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Thermal Resistance of Blown Bitumens to The Conditions of Sharp-continental Climate

Bagdat Teltayev and Evgeniya Kaganovich
Kazakhstan Highway Research Institute, 050061, Almaty, Kazakhstan

Abstract: The studies the results of which are presented in the article have been performed to evaluate blown bitumen resistance in the temperature range characteristic of Kazakhstan's sharp-continental climate. The tests were performed at different temperatures using the Superpave methods and devices. The comparison of the values of shear complex modulus, stiffness and relaxation rate index with the specified values has indicated that the bitumens applied meet the climatic conditions requirements only for the part of the territory and the use of polymers is required to improve the thermal resistance. The thermal resistance shall be determined at the asphalt concrete mix design.

Key words: Blown bitumen, thermal resistance, shear complex modulus, bitumen stiffness, relaxation rate

INTRODUCTION

Main roads in Kazakhstan are predominantly provided with asphalt concrete pavements which performance is substantially dependent on temperature. Therefore the climatic conditions of the region along with traffic loads now in force dictate the requirements for asphalt concrete and bitumen as a component that controls to the largest degree the thermal resistance of asphalt concrete. Most of the Kazakhstan regions, except for the South-Western and Southern ones, are characterized by a combination of low winter and high summer temperatures which governs their harp-continental climate as well as the necessity for the bitumen and asphalt concrete to perform over a wide range of temperatures. This range for the pavements can approach 100°C (for example, from 54°C in summer to -42°C in winter under the conditions of Ust-Kamenogorsk). That is why, for evaluating the asphalt pavement performance it is very important to have a reliable idea of bitumen properties in this temperature range (Papagiannakis and Masad, 2008; AI, 2007; D'Angelo *et al*., 2007).

It is necessary therewith to consider that in the road construction and repair in Kazakhstan, the use is made of viscous road bitumens produced at the Kazakhstan and Russian refineries according to the technology of oil tar air oxidation whereas in the majority of foreign countries residual bitumens are preferred. As is known, the blown and residual bitumens possess substantially different properties, in particular, group composition, stability under low temperature conditions and ageing resistance.

Studies of the bitumen thermal resistance, characterizing most exactly the asphalt pavement behavior in operation, were started in the Kazakhstan Highway Research Institute in 2002-2003 on the basis of the results of tests carried out by standard methods subject to a certain conventionality. With the development of Superpave Specifications based on complying the bitumen properties with the operation conditions as well as working out methods and devices simulating more reliably the bitumen performance in various temperature intervals, these investigations have been continued at a new methodical level.

MATERIALS AND METHODS

Materials used: For preparing the asphalt mixtures in Kazakhstan, two grades of a viscous road bitumen are used, which are as follows: BND 60-90 and BND 90-130. This has predetermined the bitumen choice for the studies:

- BND 60-90 produced by TOO ABZ-1, the city of Almaty, Kazakhstan, through oxidation of oil tar from Bashkir petroleum (further "Bitumen 1")
- BND 90-130 of the same refinery (further "Bitumen 2")
- BND 90-130 produced by the Omsk refinery through oxidation of oil tar from West-Siberian petroleum (further "Bitumen 3")

On the basis of the analysis of physical-mechanical indices for a number of bitumens used in the road construction and repair during several years, it can be stated that these bitumen samples are sufficiently typical for the conditions of Kazakhstan.

Corresponding Author: Bagdat Teltayev, 35 Flat, 246 Build., Turkebayev Street, Almaty, 050046, Kazakhstan
Tel: +7-(727)-241-43-39, +7-(727)-256-05-04 Fax: +7(727)-241-43-39

Table 1: Indices of Physical-mechanical properties for studied bitumens

Specified indices	Standards for test methods	Bitumen 1	Bitumen 2	Bitumen 3
Needle penetration (0.1 mm)				
at 25°C	ST RK 1226*	75	102	63
at 0°C		35	33	23
Ring and ball softening point (°C)	ST RK 1227	50	45	51
Ductility (cm at 25°C)	ST RK 1374	80	120	62
Fraas brittle point (°C)	ST RK 1229	-22.2	-20.5	-24.3
Flash point (°C)	ST RK 1804	250	250	275
Penetration index	ST RK 1373	-0.20	-0.72	-0.46
Dynamic viscosity at 60°C (Pa sec)	ST RK 1211	347	113.7	399
Kinematic viscosity at 135°C (mm^2 sec^{-1})	ST RK 1210	534	310	572

*The State Standard of The Republic of Kazakhstan

The indices of physical-mechanical properties of the bitumens studied are presented in Table 1.

