



## INFLUENCE OF TEMPERATURE ON THE FORMATION OF DAMAGES IN ASPHALT CONCRETE PAVEMENTS UNDER CLIMATIC CONDITIONS OF THE REPUBLIC OF BELARUS

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**Abstract.** Climatic conditions of the territory where the road is located (air temperature, solar radiation) influence the “work” of asphalt concrete pavements. The influence causes shear deformations at high positive temperatures and the occurrence of cracks at low negative temperatures. In the late 80s, in the USA the asphalt pavement design system Superpave (*Superior Performing Asphalt Pavements*) defined the temperature limits of pavement “work”. The Performance Grade parameter has been introduced associated with the choice of bitumen. Based on the long-term climatic data the temperature limits have been determined for the territory of the Republic of Belarus.

**Keywords:** climatic conditions, asphalt concrete pavements, ruts, temperature cracks, reflected cracks, weather-climatic factors, Superpave, Performance Grade (PG), zoning.

### 1. Introduction

Asphalt concrete (AC) road pavements are subjected to not only transport loads. Significant influence on their work is made by the weather and climatic conditions of the territory where the road is located.

AC has the properties of a viscous-plastic material at positive temperatures and the properties of an elastic material at negative temperatures. During the summer period at the highest air temperatures the surface of AC pavement heats up to 50–60 °C. Due to the rise in surface temperature over the temperature of bitumen melting the asphalt softens and causes formation of waves, inflows and ruts. During the winter period as a result of pavement cooling and expansion-compression phenomenon the temperature cracks and the reflected cracks appear. In connection with these adverse conditions, the development of measures against the occurrence of road pavement defects and the definition of real maintenance conditions of AC pavements in a long-term perspective are very important.

### 2. Road maintenance in terms of weather and climatic conditions

Climatic conditions influence the choice of technology and the organization of road works. Roads are influenced by air temperature, solar radiation, atmospheric precipitation, wind, fog, a glaze ice and other natural phenomena

which are considered as the objective reality and in some cases cannot be eliminated by people. In this case it is necessary to search for engineering decisions which would provide the necessary technical solutions (Leonovich, Melnikova 2011).

Temperature and air humidity, speed and wind direction, average quantity of deposits, height of a snow cover and other meteorological factors are taken into consideration when designing, constructing and maintaining roads. However, the air temperature and solar radiation should be especially taken into account.

During the summer period of high positive temperatures the repeated influence of solar radiation and temperatures leads, first of all, to the occurrence of shear defects in AC pavements, such as waves and ruts that are caused by melting of free bitumen in the softened asphalt layer. Such pavement damages are formed under the action of normal (vertical)  $F_n$  and shearing (horizontal)  $F_t$  forces from the car (Fig. 1) (Bonchenko 1994).

During the winter period influence of the weather-climatic factors causes in AC pavements a tension from non-free compression at cooling, deformations from changes in asphalt humidity at frequent transition of temperature through 0 °C, or a bend of pavements, etc. (Verenko 2008). Daily temperature fluctuations cause in asphalt layers on a concrete base not only horizontal movement in a concrete layer, but are also the reason of the bend and warping of

the plate, that creates shear and stretching pressure in the bottom of asphalt layer above joint or crack (Fig. 2).

Generally, due to the daily temperature fluctuation, the phenomena of expansion-compression and sunlight effect on the road pavement, the temperature cracks and the reflected cracks appear in the road pavement (Fig. 3) (Nunn 1989).

Because of these phenomena, it is necessary to reveal a degree of influence of natural factors on the road during its maintenance, to develop constructive, material and technological recommendations for the improvement of design and construction of road pavements and for the prevention of occurrence of pavement damages caused by weather-climatic factors.

### 3. Functional classification of asphalts according to the Superpave

The unsatisfactory state of highways in the USA has resulted in the 80<sup>th</sup> of the last century in creation of a special committee to decide this problem. The committee included the leading experts of transport companies, the workers and scientists (experts in road design, construction and maintenance). Within five years, from October 1987 to March 1993, the *Strategic Highway Research Program* (SHRP) was developed. The leading experts in the field of the newest technologies of construction, materials and road maintenance searched for technical decisions to increase road safety, the quality and service life of roads, and to save funds allocated to road construction and maintenance (McDonnell 2002).

