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Bitumen Binders Properties – Middle-European Climate Requirements

Piotr Radziszewski[1], Michał Sarnowski[2], Jan B. Król[3], Karol J. Kowalski[4]

Road Materials and Technology Division, Institute of Roads and Bridges,
Faculty of Civil Engineering, Warsaw University of Technology, Warsaw, Poland
E-mails: [1]p.radziszewski@il.pw.edu.pl (corresponding author);
[2]m.sarnowski@il.pw.edu.pl; [3]j.krol@il.pw.edu.pl; [4]k.kowalski@il.pw.edu.pl

Abstract. The article concerns the properties of bitumens and modified binders manufactured in Poland and used in Central and Eastern Europe for road paving. The aim of the article is to evaluate the properties of bituminous binders in terms of the climatic conditions of Central and Eastern Europe, taking the Polish climate as an example. In order to obtain a qualitative assessment of binders taking into account their role in the formation of road surface and its operating conditions in a wide range of temperatures, extensive research of the binders most commonly used in the construction of asphalt pavement were carried out. Aside from the results of standard tests, this article also presents the results of studies determining the functional properties of binders according to the SUPERPAVE method.
Based on the results, it was found that the bituminous binders meet the requirements specified in European standards and technical guidelines. The temperature range of viscoelasticity of all the tested bituminous binders is very wide and exceeds 80 °C. However, in view of the Polish climate, an unfavourable phenomenon is a shift in the temperature range of viscoelasticity towards higher operating temperatures, at the same time lowering the binder performance at low temperatures.

Keywords: bituminous binders, climatic conditions, functional properties.

Conference topic: Roads and railways.

Introduction

Bituminous binders and asphalt mixes are important materials used in road surfacing in Europe and the world. Approximately 95% of structural layers of road pavement built in Poland contains road asphalt or modified binders. The same scale of growing asphalt market is noted on other Baltic countries (Sivilevičius, Šukevičius 2009; Radziszewski *et al.* 2014). Binder properties have a major impact on the performance of road surfaces and determine its durability.

Bituminous binder properties undergo significant changes as a function of temperature and duration of the load, since – as a thermoplastic material – it exists in different rheological states, from liquid (viscous) to fragile elastic state. In intermediate temperature conditions, binders exhibit viscoelastic properties, i.e. both those of viscous liquids and those of elastic solids. From the point of view of road usage, it is beneficial if the range of viscoelasticity of bituminous binders is sufficiently wide to correspond with the climatic conditions of the particular region where the binder is used (Piłat, Radziszewski 2010). In the case of Polish climatic conditions, it means maintaining the state of viscoelasticity within the temperatures between -30 °C and +60 °C. In the case of Estonia, the lowest pavement temperature reaches -40 °C (Kontson *et al.* 2016). Additionally, binders should exhibit high durability and fatigue life properties, which provide resistance to cracking and deformation of the pavement, high cohesion and adhesion in the operating temperature range, and resistance to short and long term ageing (Read, Whiteoak 2003). The normative requirements currently in force for bituminous binders are not sufficient for the evaluation of the quality of asphalt in a wide range of temperatures (Radziszewski *et al.* 2014; Król *et al.* 2013).

In 2009–2011, a comprehensive study of binders manufactured in Polish refineries, commonly used in the construction of wearing courses, binder courses and base courses of pavement, was carried out at Warsaw University of Technology on behalf of the General Directorate for National Roads and Highways (Poland). One of the aims of the project was to analyse the technical characteristics of binders. A comprehensive research was carried out concerning the normative and rheological properties of bituminous binders available on the market and most commonly used in the construction of asphalt pavement. The research included basic tests of binders for classification purposes and advanced rheological studies, taking into account proposals for the measurement of functional characteristics (Kennedy, Huber 1994). Under the ongoing project titled "Road bitumens and modified binders in Polish climatic conditions" (research grant of the National Centre for Research and Development and the General Directorate for National Roads and Highways for 2016–2018), extensive studies of road bitumens and polimer modified binders (PmB) manufactured in Poland were carried out.