Test at high temperatures: The high temperature behavior of the bitumens, in the initial state and after ageing in a rolling thin film oven test (RTFOT) as to AASHTO T 240 (2008), was studied in a Dynamic Shear Rheometer (DSR) in compliance with AASHTO T 315, (2008). The tests were carried out at temperatures from +46°C to +88°C. This temperature range has been substantiated in the course of zoning of the Republic's territory as to the asphalt pavement service temperatures with consideration for the traffic conditions on main roads (Teltayev and Kaganovich, 2011).

Test at mean temperatures: The mechanical behavior of bitumens at mean temperatures was studied in a Dynamic Shear Rheometer (DSR) as to AASHTO T 315 (2008) after ageing in a rolling thin film oven test AASHTO T240 (2008) and in a pressurized ageing vessel ASTM D 6521 (2008). The tests were conducted at temperatures between +4 and +40°C. This temperature interval has been also substantiated on the basis of probable pavement temperatures in the Republic's regions (Teltayev and Kaganovich, 2011).

Test at low temperatures: The low temperature behavior of bitumens have been studied in a Bending Beam Rheometer (BBR) in compliance with AASHTO T 313, (2008) after their ageing in a Rolling Thin Film Oven Test (RTFOT) and in a Pressurized Ageing Vessel at high temperature (PAV). The studies have been conducted in the range of temperature change from -12 to -34°C.

RESULTS AND DISCUSSION

Tests at high temperatures: Based on the tests results, the temperature relationships of complex shear modulus G*, phase angle δ and ratio G*/sin (δ) have been built for the bitumens. The above relationships are presented in Fig. 1-3 for the studied bitumens in the initial state and in Fig. 4-6 for those in the aged state (RTFOT).

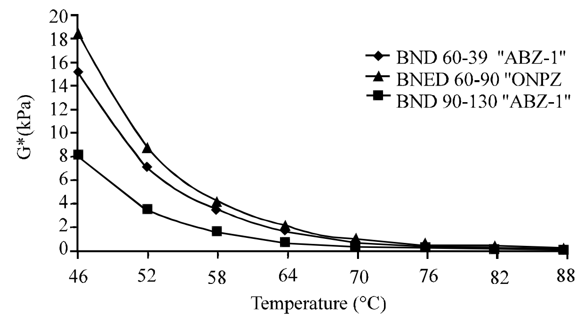

Fig. 1: Complex shear modulus-temperature relationship for bitumens in the initial state

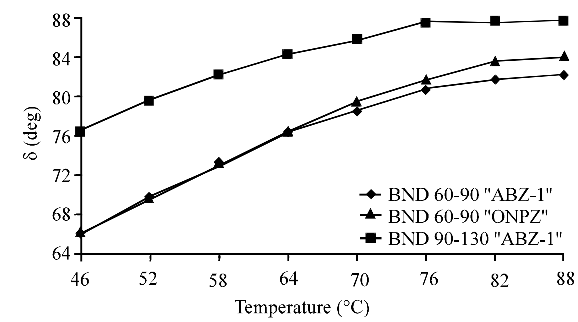

Fig. 2: Phase angle-temperature relationship for bitumens in the initial state

When analyzing the complex shear modulus-temperature relationships for bitumens, it is seen that they are nonlinear (Fig. 1, 4). Thereby, a degree of the nonlinearity grows with temperature lowering. At a temperature above 80°C all the bitumens tested have practically the same value of the complex shear modulus-less than 1 kPa. With decrease in temperature the complex shear modulus value of bitumens grows.