The committee decided that in order to provide the max service life of asphalt pavements it is important to select the right structure of AC taking into account two main factors:

- 1) summer maintenance when the material, heated up to above 50 °C, loses its durability and forms ruts, inflows and shear;
- 2) winter maintenance when at low temperatures asphalt becomes very firm but at the same time rigid and this leads to the appearance of cracks (Radovskij 2007).

Researches within the program SHRP have led to creation of the whole system of asphalt pavement design called *Superior Performing Asphalt Pavements* (Superpave). It is a system of material classification for the design of AC mixtures, design of the mixture itself and the analysis of the obtained composition, and also estimation and forecasting of the work of asphalt layer in road pavement.

During road maintenance it is very important to know the conditions under which asphalt pavement “works”: to know the structure and traffic volume and the weather-climatic conditions. Depending on climatic and traffic conditions there are some boundary limits in which the pavement works better (with smaller probability of damage occurrence). Such functional classification of AC depending on the air temperature and the surface temperature has been developed also in the USA, in late eighties.

During the SHRP program the temperature limits in which asphalt “works” were established. These limits are

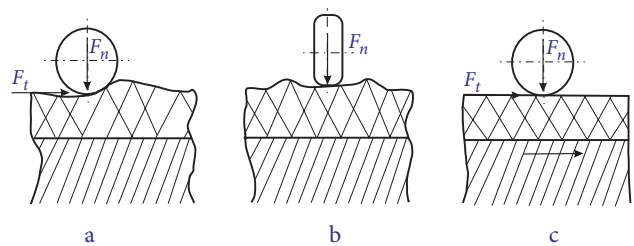


Fig. 1. Shear of road pavement under the action of a car wheel: a – on braking sites, cross-section waves are formed; b – on driving sites, residual strain as a track is formed; c – at braking, sliding of pavement in respect of a base

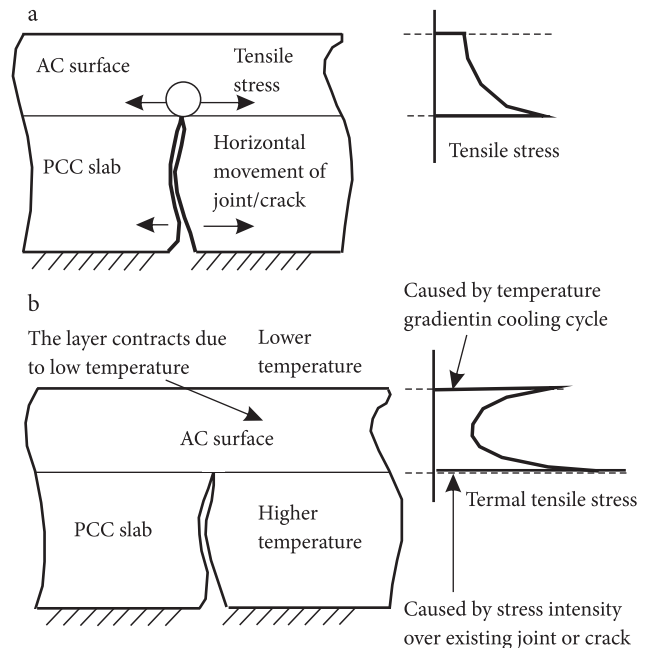


Fig. 2. Stresses in asphalt layer on a concrete base caused by daily temperature fluctuations: a – compression of a base; b – compression of the top pavement layer

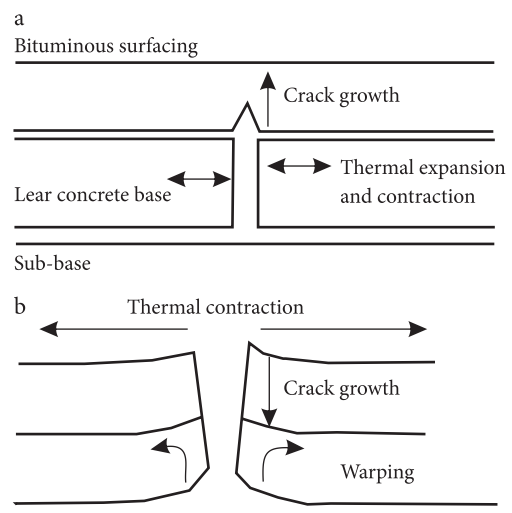


Fig. 3. Appearance of reflected cracks caused by the action of temperature: a – thermally induced fatigue; b – surface initiated cracking (temperature gradient giving greater contraction at the surface)