In order to obtain a more comprehensive qualitative assessment of binders taking into account their role in the road surface and its operating conditions in a wide range of temperatures, this article presents the results of studies determining functional characteristics in addition to the results of standard tests. A comparative analysis was presented concerning the functional characteristics of bituminous binders determined in the tests carried out in 2009–2011 and the properties of currently manufactured bituminous binders.

Climatic zones in Central and Eastern Europe as exemplify by the area of Poland

Central and Eastern Europe, which includes Poland, is characterised by transitional temperate climate, which is in between marine and continental climate types. In particular years, depending on the predominant air circulation, there is a marked dominance of marine or continental influence. There are very low temperatures in winter and very high temperatures in summer.

In the late 1990s, the climatic zones in Poland were delineated in accordance with the principles specified under the SHRP program carried out in the United States (Asphalt Institute 2001; Sybilski, Mirski 2000). Main idea of the SHRP/Superpave, differently than European specifications, is to relate binder properties with climatic region when the binder will be applied (McGennis *et al.* 1994; Radziszewski *et al.* 2014). The highest seven-day temperature and the lowest single-day temperature of the pavement were calculated for the wearing course (at the depth of 20 mm), the binder course (at the depth of 90 mm) and the base course (at the depth of 200 mm). On the basis of the obtained results, the climatic zones in Poland were determined with the highest and the lowest temperature relative to the layers of pavement structures: the wearing course (Fig. 1), the binder course (Fig. 2) and the base course (Fig. 3).

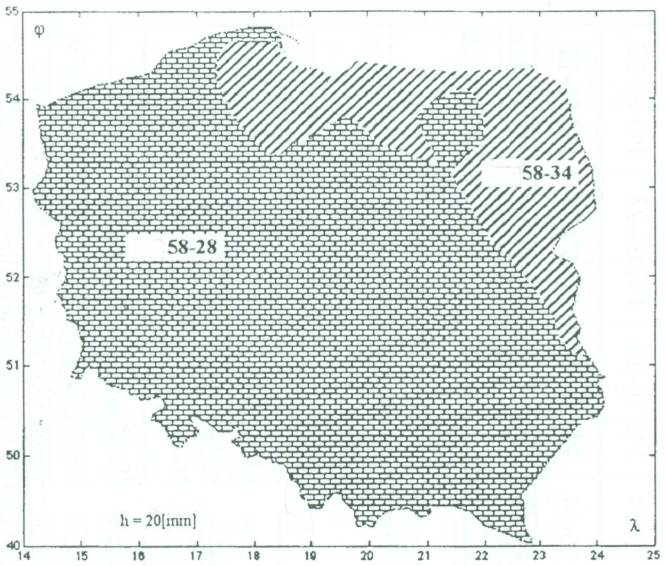

Fig. 1. Climatic zones in Poland for the wearing course (Source: Sybilski, Mirski 2000)

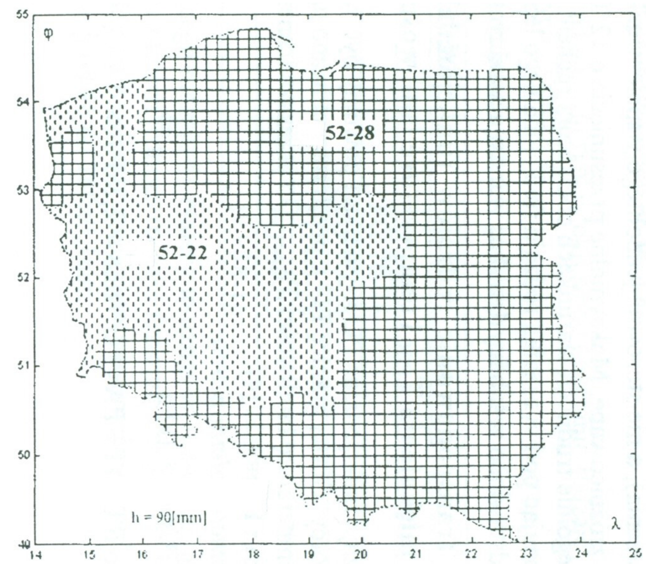

Fig. 2. Climatic zones in Poland for the binder course (Source: Sybilski, Mirski 2000)

