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Assessment of tensile strength reserve of asphalt mixtures at low temperatures

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Abstract. During winter conditions, low-temperature cracks develop at the surface of the asphalt pavement when tensile thermal stress induced in the asphalt layer during cooling equals and exceeds the tensile strength of the material. The paper presents the results of tensile strength reserve assessment of asphalt mixtures with neat and SBS-polymer modified bitumen application. The tensile strength reserve was calculated as difference between the tensile strength $\beta_t(T)$ obtained from the uniaxial tension stress test (UTST) and the cryogenic (thermal) stress $\sigma_{cry}(T)$ obtained from the thermal stress restrained specimen test (TSRST) at the same temperature T. It can be useful factor assessing the low-temperature properties of asphalt mixtures. It was found that the highest values of tensile strength reserve were obtained for the asphalt mixture with SBS-polymer modified bitumen.

Keywords: low temperature cracking, strength reserve, Thermal Stress Restrained Specimen Test (TSRST), Uniaxial Tension Stress Test (UTST)

1 Introduction

In regions with extreme winter conditions, asphalt pavements can be subjected to low temperature action that create tensile stresses as the result of limited internal stress relaxation. As a result of low-temperature action, thermal tensile stresses increase because the asphalt layer is constrained in the road pavement structure. When induced stresses exceed the fracture strength, low-temperature cracks may appear in surface of the pavement [1–5]. One of the most common laboratory method that utilizes that phenomenon of asphalt mixtures at low temperatures is the thermal stress restrained specimen test (TSRST), which was presented for the first time by Monismith et al. in 1965 [6] and described in European standard EN 12697-46 [7]. The test method that describe directly tensile strength of asphalt mixtures at low temperatures is the uniaxial tension stress test (UTST) [8, 9]. Tensile strength reserve is defined as the difference between stress curves derived from both the TSRST and the UTST. The relationship between tensile stress and tensile strength as a function of temperature was investigated by Stock and Arand [10]. The maximum value of this reserve is an important parameter helpful in understanding the low-temperature properties of asphalt mixtures in terms of thermal stresses and traffic loads.

The main objective of the paper is to assess the influence of bitumen type on tensile strength reserve properties of asphalt mixtures at low temperatures.

2 Materials and methods

Laboratory tests were conducted on asphalt mixtures for wearing course layer: asphalt concrete AC 11S for low traffic KR1÷2 (LT) and asphalt concrete AC 11S for medium traffic KR3÷4 (MT). Four types of bitumen were selected for assessment the tensile strength reserve at low-temperatures: two neat road bitumens 50/70, 70/100, and one polymer Styrene-Butadiene-Styrene (SBS)-modified bitumen 45/80–55. Standard properties of the asphalt binders used in this research are shown in Table 1. All mixes were designed in compliance with the Polish technical guidelines WT-2 2014 [11]. The properties of asphalt mixtures are presented in Table 2.

Table 1. Properties of asphalt binders

Property		Type of bitumen		
		50/70	70/100	45/80–55
Penetration at 25 °C, 0.1 mm, acc. to PN-EN 1426	original	54	81	60
	after aging RTFOT	40	48	40
R&B Temperature, °C, acc. to PN-EN 1427	original	50.8	47.8	68.6
	after aging RTFOT	57.8	53.4	67.4
Fraass Breaking Point Temperature, °C, acc. to PN-EN 12593	original	−14	−16	−16
	after aging RTFOT	−12	−10	−15

Table 2. Properties of asphalt mixtures

Type of layer	wearing course															
Type of traffic	low, design life from $0.03x10^6$ to $0.50x10^6$ of 100 kN standard axle loads								medium, design life from $0.50x10^6$ to $7.3x10^6$ of 100 kN standard axle loads							
Aggregate type	crushed gravel								crushed granite							
Filler type	limestone								limestone							
Bitumen type	70/100								50/70				45/80-55			
Bitumen content (% by mass)	5.8								5.6				5.6			
Sieve size (mm)	16	11.2	8	5.6	4	2	0.125	0.063	16	11.2	8	5.6	4	2	0.125	0.063
% Passing (by mass)	100	97	83	71	60	40	11	8.0	100	98	77	62	52	39	11	7.2