reflected by the Performance Grade (PG) parameter. It is the so-called functional asphalt type which is characterized by two temperatures: the max and min surface temperature. For example, in "PG 64–22", "64" is the max pavement temperature under which bitumen can be used for low traffic levels, "–22" is the min pavement temperature under which the selected bitumen use will not lead to failure in any case. Thus, the figures of PG parameter represent the extreme high and low temperatures under which the selected bitumen is suited.

The aim of AC classification and the bitumen choice according to the PG is to make sure that bitumen will work correctly in a period of road maintenance, to define asphalt type which should be used under the given climatic conditions. The essence of PG system is:

- to connect the requirements for bitumen with the requirements for pavement functioning;
- to consider climatic influence through the temperature of pavement;
- to take into account the phenomenon of technological (short-term) and operational (long-term) ageing.

#### 4. Method for the definition of AC functional type

The AC functional type according to the Superpave pavement design can be divided into four basic steps: analysis of climatic data, calculation of pavement temperature, calculation of values of the functional type parameter PG, and correction of the calculated values.

##### 4.1. Analysis of climatic data

Climatic parameters, the so-called seven-day average max air temperatures and the min air temperatures of each year, are defined according to the data from meteorological stations for at least 20 years. In the USA, on the basis of the data from 6500 stations the PG temperature scheme has been made for the whole territory of the country. A similar analysis is carried out for the territory of Belarus according to "BelHydroMeteoCenter" data (Fig. 4). Based on the measurements of the daily air temperature from 1989 to 2010 the max average air temperature for the period of seven calendar days in each year and the min air temperature for each year are determined. Moreover, the probability at which in one year the extremum of temperature will not be exceeded was defined. Calculations were made by using statistical methods for 50% and 98% probabilities (Błażejowski, Styk 2004).

For example, the 7-day max for the territory of Belarus is 29 °C with the standard deviation  $s$  of 2 °C. This means that in any given year the probability of occurrence of seven-day average temperature above 29 °C is 50%. But the probability of occurrence of the period with the temperature above 33 °C (31 °C + 2 standard deviations) is only 2%. The calculation is similar for the min temperatures: the average temperature is –22 °C with a standard

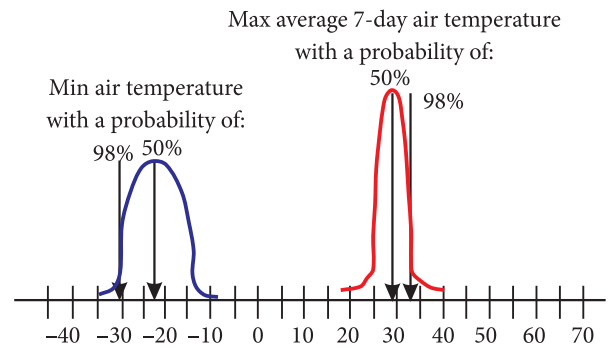


Fig. 4. The min and max air temperatures depending on the assumed probability for the territory of the Republic of Belarus

deviation of 4 °C, and for the probability of 98% the min temperature is –30 °C (–22 °C – 2 standard deviations).

##### 4.2. Calculation of pavement temperature

After calculation of air temperatures the temperature of road surface according to the Superpave method should be defined. AC pavement max temperature in summer could be defined on the basis of theoretical analysis of maintenance conditions by using mathematical models of thermal streams and power balance, an assumption of typical values for solar adsorption, transfer of radiation through the air, atmospheric radiation and a wind speed. The temperature is calculated as the yearly, 7-day average max pavement temperature, measured 20 mm below pavement surface.

$$T_{\max(20mm)} = 0.9545 \times (T_{air} - 0.00618\varphi^2 + 0.2289\varphi + 42.2) - 17.78, \quad (1)$$

where  $T_{\max}$  – the max design temperature of AC pavement at a depth of 20 mm, °C;  $T_{air}$  – average max air temperature in a shadow during the 7-day period, °C;  $\varphi$  – northern latitude in degrees. In this formula the factor of absorption of solar radiation is 0.9, the factor of passing through a sunlight by an atmosphere is 0.81, atmospheric change is 0.7 and a wind speed is 4.5 km/s (Teltaev 2008).