The rate of increase in complex shear modulus is the highest for bitumen 3, somewhat lower for bitumen 1 and the least for bitumen 2. In the initial state at a temperature of +46°C, value G* reaches 15 kPa and 19 kPa for bitumens 1 and 3, respectively and 8 kPa for bitumen 2. After ageing these values increased up to 32, 36 and 27 kPa for the

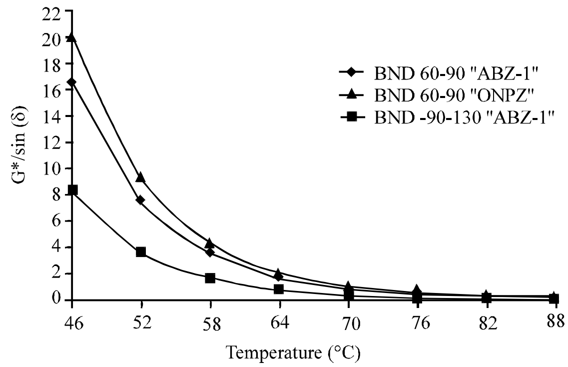

Fig. 3: Rutting resistance index-temperature for bitumens in the initial state

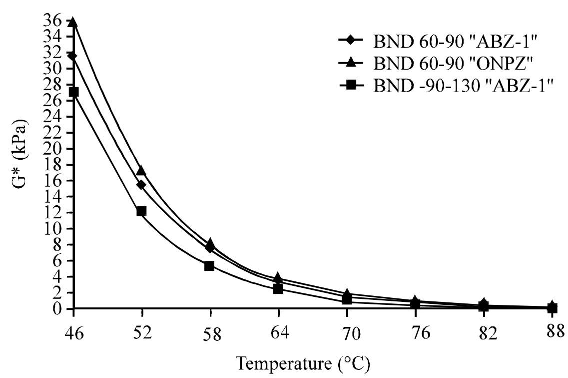

Fig. 4: Complex shear modulus-temperature relationship for bitumens after ageing (RTFOT)

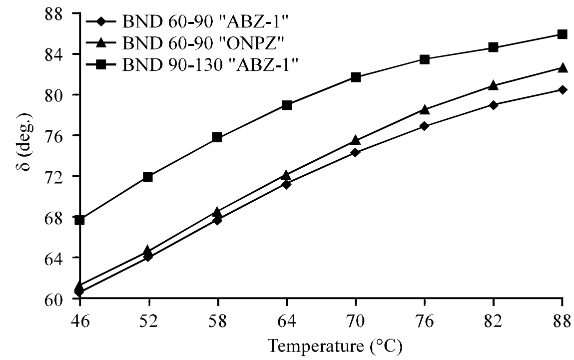

Fig. 5: Phase angle-temperature relationship for bitumens after ageing (RTFOT)

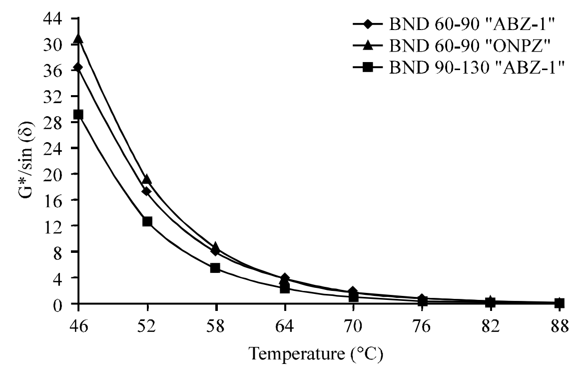

Fig. 6: Rutting resistance index-temperature relationship for bitumens after ageing (RTFOT)

bitumens under consideration, respectively. Thus, after ageing (RTFOT) the complex shear modulus increased by a factor of 1.9 for bitumen 3, by a factor of 2.1 for bitumen 1 and by a factor of 3.4 for bitumen 2.