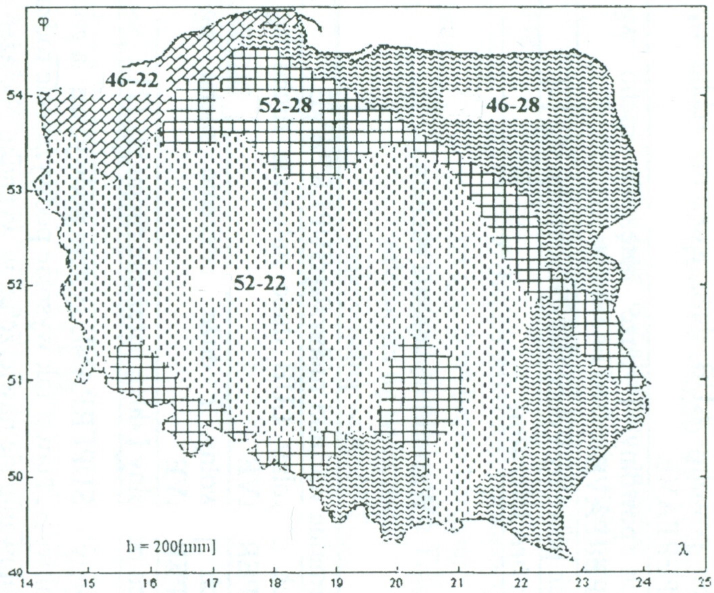

Fig. 3. Climatic zones in Poland for the base course (Source: Sybilski, Mirski 2000)

Figure 1 shows that the range of the most extreme pavement temperatures, identified according to the principles of Superpave, is between –34 °C and +58 °C. For this climatic zone, the performance grade PG of binder for the wearing course should be taken as PG 58-34.

Considering the calculated values of temperatures for all the structural layers of road pavement, it is important to note the occurrence of very low temperatures of pavement in Poland.

Standard properties of road and modified bitumens

Both aged and non-aged binders were tested. Samples of bituminous binders were taken from randomly selected manufacturers of asphalt mixes from all over Poland. Tests samples were taken from various grades of road and modified bitumens. The properties of the following binders were analysed: 20/30, 35/50, 50/70, PmB 25/55-60, PmB 45/80-55. The analysis of standard properties of bituminous binders concerned the following tests:

– penetration,
– ring and ball softening point,
– flashpoint,
– RTFOT aging resistance,
– brittleness temperature (Fraass breaking point),
– range of plasticity,
– penetration index,
– elastic recovery,
– ductilometer tensile strength tests,
– storage stability.

Penetration

The results of binder hardness testing showed various penetration values within hardness groups (Fig. 4), yet aside from single tested binders, they complied with the penetration requirements for the particular hardness groups. 20/30 asphalts exhibited penetration at 25 °C from 23.6 to 26.2 ·0.1 mm. Bitumens in the hardness group of 35/50 exhibited penetration from 38.0 to 43.3 ·0.1 mm. The 50/70 group of binders showed a high variation of penetration from 50.9 to 69.0 ·0.1 mm. The polimer modified bitumen PmB 25/55-60 exhibited penetration from 24.6 to 41.3, whereas the variation of penetration in 45/80-55 PmBs was from 46.0 to 55.5 ·0.1 mm.

Softening point

In general, the results of the softening point tests showed that bituminous binders complied with the standard requirements. Lower variation of softening point was found in the case of groups of non-modified bitumens in comparison with modified bitumens. The highest variation during the softening point tests was found in the case of polymer modified bitumens of the 25/55-60 hardness group (Fig. 5).