The min surface temperature is defined by two methods. According to the first, classical method, the temperature on the surface of asphalt pavements is equal to the air temperature. By the second method based on SHRP, widespread in the USA and Canada, the min surface temperature is defined as:

$$T_{\min} = 0.859T_{air} + 1.7, \quad (2)$$

where  $T_{\min}$  – the min surface temperature, °C;  $T_{air}$  – the min air temperature, °C.

The results of surface temperature definition for the territory of Belarus on the basis of climatic data are presented in Table 1.

**Table 1.** Temperature for the territory of the Republic of Belarus

Probability of	Air temperature, °C		Surface temperature, °C	
	7-day average maximum	minimal	maximum on a depth of 20 mm	minimal
50%	29	-22	45	-22 classically
				-17 by calculation
98%	33	-30	49	-30 classically
				-24 by calculation

**4.3. Calculation of values of the functional type parameter PG**

On the basis of the earlier determined extreme temperatures the functional asphalt type was determined. According to the Superpave specification of the asphalt functional type is carried out according to the Table 2 with an interval in 6 °C.

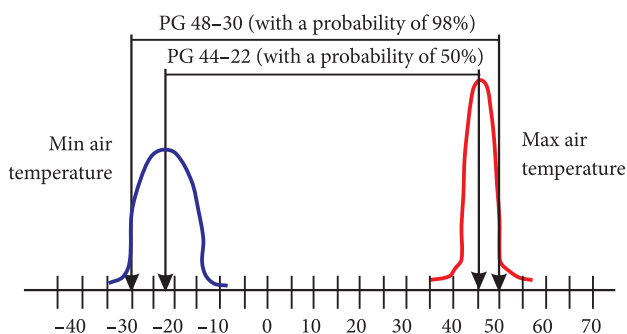
**Table 2.** Specification of the asphalt functional type according to the Superpave

The max design surface temperature, °C	The min design surface temperature, °C
PG 46	-34, -40, -46
PG 52	-10, -16, -22, -28, -34, -40, -46
PG 58	-16, -22, -28, -34, -40
PG 64	-10, -16, -22, -28, -34, -40
PG 70	-10, -16, -22, -28, -34, -40
PG 76	-10, -16, -22, -28, -34
PG 82	-10, -16, -22, -28, -34

In this case the values of functional type PG are (Fig. 5):

- with a probability of 50% the limits are from 45 °C up to -22 °C;
- with a probability of 98 % the limits are from 49 °C up to -30 °C.

In both cases the min surface temperature is determined by the classical method.



**Fig. 5.** Probabilities of the occurrence of min and max surface temperatures

According to the Superpave specification and having made a rounding the following functional limits for the climatic conditions of Belarus were obtained:

- with a probability of 50%: PG 46–34;
- with a probability of 98%: PG 52–34.

The assumed probabilities of extreme temperatures are of great importance. Except for the statistical parameter, the way of definition of the min surface temperature – classical or calculated – also influences the PG values.

**4.4. Correction of the calculated values**

The asphalt functional type, determined in the previous stages for Belarus, considers only climatic conditions and takes no account of traffic loadings. Though, it is well known that cyclic loadings lead to the increase in bitumen rigidity, i.e. to the same effect as the rise in temperature. The primary system for the selection of asphalt functional type assumes the so-called “normal” conditions of movement. For example, the speed limit is 90 km/h.

However, it has been established that in some cases the increase in the top limit of values of the functional type is necessary. These cases are presented in Table 3.

**Table 3.** Correction of the top limit of PG

Special traffic conditions	Increase in the top limit, °C
Slow vehicle movement is expected	6
Vehicle stop is expected	12
Intensive movement of vehicles is expected (according to the design project):	
– 10–30 mln ESAL*	6
– more than 30 mln ESAL*	12
Slow intensive vehicle movement is expected	12

\* ESAL – Equivalent Single Axle Load – standard loading on a single axis of 80 kN.