The phase angle of bitumens also changes nonlinearly depending on a temperature showing an increase as the temperature rises (Fig. 2, 5). Within the temperature range under consideration the value of phase angle changes from 66 to 84 degrees for bitumens in the initial state and from 61 to 82 degrees for those after ageing. The phase angle over the whole temperature range considered for bitumen 2 in the both state is 7-10 degrees higher. It should be therewith noted that the values of phase angle for bitumens 1 and 3 in the initial state coincide in the temperature range from 46 to 64°C. The phase angle for bitumen 3 is higher by 1-2 degrees in the temperature range from 64 to 88°C in the initial state and in the whole temperature range under consideration from 46 to 88°C after ageing (RTFOT).

The rutting resistance index-temperature relationship G*/sin (δ) for all the bitumens tested is similar to their relationships between complex shear modulus G* and temperature (Fig. 3, 6).

According to the condition of preventing road rutting in Superpave Specifications (AI, 1999) it is required that at maximum design temperatures a minimum admissible value of ratio G*/sin(δ) is not less than 1.0 kPa for bitumens in the initial state and not less than 2.2 kPa for those after RTFOT ageing. For the territory of Kazakhstan, in conformity with the map of asphalt pavement zoning as to operational temperatures (Teltayev and Kaganovich, 2011), the maximum design temperatures equal to 52 58 and 64°C have been established. An analysis of the results of bitumen DSR tests with regard to the Superpave requirements and traffic conditions on the main roads in Kazakhstan has shown that bitumens 1 and 3 meet the requirements of high temperature resistance at temperatures of 52°C and lower and bitumen 2 complies with them at 46°C and lower. Hence, according to the Superpave conditions bitumens 1 and 3 meet the requirements of high temperature resistance only for a small part of the territory on the north of Kazakhstan while bitumen 2 does not meet the requirements for the whole territory of the Republic.

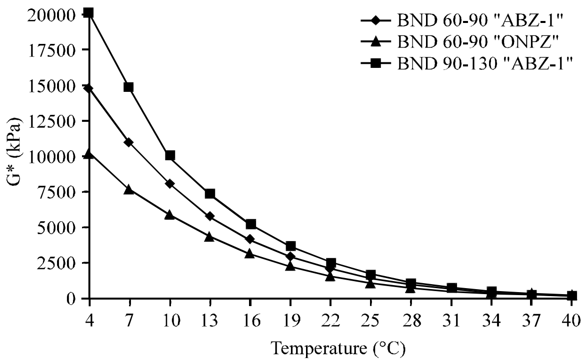

Fig. 7: Complex shear modulus-temperature relationship for bitumens after RTFOT and PAV ageing

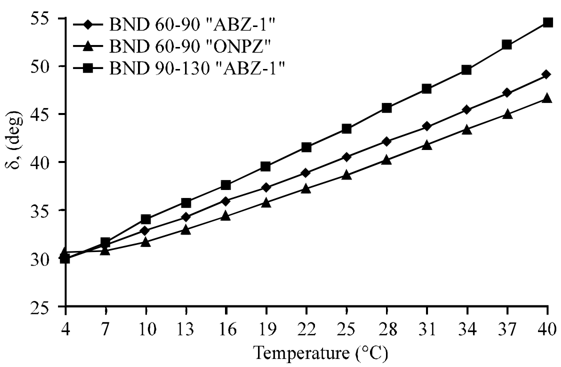

Fig. 8: Phase angle-temperature relationship for bitumens after RTFOT and PAV ageing

Test at mean temperatures: Based on the bitumen test results, the temperature relationships for complex shear modulus G*, phase angle δ and product G*sin(δ) are plotted in Fig. 7-9.

As is seen, with a decrease in temperature the values G* of the bitumens grow in conformity with the nonlinear law. At a temperature of +40°C all the bitumens studied have practically the same value G* equal to about 200 kPa. With lowering temperature, the rate of G* increase is various for different bitumens. The highest rate of G* growth shows bitumen 2 and bitumen 3 has the lowest one. It should be noted that after double ageing (first in RTFOT and then in PAV), the highest stiffness was obtained for bitumen 2 for which G* reached about 20000 kPa at +4°C. Bitumen 3 was the softest one which had value G* equal to 10000 kPa at the same temperature. Bitumen 1 for which G* reaches 15500 kPa at +4°C occupies an intermediate position as to the stiffness. After double ageing bitumens 1 and 2 have become stiffer as compared with bitumen from the Omsk refinery.