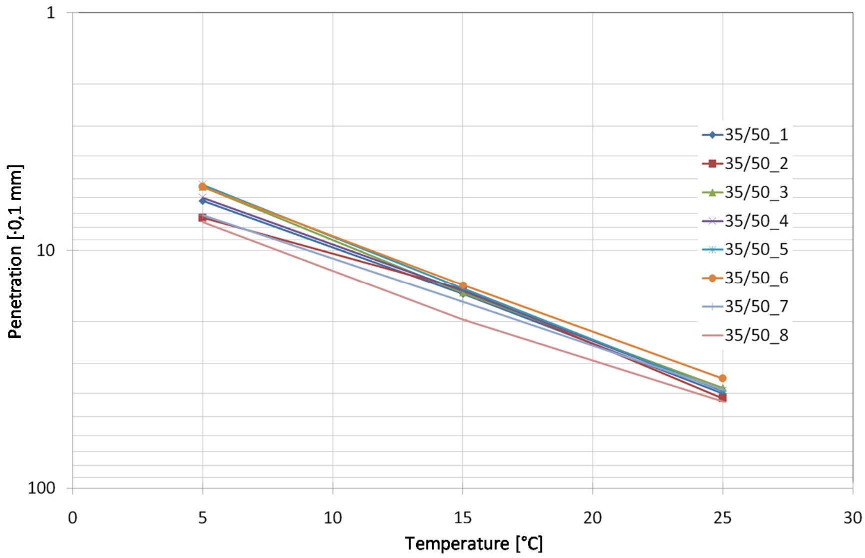

Fig. 4. Penetration of 35/50 bitumens as a function of temperature (Source: Radziszewski *et al.* 2011)

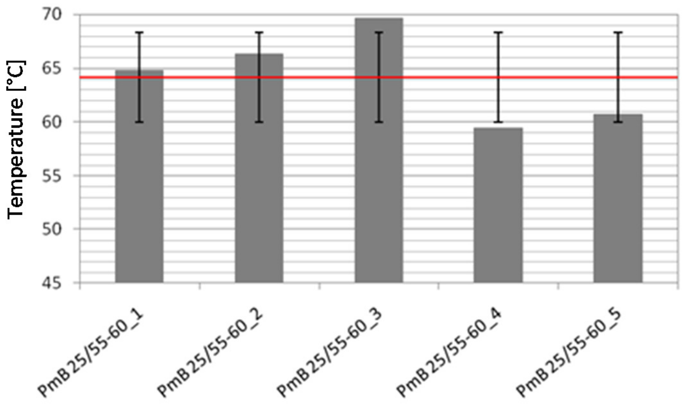

Fig. 5. Softening point of PmB 25/55-60 binders (Source: Radziszewski *et al.* 2011)

Flashpoint

The results of flashpoint tests of road bitumens and modified bitumens, amounting to over 330 °C, indicate that flashpoint values greatly exceed the permissible minimum values of approximately 220 °C defined in the PN-EN standard. We can assume that the tested bituminous binders are characterised by a wide margin of safety in the use with asphalt mixes.

Binder resistance to the short term ageing

It is important to emphasise the high variation of results obtained in the ageing resistance test of the particular hardness groups of bituminous binders. It applies in particular to the change of consistency determined on the basis of penetration. The change in binder weight after RTFOT ageing were favourably lower than the required normative values. The ageing resistance according to the PN-EN standard determined with the value of retained penetration and increase of softening point after the RTFOT test complied with the normative requirements for non-modified and modified bitumens.

Brittleness temperature (Fraass breaking point)

Highly variable results were obtained in the particular binder hardness groups. It applies to in particular to modified binders (Fig. 6). Additionally, it should be noted that road bitumens and modified bitumens, except for individual samples, were consistent with the normative requirements in terms of the brittleness temperature.

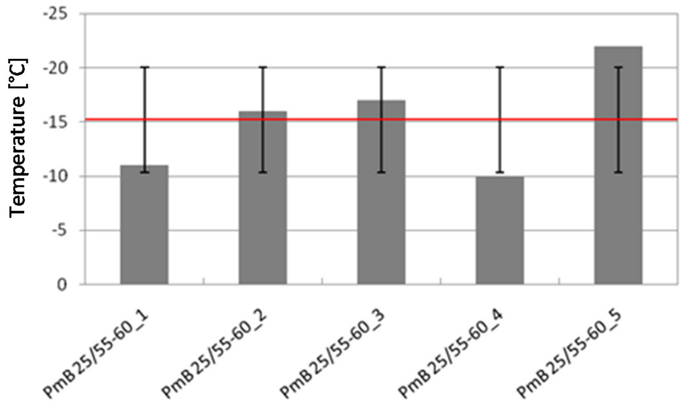

Fig. 6. Brittleness temperature of PmB 25/55-60 binders (Source: Radziszewski *et al.* 2011)

Range of plasticity

The results of test conducted on bituminous binders showed that their range of plasticity depends on the consistency and amounted to approximately 62 °C for 20/30 binders, approximately 55 °C for 35/50 binders, approximately 50 °C for 50/70 binders, and between 72 and 86 °C for polymer modified bitumens. PN-EN standards provide range of plasticity requirements only for PmBs. In the case of polymer modified bitumens intended for use in Poland, these requirements were marked as NR (no requirements).