Strength reserve properties of asphalt mixtures at low temperatures were assessed by means of uniaxial tension test methods according to EN 12697-46 standard [7]. Two test methods were used: the thermal stress restrained specimen test (TSRST) and the uniaxial tension stress test (UTST). In the TSRST, the specimen, whose length is held constant, is subjected to a decrease in temperature at a constant rate of 10°C/h. Due to the prohibited thermal shrinkage, cryogenic (thermal) stress is built up in the specimen. The results of the test are the progression of the cryogenic (thermal) stress over the temperature $\sigma_{cry}(T)$ and the failure stress $\sigma_{cry,\ failure}(T)$ at the failure temperature $T_{failure}$. In the UTST, the specimen is pulled with a constant strain rate of 0,625 ±0,025 %/min at a constant temperature until failure. The strain rate for test specimens with length of 160 mm corresponds to the tension rate of 1 mm/min. The temperatures of +20°C, +5°C, -10°C and -20°C were applied. For asphalt mixture with SBS-polymer modified bitumen the additional temperature of -30°C was applied because higher strength properties of that mixture in lower temperatures. Results of the UTST are the values of the maximum stress (tensile strength) $\beta_t(T)$, and the corresponding tensile failure strain $\varepsilon_{failure}(T)$ at the test temperature T. The failure stress is equivalent to strength of the specimen at the failure temperature. On the basis of the UTST and TSRST results, the tension strength reserve $\Delta\beta_t(T)$ for each asphalt mixture was derived. The tensile strength reserve was calculated as the difference between the tensile strength $\beta_t(T)$ (obtained from the UTST as the temperature/tensile strength diagram using a quadratic function) and the cryogenic (thermal) stress $\sigma_{cry}(T)$ obtained from the TSRST at the same temperature T, using Equation (1):

$$\Delta\beta_t\ (T)=\beta_t\ (T) - \sigma_{cry}\ (T) \qquad (1)$$

where:
$\Delta\beta_t(T)$ - tensile strength reserve, MPa;
$\beta_t(T)$ - tensile strength, MPa;
$\sigma_{cry}(T)$ - cryogenic (thermal) stress, MPa.

The tensile strength reserve was also calculated as area between the tensile strength $\beta_t(T)$ and the cryogenic (thermal) stress $\sigma_{cry}(T)$ using Equation (2):

$$\beta_t\ (T)_{area}=\sum[\beta_t\ (T) - \sigma_{cry}\ (T)]\cdot\Delta T \qquad (2)$$

where:
$\beta_t(T)_{field}$ - tensile strength reserve as area, MPa·°C;
$\beta_t(T)$ - tensile strength, MPa;
$\sigma_{cry}(T)$ - cryogenic (thermal) stress, MPa;
ΔT – temperature increment, °C, ΔT=0,1°C.

The schematic diagram that explain of the test results analysis is presented in Fig. 1.

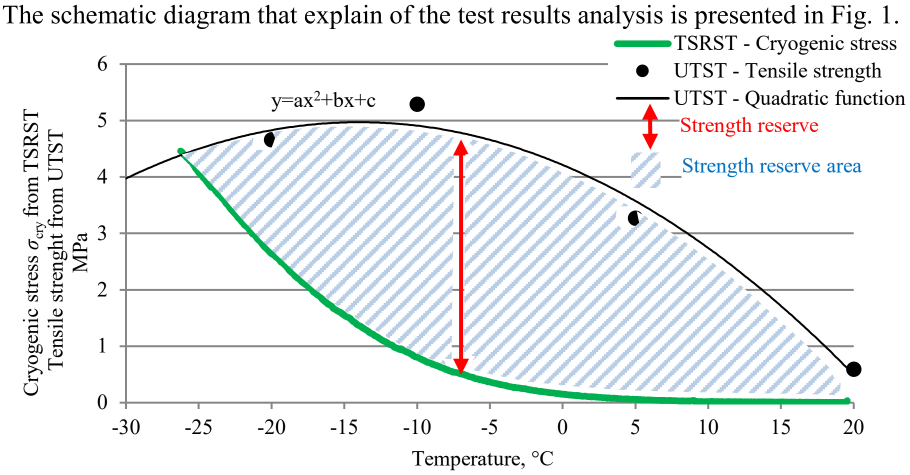

Fig. 1. Graphical explanation of Strength reserve and Strength reserve area calculation on the basis of TSRST and UTST results

3 Results and discussion

The results of tensile strength from UTST (Fig. 2a) and the results of cryogenic stresses from TSRST versus line obtained from UTST as quadratic function according to EN 12697-46 standard [7] were presented in Fig 2b, 2c and 2d.