The values of phase angle for the investigated bitumens grow ith increase in temperature according to

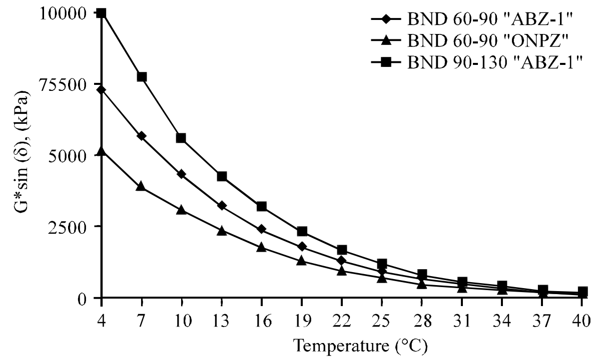

Fig. 9: Relationship between index of fatigue cracking resistance and temperature for bitumens after RTFOT and PAV ageing

the curvilinear relationship with a slight nonlinearity. In the temperature range between 4 and 7°C practically all the bitumens studied are characterized by the same value of the phase angle approximately equal to 30 degrees. With a further increase in temperature the values of the phase angle for different bitumens grow at various rates. The value of the phase angle grows most rapidly for bitumen 2 and most slowly for bitumen 3, bitumen 1 holds an intermediate position. At 40°C the values of the phase angle of the above bitumens are equal to 54, 46 and 49 degrees, respectively.

In conformity with the Superpave requirements (AI, 1999), product G*sing(δ) after double ageing (RTFOT+PAV), being not higher than 5000 kPa, is a criterion of preventing premature fatigue cracking of the asphalt pavement at the mean design temperatures. The mean design temperatures have been set for the separate regions of Kazakhstan, which are as follows: +10, +13, +16, +19 and +22°C (Teltayev and Kaganovich, 2011). The comparison of the values of product G*sin(δ) for bitumens at these temperatures with its specified value have shown that bitumens 1 and 3 meet the requirements of mean temperature resistance throughout the whole territory of Kazakhstan and bitumen 2 does not comply with the requirements only for a small part of the territory situated on the north of the Republic.

Test at low temperatures: it is known, the Superpave requirements envisage that at a loading duration 60 sec, the modulus of stiffness S_{60} for a bitumen at the minimum design temperature should not exceed 300 MPa while the value of the index of stress relaxation rate m_{60} should be not less than 0.3 (AI, 1999). Therefore, the above indices for the bitumens are of important practical interest at the analysis of their low temperature behavior under actual operation conditions (Michalica *et al*., 2008;

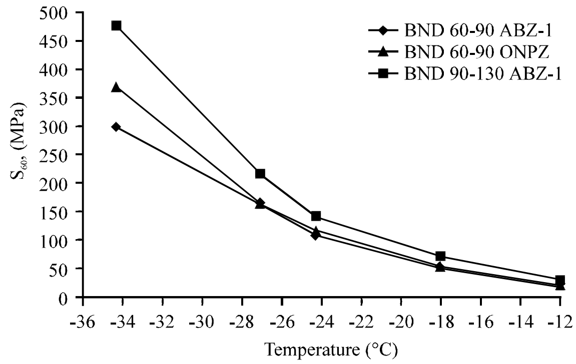

Fig. 10: Stiffness S_{60}-temperature relationship for bitumens after RTFOT and PAV ageing