Penetration index

The results of penetration index designation for 20/30, 35/50 and 50/70 bitumens are compliant with the requirements of the PN-EN standard, i.e. from –1.5 to +0.7. The penetration indexes for polymer modified bitumens have favourable positive values between 0 and 1.5. It should be noted that in the particular hardness groups of bituminous binders, penetration indexes exhibited a high variation of results, which was particularly apparent in the case of PmB 45/80-55 (Fig. 7).

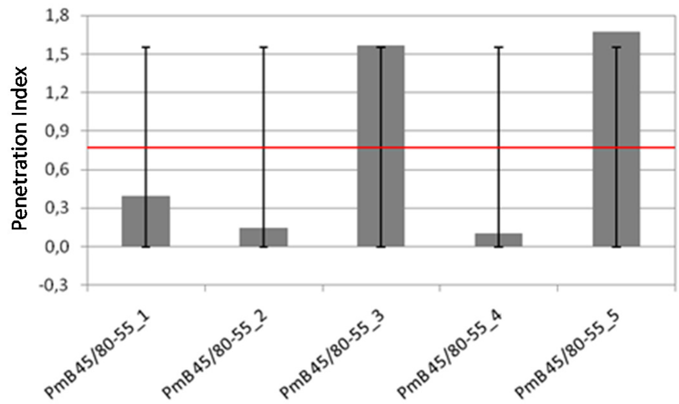

Fig. 7. Penetration index of PmB 45/80-55 binders (Source: Radziszewski *et al.* 2011)

Elastic recovery

Elastic recovery tests are typical tests intended for the assessment of polymer modified binders. In the case of 25/55-60 and 45/80-55 PmBs, elastic recovery of more than 50% is required before and after RTFOT ageing. The tested polymer modified bitumens exhibited elastic recovery of more than 70% before ageing. It should be noted, however, that after the ageing test, two binders of the five tested 25/55-60 PmBs exhibited no elastic recovery. We can assume that these polymer modified bitumens were manufactured using inappropriate polymers or wrong modification technology.

Ductilometer tensile strength tests

A conventional strain energy rating belongs to the group of basic properties of polymer modified binders. The tested polymer modified bitumens exhibited strain energy of over 5.0 J/cm^2, therefore they were compliant with the requirements of the standard (≥2.0 J/cm^2).

Attention must also be paid to the change in the strain energy values after the ageing process. The tested 25/55-60 PmBs included samples of binders characterised by unfavourable strain energy which was two times lower.

Storage stability of bituminous binders

The results of storage stability tests of both types of tested polymer modified bitumens showed that the obtained results were compliant with the requirements of the PN-EN standard, both in the scope of retained penetration and increase of softening point.

Functional properties of road bitumens and modified bitumens according to SUPERPAVE

The functional properties of bituminous binders were determined on the basis of G* dynamic shearing tests in a DSR rheometer (designation of the complex shear modulus and phase shift angle between stress and strain as a function of temperature) and creep stiffness S while bending with the use of a BBR rheometer. According to the SUPERPAVE method, a PG performance grade was defined for the tested road bitumens and modified bitumens.

Complex shear modulus tests as a function of temperature

Analysing the test results, it should be stated that favourably high values of the G* modulus at high operating temperatures were exhibited by 25/55-60 PmBs and 20/30 bitumens. The remaining road bitumens and PmB 45/80-55 were characterised by a much lower complex modulus of similar values. After RTFOT ageing process, the highest stiffness modulus and the highest stiffening at all the tested temperatures (in a range from 0 to 82 °C) was exhibited by 20/30 road bitumens, followed by 35/50 and 50/70 road bitumens. Polymer modified bitumens showed a favourably lower degree of stiffening. Complex modulus tests after process and operational ageing (RTFOT + PAV) showed that road bitumens exhibited much higher stiffening compared to modified bitumens. A high variation of the G* complex modulus test results were obtained for all hardness groups of bituminous binders, regardless of the manufacturer.