The special traffic conditions resulted above does not influence requirements for low bitumen temperatures.

**5. Results of the definition of operating mode of AC pavements**

As a result of the calculation on the basis of Belarusian climatic characteristics the limiting temperature values of asphalt pavement “work” were determined: with a probability of 50% – PG 46–34, 98% – PG 52–34.

Two figures of the parameter characterize extreme max and lowest surface temperature values when bitumen will work correctly. It is important to understand how these values are determined.

As it was mentioned above, the 7-day average max of surface temperature at a depth of 20 mm from the surface (the so-called max asphalt mixture design temperature) is accepted as the highest temperature value. The design high

pavement temperature varies from year to year and cannot be defined precisely, by a single value. Instead, statistical methods shall be used through the concept of reliability. Reliability of the given high pavement temperature refers to the probability that it will not be exceeded in any given year.

For example, according to the results of 20-year observations and calculations for Brest, the average value of the highest pavement temperature is 46.4 °C. That means that in any given year, there is a 50% chance that the actual high pavement temperature will be lower than this, and a 50% chance that it will be higher than 46.4 °C. Therefore, the highest surface temperature for Brest with 50% reliability is 46.4 °C. At a 98% level of reliability the max temperature will be 50.1 °C. In other words, in any given year there is 98% probability that the max pavement temperature in Brest will be less than 50.1 °C.

The same approach is used in low-temperature performance grading. In this case, the low pavement temperature is defined simply as the min pavement temperature at the pavement surface experienced at a given location in a given year. For example, for Gomel the average low pavement temperature is -20.0 °C. Thus, the lowest surface temperature at a 50% reliability level is -20.0 °C. At a 98% reliability level this temperature will be equal to -24.7 °C.

Fig. 6 gives a plot of performance grade reliability for the design high and low pavement temperatures for Minsk. In this example, at a 76% reliability level the design high pavement temperature is 45.5 °C, and the design low pavement temperature is -23.8 °C.

It should be emphasized that the max pavement temperature does not coincide with a max of air temperature, and it is defined by the Eq (1). In Gomel, for example, the average highest air temperature is 37.5 °C and this is considerably below the calculated max surface temperature of 53.5 °C.

At the same time the average min surface temperature is not equal to the min air temperature according to the classic method. Typically, the design low pavement tempe-

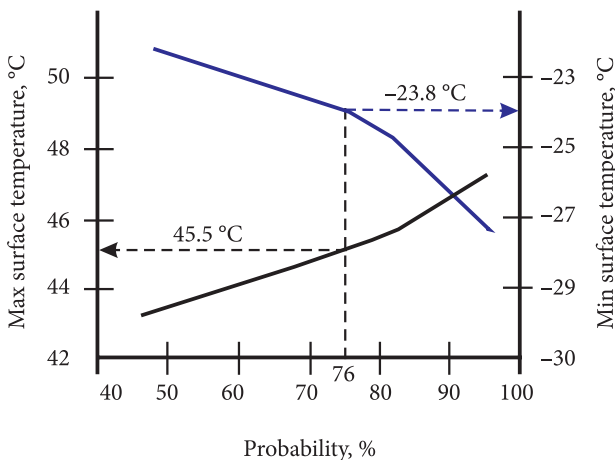


Fig. 6. Example of performance grade reliability under the climatic conditions of Minsk

perature is significantly higher than the min air temperature for a given location.

The question of what level of reliability should be used when selecting bitumen is also important. Engineers and technicians should keep in mind that at a 50% reliability level, there is a 50–50 chance in any year that the high and/or low temperature will exceed or will be lower than the designed temperature. That is, road pavement laid by using bitumen selected at a 50% reliability level is likely to exhibit rutting and/or low-temperature cracking within a few years. Therefore, it is necessary to define temperature values at higher level of reliability, at least 90%. According to the Superpave method it is not less than 95% for interstate highways.