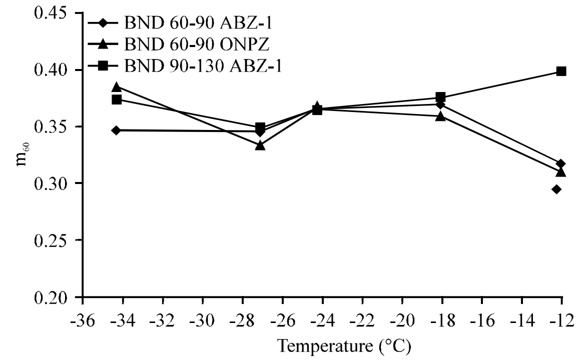

Fig. 11: Relationship between index of stress relaxation rate m_{60} and temperature for bitumens after RTFOT and PAV ageing

Anderson *et al*., 2011). The relationships of the stiffness S_{60} and the index of relaxation rate m_{60} from the temperature obtained from the results of bitumen tests at a loading duration 60 sec are presented in Fig. 10 and 11.

As it can be seen from Fig. 10, the stiffness at -12°C for all the bitumens is virtually the same. The values of the stiffness increase according to the nonlinear relationship with further temperature lowering. In the temperature interval of -12 to -27°C, the curves of the stiffness-temperature relationship for bitumens 1 and 3 practically coincide whereas a further decrease in temperature brings about a rapid growth of the stiffness of bitumen 3. At present, among the specialists an opinion prevails that the bitumens of less viscous consistency (when evaluating the consistency by value of penetration at 25°C) resist better to temperature cracking. However the data from Fig. 10 demonstrate that this opinion is not always true. So, less viscous bitumen 2 in the whole range of temperature change from -12 to 34°C has a higher stiffness than more viscous bitumens 1 and 3.

The relationships between the indices of stress relaxation rate and the temperature for the bitumens under consideration are not complicated (Fig. 11). The rate of stress relaxation at -12°C for bitumens 1 and 3 is essentially lower than that for bitumen 2. In the range of temperature change from -18 to -34°C all three bitumens have a more or less constant value m_{60} equal to 0.33-0.38.

The above analysis indicates that the mechanical behavior of the investigated bitumens at low temperatures is not simple and the peculiarities of each of them shall be taken into consideration at the asphalt concrete mix design for a particular climatic region.

For the separate regions of Kazakhstan the design low temperatures equal to -28, -34, -40 and -46°C have been set up (Teltayev and Kaganovich, 2011). As the result of comparison of values S_{60} and m_{60} for the bitumens investigated at the above design low temperatures with their specified values it has been established that bitumens 1 and 3 meet the requirements of the low temperature resistance for a larger part of the territory of Kazakhstan, except for its eastern part while bitumen 2 conforms to the requirements of the low temperature resistance only for the half of the Republic's territory.

CONCLUSION

Based on this research, the following conclusions could be made:

- For the studies at high, mean and low design temperatures blown bitumens have been selected, which are the most typical ones for the conditions of Kazakhstan
- The results of bitumen tests in DSR in the initial state and after RTFOT ageing have indicated that BND 60/90 bitumens from the Almaty and Omsk refineries meet the Superpave requirements for the high temperature resistance only for the extreme north of Kazakhstan. BND 90/130 bitumen from the Almaty refinery does not conform to these requirements throughout the whole territory of the country
- The data of the bitumen tests in DSR after double ageing (RTFOT+PAV) at mean temperatures have indicated that practically all the investigated bitumens (with the exception of bitumen of BND 90/130 grade for the extreme north of the Republic) meet the Superpave requirements as to the fatigue cracking resistance of asphalt pavements
- Based on the results of BBR investigating the low temperature behavior of bitumen after double ageing (RTFOT+PAV), it has been established that both bitumens of BND 60/90 grade meet the Superpave

requirements for the low temperature resistance for the most part of the territory of Kazakhstan, except for a small eastern part and bitumen of BND 90/130 grade conforms these requirements only for the half of the Republic's territory

- Due to a various character of the behavior of bitumens of different grades, refineries and petroleum raw it is required to define their conformity with operational (temperature) conditions of a construction region when designing the asphalt mix compositions
- The study results indicate that it is necessary to apply special technical solutions for improving the temperature resistance of bitumens and preventing premature failure of asphalt pavements resulting from the non-conformity of bitumens with climatic conditions

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