Phase shift angle tests as a function of temperature

Phase shift angle between stress and strain in complex modulus tests under cyclic load is a good measurement for the assessment of viscoelastic properties. The value of phase shift angle nearing 0° indicates complete stiffening of the binder, which leads to brittle fracture. At high operating temperatures, due to the risk of liquefaction of the binder, the phase shift angle should reach the value of 90°. Analysing the results of the phase shift angle tests regarding binders before ageing, after RTFOT and after RTFOT+PAV ageing, it should be noted that the most favourable properties in the range of low and high temperatures were exhibited by modified binders. Road bitumens at 82° were characterised by a loss of elastic properties and their behaviour resembled a Newtonian fluid (angle of approximately 85 °C). At these high temperatures, modified bitumens exhibited a higher proportion of elastic parts (angle of approximately 63–71°).

Temperature range of viscoelasticity and PG performance grade

The results of brittle fracture temperature tests based on BBR rheometer measurements (lower range) were used for determining the range of viscoelasticity. The viscous flow temperature obtained using a DSR rheometer was used for determining the upper range of viscoelasticity. The temperature range of viscoelasticity results for asphalt binders and PG performance grade are listed in Table 1.

Table 1. Temperature range of viscoelasticity and PG performance grade

Binder type	BBR brittle fracture temperature	DSR viscous flow temperature	Range of plasticity	Range of viscoelasticity	PG functional type – tested in 2009	PG functional type – tested in 2016
20/30	–14	82	73	96	PG 82 – 10	PG 82 – 10
35/50	–18	70	72	88	PG 70 – 16	PG 76 – 10
50/70	–22	64	62	85	PG 64 – 22	PG 70 – 16
PmB 25/55-60	–17	82	76	99	PG 82 – 16	PG 88 – 10
PmB 45/80-55	–22	76	72	96	PG 76 – 22	PG 70 – 22

Analysing the brittle fracture temperature obtained on the basis of tests using BBR equipment (lower range of the PG), it should be noted that the tested binders showed unfavourable values, too high relative to the minimum temperatures required for use in the Polish climatic conditions (for the wearing course – from 28 to 34 °C). The viscous flow temperatures obtained during the DSR tests showed that the binders had an excessively high resistance to permanent deformations. It should be noted that the temperature range of viscoelasticity of all the tested bituminous binders is very wide and exceeds 80 °C, whereas it is unfavourable that this range is shifted towards higher operating temperatures. There are noticeable differences in the assessment of the PG performance grade of bituminous binders carried out in 2009 and 2016. In the case of 35/50 and 50/70 bitumens and PmB 25/55-60, an unfavourable binder stiffening has occurred, causing an increase in the values of the lower and upper PG range. To summarise, it should be emphasised that the bituminous binders manufactured in Poland characterised by an excessively high value of the lower PG range cause an actual risk that the road surfaces constructed in Central and Eastern Europe with the use of these binders will lack the resistance to low temperatures.

Conclusions

Based on the results of properties assessment of bituminous binders manufactured in Poland, the following conclusions were drawn:

- The tested bituminous binders meet the requirements specified in European standards and technical guidelines in force in Poland.
- It was found that polimer modified bitumens with unfavourable, inhomogeneous structure with inferior technical properties were present on the market.
- Bituminous binders of specific hardness groups exhibit a high variation in terms of properties regardless of their manufacturer. Similar variations of properties exist in comparison of binders from different manufacturers.
- The temperature range of viscoelasticity of all the tested bituminous binders is very wide and exceeds 80 °C.
- The shift in the temperature range of viscoelasticity towards higher operating temperatures, at the same time lowering the binder performance at low temperatures, is an unfavourable phenomenon.
- The functional properties of bituminous binders currently in production in comparison with the binders from seven years ago exhibit unfavourable changes which led to a shift in the temperature range of viscoelasticity towards higher operating temperatures.

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