PMB 65/105-80[2)]	PG 52-16	PMB 10/45-60 [1)] 35/50[1)] PMB 25/55-60[1)] PMB 25/55-80[2)] 50/70[1)] PMB 45/80-60[3)] PMB 45/80-80[2)] PMB 65/105-80[2)]	PG 58-22
		PMB 10/45-60 [1)] 35/50[1)] PMB 25/55-60[1)] PMB 25/55-80[2)] 50/70[1)] PMB 45/80-60[3)] PMB 45/80-80[2)] PMB 65/105-80[2)]	PG 52-22		
Binding course	50/70[1)] PG52-22	20/30 [2,3)] PMB 10/45-60 [2,3)] 35/50 PMB 25/55-60[3)] PMB 25/55-80[3)] 50/70 PMB 45/80-60 PMB 45/80-80	PG 52-16	PMB 10/45-60 [1)] 35/50[1)] PMB 25/55-60[1)] PMB 25/55-80[2)] PMB 45/80-60[3)] PMB 45/80-80[2)]	PG 64-22
		PMB 10/45-60 [2,3)] 35/50 PMB 25/55-60[3)] PMB 25/55-80[3)] 50/70 PMB 45/80-60[3)] PMB 45/80-80[3)]	PG 52-22	PMB 45/80-60[3)] PMB 45/80-80[2)] PMB 25/55-80[2)]	PG 64-28

Asphalt layer	Bitumen type by traffic load, type and location of the road				
	Low traffic load (below 500 000 ESALs)	**Medium and high traffic load (above 500 000 ESALs)**			
	Other roads			**Motorways**	
	Bitumen type by European standards Performance Grade climatic zone (*p* = 50%)	**Bitumen type by European standards**	**Performance Grade climatic zone (*p* = 80%)**	**Bitumen type by European standards**	**Performance Grade climatic zone (*p* = 95%)**
Wearing course	50/70[1)] 70/100 PG52-22	50/70 PMB 45/80-60[3)] PMB 45/80-80[2)] PMB 65/105-60[2)] PMB 65/105-80[2)]	PG 58-22	PMB 45/80-60[3)] PMB 45/80-80[2)] PMB 65/105-60[2)] PMB 65/105-80[2)]	PG 64-22
		PMB 45/80-60[3)] PMB 45/80-80[2)] PMB 65/105-60[2)] PMB 65/105-80[2)]	PG 58-28	PMB 45/80-60[3)] PMB 45/80-80[2)] PMB 65/105-60[2)] PMB 65/105-80[2)]	PG 64-28

Note:
2) The low-temperature performance grade should be improved in comparison to the test results presented in the paper;
3) Bitumen is available at the Polish market, but the performance grade of bitumen was not tested in the research programme;
4) It is proposed to replace bitumen types PMB 45/80-55 and PMB 45/80-65 with similar performance properties into one special bitumen PMB 45/80-60.

Correspondingly, for the remaining national and local roads, fewer probabilities were assumed at the level of 80% and 50%.

Some of the bitumens cannot meet the performance requirements in the range of low temperatures, and they are marked in Table 4. Basing on the reports published by Polish bitumen producers and literature the low-temperature properties of those bitumens should be improved (Błażejowski, & Wójcik-Wiśniewska, 2018). Table 4 also includes bitumen classes that were excluded in the laboratory test. The performance grade for those bitumens was assumed based on properties of tested bitumens given in Table 2, and that assumption should be verified in further research.

Table 4 shows that at present there are no binders that should be used in regions with a minimum asphalt layer temperature of −40 °C and −34 °C such as Estonia or Belarus (Table 1). For those temperature zones, an asphalt binder with unique low-temperature properties should be developed and produced. Particular attention should be paid to extensive areas of Central and Eastern Europe where the surface layers reach the temperature of −28 °C. In those areas, soft bitumens modified by a rubber or high-polymer modified bitumen may obtain desirable low-temperature properties, but more research should be done in this field.