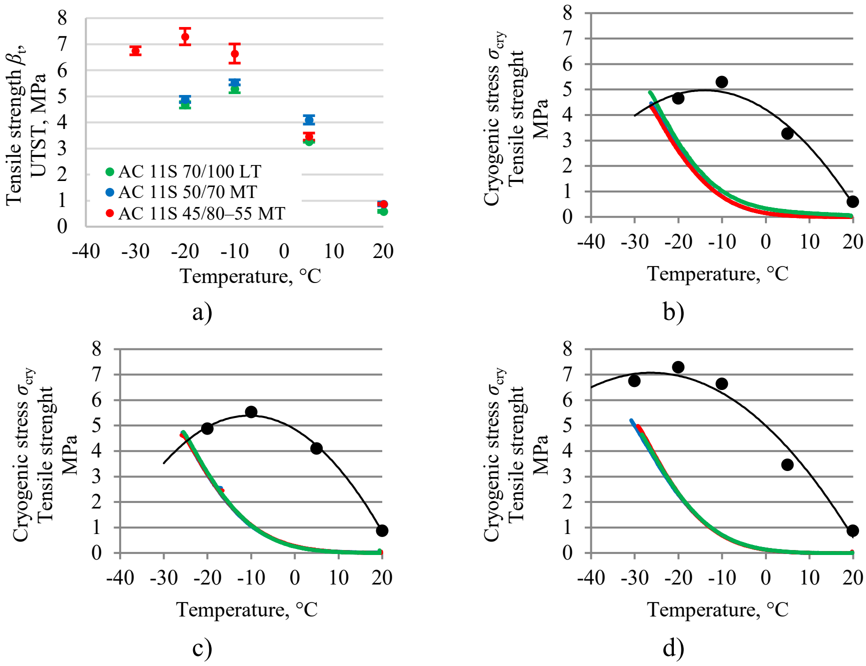

Fig. 2. Results of tensile strength from UTST (a) and cryogenic stresses from TSRST limited by line from UTST as quadratic function: AC 11S 70/100 LT (b), AC 11S 50/70 MT (c), AC 11S 45/80–55 MT (d)

Figure 3a shows the results of the tensile strength reserve calculations versus temperature, measured for the standard cooling rate 10 °C/h used in the TSRST procedure. The interpretation of the results is that the asphalt mixtures with a higher value of strength reserve have a better resistance to low-temperature cracking. There are two indicators of this resistance. One is the maximum value of strength reserve and the second is the strength reserve area.

Figure 3b presents the maximum values of tensile strength reserve calculations, 3c presents temperature corresponding maximum strength reserve. The strength reserve area calculations were presented in Fig. 3d. The temperature increment was applied as ΔT=0,1°C.

The results of the analysis indicated that the best low-temperature properties were obtained for the asphalt mixture with an SBS-polymer modified bitumen 45/80–55. The results of mixtures with neat bitumen are not clear. Mixture with 50/70 bitumen is characterized by higher maximum strength reserve but received at higher temperature than mixture with 70/100 bitumen. In case of strength reserve area the calculation are rather clear. Asphalt concrete AC 11S 45/80–55 is characterized by the highest value of strength reserve area what means has the best low temperature cracking resistance. As can be seen on Fig. 3a asphalt concrete with polymer modified bitumen below -10°C has twice higher strength reserve than asphalt concretes with neat bitumens.

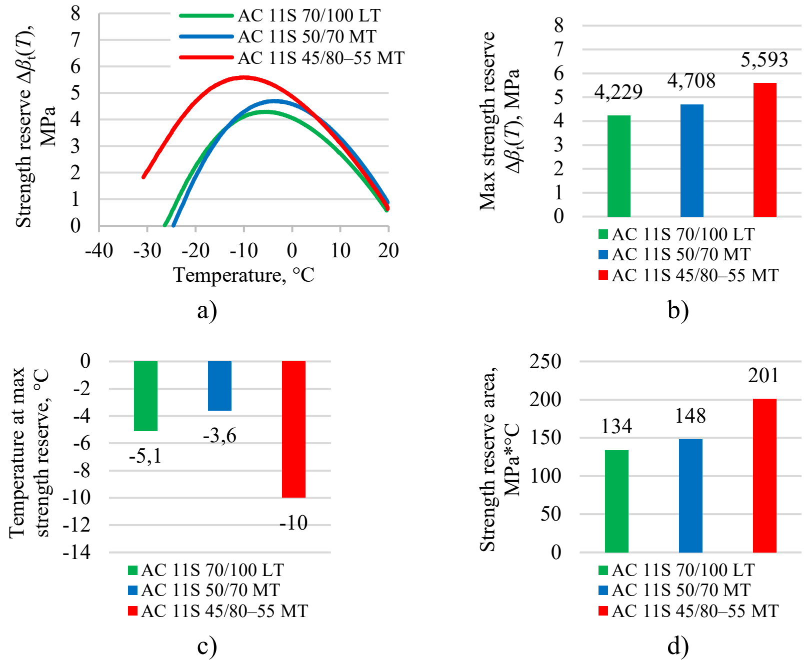

Fig. 3. Strength reserve calculations – diagram of differences between cryogenic stress from TSRST and tensile strength quadratic function from UTST (a), maximum strength reserve (b) and corresponding temperature (c), strength reserve area (d)

4 Conclusions

Based on the laboratory test results and calculations of strength reserve properties of asphalt mixtures with application of neat and SBS-polymer modified bitumens the following conclusions can be drawn:

1. On the basis of calculated values of maximum strength reserve and area between TSRST and UTST test results it was found that the highest values of tensile strength reserve were obtained for the asphalt mixture with SBS-polymer modified bitumen.
2. Not only strength reserve should be considered but also temperature at maximum strength reserve is very important. That information is essential for low temperature cracking investigation.

3. The procedure presented in the paper based on strength reserve behavior can be the useful tool to assess the low-temperature properties of asphalt mixtures.
4. In case of asphalt mixtures with polymer modified bitumen it is recommended to conduct more detailed researches taking into consideration changes in test conditions. In this case the tensile strength obtained from UTST is higher than cryogenic stress at fracture temperature during TSRST.

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