To calculate the lowest and the highest temperature values with the certain reliability it is necessary:

- 1) to calculate average temperatures of the warmest seven days in a year and to define the lowest temperature in a year on the basis of climatic data for at least 20 years;
- 2) to calculate the max pavement temperatures at a depth of 20 mm from the surface according to the Eq (1);
- 3) to approximate the calculated values of the max positive and negative temperatures to the tenth and to arrange in ascending order appropriating to each value a serial number; if some numerical values coincide, it is necessary to appropriate to this value the average serial number;
- 4) to calculate values of integrated probabilities for each member of the sample according to Gauss Eq (3):

$$P = \frac{m}{n} 100\%, \quad (3)$$

where  $P$  – the empirical reliability;  $m$  – a serial number of the member of the ranked sample;  $n$  – number of members of the sample;

- 5) to make a schedule of the reliability curve ( $P_i, x_i$ ) on which the value of parameter  $x$  (in our case – temperatures) is defined depending on the value of probability  $P$ .

Under conditions of the Republic of Belarus it is suggested to accept a 95% reliability level for the roads of the lowest categories. For the highways of the I, II and III category this parameter should be equal to 98%.

The temperature limits of asphalt pavements “work” for the regional centers of Belarus also have been determined according to the results of the calculation on the basis of “BelHydroMetCencer” climatic data for the last 20 years. These limits were corrected according to the Superpave method (Table 2). The results are presented in Table 4.

Thus, depending on a disposition of the regional center, the values of asphalt “work” temperature limits under the conditions of the Republic have some differences. These differences are necessary to be considered at a design stage (selection of bitumen for AC mixtures).

**Table 4.** Results of the calculation of asphalt functional type PG for the regional centers of Belarus

Regional center	PG obtained by calculation	Corrected PG
Brest	PG 51–26	PG 52–28
Grodno	PG 49–28	PG 52–28
Vitebsk	PG 51–31	PG 52–34
Mogilev	PG 49–31	PG 52–34
Gomel	PG 54–25	PG 58–28
Minsk	PG 47–28	PG 52–28

**Fig. 7.** Zoning of the Republic of Belarus according to PG coefficient

Besides, it is possible to allocate temperature zones on a parameter of the asphalt functional type PG (Fig. 7).

As to Superpave system of asphalt mixtures design the top temperature limit on parameter PG is used as a temperature of carrying out the DSR (dynamic shear rheometer) bitumen test, and the bottom temperature limit – in BBR (bending beam rheometer) test and DDT (the direct tension test) bitumen test.

In some papers one can find a simple parity between max and min critical temperatures and, well known to us in Belarus, test for a softening temperature (Claxton, Green 1999). This dependence has been received during BP Bitumen company's researches on the asphalt samples made by the company. Therefore, it is necessary to concern with care the determined dependences, especially from a position that AC is made by using various technologies and bitumen is used from various kinds of oil.

## 6. Conclusions

1. Weather and climatic conditions of the territory where the road is located (air temperature, solar radiation and deposits) influence the “work” of asphalt pavements. High temperatures in summer lead to the occurrence of shear

deformations, and low negative temperatures in winter often assist to the formation of pavement cracks.

2. According to the asphalt mixture design system Superpave the main operation in the stage of mix design is the selection of bitumen taking into account summer and winter road maintenance (the real conditions of maintenance).

3. In the framework of the *Strategic Highway Research Program* (SHRP) the real temperature limits in which asphalt pavements “work” have been determined for various regions of the USA. Calculation of these limits resulted in the creation of the asphalt functional type specification.

4. The weather and climatic conditions of the Republic of Belarus according to the Superpave technique were analyzed on the basis of climatic data for the last 20 years. The Belarusian AC pavements work within the next temperature limits: from  $-34\text{ }^{\circ}\text{C}$  up to  $52\text{ }^{\circ}\text{C}$  at a 98% reliability level which corresponds to roads of the I, II and III category, and from  $-34\text{ }^{\circ}\text{C}$  up to  $46\text{ }^{\circ}\text{C}$  at a 50% reliability level that corresponds to roads below the III category.

5. When designing AC mixture, especially when selecting bitumen, it is necessary to take into consideration the temperature operating modes of pavement in view of the asphalt functional type PG classification. In this case it could be said with the certain confidence that bitumen will work in pavement for a long time without formation of damages in summer and in winter.

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