Conclusions

The following conclusions based on research and analyses were stated:

1. The climate conditions in Central and Eastern Europe are characterised by the occurrence of very low temperatures in winter, which is disadvantageous due to the durability of the road pavement structure. Low-temperature cracking is common distress of pavements, and thus some efforts to improve the low-temperature properties of bitumens should be taken, as support of using Performance Grade specification in assessing the bitumen.
2. Neat bitumens 35/50, 50/70 are used in the binder, and base course layers and Styrene-Butadiene-Styrene polymer modified bitumen PMB 45/80-55 is increasingly used for wearing course layer in Poland. By the performance grade system based on Polish climate conditions, those bitumens do not fulfil enough the resistance to low-temperature cracking despite that they meet European standards requirements.
3. The requirements of European standards for Fraass Breaking Point seems to be insufficient and should be verified or extend by other extra requirements. The required bitumen breaking point temperatures used at the European standards are much higher than minimum temperatures that occur in winter conditions. Tested bitumens exhibit the much lesser value of Fraass Braking Point (insufficient) than required in European standards.
4. The criterion of *m*-value decided about low-temperature performance grade of all tested bitumens. The difference between limiting temperatures determined for stiffness modulus and *m*-value range from 2 °C to 15 °C for neat and modified bitumens and can be extremely high (up to 60 °C) in the case of multigrade bitumens.
5. Multigrade bitumen types exhibit very low Fraass Braking Point and lesser value of Bending Beam Rheometer stiffness modulus at low temperatures, which could indicate advantageous low-temperature properties. Otherwise, the *m*-value parameter for multigrade bitumen type indicates that mixtures with those bitumen will exhibit less relaxation and increase in tensile stresses what can increase low-temperature cracking. Therefore

the multigrade bitumens by Performance Grade specification are not recommended to use in Poland.

6. Modification of bitumens by copolymer Styrene-Butadiene-Styrene or by crumb rubber and Styrene-Butadiene-Styrene both have a minor effect on Bending Beam Rheometer test results at low temperatures for tested bitumens available on the Polish market. In consequence, Performance Grade values are comparable both, for polymer modified and neat bitumens with the same consistency. Otherwise, modified asphalt binders have a lesser value of Fraass Braking Point what will result in improvement of the resistance to low-temperature cracking of asphalt pavements.
7. The proposal of authors of the asphalt binder selection for road pavement construction layers in Poland was presented, and it can be extended for the Central and Eastern Europe road pavement construction layers. Particular attention should be paid to those extensive areas where the surface layers reach the temperature of −28 °C. In those areas, soft bitumens modified by rubber and polymer or high-polymer modified bitumen may obtain desirable low-temperature properties.

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REFERENCES

AASHTO M 320-05 Standard Specification for Performance-Graded Asphalt Binder

Asphalt Institute (1997). Superpave: Performance Graded Asphalt: Binder Specification and Testing. Asphalt Institute.

Asphalt Institute (2011). *The Asphalt Binder Handbook*. Manual Series No. 26 (MS-26)

Błażejowski, K., & Wójcik-Wiśniewska, M. (2018). *Poradnik Asfaltowy*, Orlen Asfalt Sp. z o.o. (in Polish)

Delfosse, F., Drouadaine, I., Faucon-Dumont, S., Largeaud, S., Eckmann, B., Planche, J.P., Turner, F., & Glaser, R. (2016). Impact of the bitumen quality on the asphalt mixes performances, *6th Euroapshalt and Eurobitumen Congress in Prague* 2016. https://doi.org/10.14311/EE.2016.049

EN-12591:2009 Bitumen and Bituminous Binders – Specifications for Paving Grade Bitumens

EN-14023:2010 Bitumen and Bituminous Binders – Specification Framework for Polymer Modified Bitumens

Gajewski, M., Sybilski, D., & Bańkowski, W. (2015). The influence of binder rheological properties on asphalt mixture permanent deformation. *The Baltic Journal of Road and Bridge Engineering* 10(1): 54–60. https://doi.org/10.3846/bjrbe.2015.07

Gaweł, I., Piłat, J., Radziszewski, P., Kowalski, K. J., & Król, J. B. (2011). Rubber modified bitumen. *In Polymer modified bitumen* (pp. 72-97). Woodhead Publishing. https://doi.org/10.1533/9780857093721.1.72

Hesp, S. A., & Subramani, S. (2009, July). Another look at the bending beam rheometer for specification grading of asphalt cements. In *Proceedings of 6th MAIREPAV Conference*, Torino, Italy.

Hesp, S. A., Soleimani, A., Subramani, S., Phillips, T., Smith, D., Marks, P., & Tam, K. K. (2009). Asphalt pavement cracking: analysis of extraordinary life cycle variability in eastern and northeastern Ontario. *International Journal of Pavement Engineering*, 10(3), 209-227. https://doi.org/10.1080/10298430802343169

Kontson, K., Lill, K., Sillamate, S., Koit, M., Freiberg, R., & Aavik, A. (2016). Suitable bitumens for Estonian climate conditions, *International Scientific and Technical Conference „Highways: Safety and Reliability"*, 24–25 November 2016, Minsk, Belarus.

Król, J. B., Radziszewski, P., Kowalski, K. J., Sarnowski, M., & Czajkowski, P. (2014). Laboratory and field investigations of polymer and crumb rubber modified bitumen. *Journal of Civil Engineering and Architecture*, 8(10). https://doi.org/10.17265/1934-7359/2014.10.014

Largeaud, S., Faucon-Dumon, S., Eckmann, B., Hung, Y., Lapalu, L., & Gauthier, G. (2016). Low temperature and aging properites of polymer-modified binders, *E&E Congress 2016, 6th Eurasphalt & Eurobitume Congress*, 1–3 June 2016, Prague, Czech Republic. https://doi.org/10.14311/EE.2016.325

Leonovich, I., & Melnikova, I. (2012). Influence of Temperature on the Formation of Damages in Asphalt Concrete Pavements under Climatic Conditions of the Republic of Belarus, *The Baltic Journal of Road and Bridge Engineering* 7(1): 42–47. https://doi.org/10.3846/bjrbe.2012.06

Li, X., & Marasteanu, M. (2004). Evaluation of the low temperature fracture resistance of asphalt mixtures using the semi circular bend test (with discussion). *Journal of the Association of Asphalt Paving Technologists*, *73*.

Long-Term Pavement Performance Program (U.S.) (1998). *LTPP Data Analysis: Improved Low Pavement Temperature Prediction*, TechBrief, U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA-RD-97-104

McGennis, R. B., Shuler, S., & Bahia, H. U. (1994). *Background of SUPERPAVE Asphalt Binder Test Methods*, Report No. FHWA-SA94-069, Federal Highway Administration, Washington, D.C.

Mohseni, A. (1998). LTPP seasonal asphalt concrete (AC) pavement temperature models (No. FHWA-RD-97-103).

Piłat, J., & Radziszewski, P. (2010). *Asphalt pavements*. 2nd ed. Transport and Communication Publishers, Warsaw, Poland. (in Polish)

Pszczola, M., Jaczewski, M., Rys, D., Jaskula, P., & Szydlowski, C. (2018). Evaluation of asphalt mixture low-temperature performance in bending beam creep test. *Materials*, *11*(1), 100. https://doi.org/10.3390/ma11010100

Pszczoła, M., Judycki, J., & Ryś, D. (2016). Evaluation of pavement temperatures in Poland during winter conditions. *Transportation Research Procedia*, 14, 738-747. https://doi.org/10.1016/j.trpro.2016.05.342

Pszczoła, M., Ryś, D., & Jaskuła, P. (2017). Analysis of climatic zones in Poland with regard to asphalt performance grading. *Roads and Bridges-Drogi i Mosty*, 16(4), 245-264. https://doi.org/10.7409/rabdim.017.016

Radziszewski, P., Kowalski, K. J., Krol, J. B., Sarnowski, M., & Piłat, J. (2014). Quality assessment of bituminous binders based on the viscoelastic properties: Polish experience. *Journal of Civil Engineering and Management*, 20(1), 111-120. https://doi.org/10.3846/13923730.2013.843586

Radziszewski, P., Nazarko, J., Vilutienė, T., Dębkowska, K., Ejdys, J., Gudanowska, A., Halicka, K., Kilon, J., Kononiuk, A., Kowalski, K. J., Król, J. B., Nazarko, Ł., & Sarnowski, M. (2016). Future trends in road pavement technologies development in the context of environmental protection. *The Baltic Journal of Road and Bridge Engineering* 11(2): 160–168. https://doi.org/10.3846/bjrbe.2016.19

Radziszewski, P., Piłat, J., Sarnowski, M., Zborowski, A., & Ruttmar, I. (2015). Application of rubber modified binder to road pavement construction in Poland. *"Rubberized Asphalt Rubber 2015" Conference*, Las Vegas, USA

Radziszewski, P., Sarnowski, M., Król, J. B., & Kowalski, K. J. (2017). Bitumen Binders Properties–Middle-European Climate Requirements. In *Environmental Engineering. Proceedings of the International Conference on Environmental Engineering. ICEE* (Vol. 10, pp. 1-7). Vilnius Gediminas Technical University, Department of Construction Economics & Property. https://doi.org/10.3846/enviro.2017.145

Solaimanian, M. (1994). Development of SHRP Asphalt Research Program Climatic Databases (No. SHRP-A-685).

Turk, M. R., & Tusar, M. (2016). Effect of ageing on the low temperature properties of bitumen. E&E Congress 2016, *6th Eurasphalt & Eurobitume Congress*, 1–3 June 2016, Prague, Czech Republic. https://doi.org/10.14311/EE.2016.273