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Influence of start temperature on tensile stress testing of restrained asphalt concrete specimens

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Preliminary note

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Influence of start temperature on tensile stress testing of restrained asphalt concrete specimens

This paper presents the result of the Tensile Stress Restrained Specimen Tests on specimens of asphalt concrete AC 8 with bitumen 50/70 depending on two starting temperatures of +10 °C and +20 °C. The analysis of the results shows that there is only a non significant difference between these two start temperatures and the results are within the limit of standard precision. On the other hand, there is a difference between the results of two laboratory TU Wien and ZAG Ljubljana, who carried out the tests in accordance with EN 12697-46 at start temperature +20 °C

Key words:
asphalt concrete, start temperature, low temperatures, cracks, bitumen

Prethodno priopćenje

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Utjecaj početne temperature na ispitivanje vlačnog naprezanja pridržanih uzoraka asfaltbetona

U ovom se radu prikazuju rezultati ispitivanja vlačnog naprezanja pridržanih uzoraka obavljenog na uzorcima asfaltbetona AC 8 s bitumenom 50/70, pri čemu su korištene dvije početne temperature +10 °C i +20 °C. Analiza rezultata pokazuje da je razlika između tih dviju početnih temperatura beznačajna te da su rezultati u okviru standardnih zahtjeva točnosti. S druge strane, uočena je razlika između rezultata ispitivanja dobivenih u dva laboratorija: TU Beč i ZAG Ljubljana, gdje su ispitivanja obavljena u skladu s EN 12697-46 pri početnoj temperaturi od +20 °C.

Ključne riječi:
asfaltni beton, početna temperatura, niske temperature, pukotine, bitumen

Vorherige Mitteilung

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Einfluss der Starttemperatur bei Abkühlversuchen an Asphaltbeton-Probekörpern

In dieser Arbeit werden Resultate von Abkühlversuchen an Proben aus AC 8 Asphaltbeton und 50/70 Bitumen mit zwei verschiedenen Starttemperaturen (+10 °C und +20 °C) dargestellt. Die Analyse der Testresultate zeigt, dass keine signifikanten Unterschiede für diese zwei Temperaturwerte auftreten und die Ergebnisse sich im Bereich der Wiederholbarkeit befinden. Im Gegensatz dazu sind jedoch Unterschiede in den Resultaten zwei verschiedener Versuchsanstalten, der TU Wien und ZAG Ljubljana, die der EN 12697-46 Norm folgend ermittelt worden sind, festgestellt worden.

Schlüsselwörter:
Asphaltbeton, Anfangstemperatur, niedrige Temperaturen, Risse, Bitumen

1. Introduction

In nature, most substances including asphalt expand when they are heated and contract when they are cooled. If the contraction due to cooling is prevented with falling temperatures increasing tensile stresses in the asphalt material will be generated, which can lead to fracture (micro-cracking in the binder matrix) if the maximum tensile strength is reached [1]. Tensile Stress Restrained Specimen Tests (TSRST) simulate the condition of asphalt pavement at low temperatures, where the resulting thermally induced tensile stresses, called cryogenic stress, primarily reflect as transverse cracks spaced at 3 to 5 m [2].

The [3] concept of tensile stress, tensile strength and tensile strength reserve is shown in Fig. 1. The thermally inducted (cryogenic) stress in asphalt specimen gradually increases as temperature decreases, until the specimen fractures. At the break point, the stress reaches its maximum value – the fracture stress $\sigma_{cry,fracture}$ at fracture temperature $T_{failure}$ (hereinafter T_f). At lower temperatures the slope of the stress-temperature curve dS/dT becomes constant, and the curve is linear (elastic behaviour). The transition temperature T_u divides the curve into two parts – relaxation zone and elastic zone (non-relaxation) and tangent point of intersection T_{TS} is intersection between tangent of the stress-temperature curve at elastic zone and relaxation zone. The bitumen in asphalt specimen becomes stiffer when the temperature approaches the transition temperature and the thermally inducted stresses are not relaxed below this temperature [4].

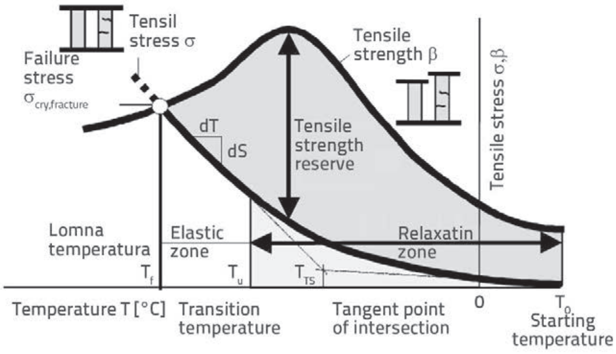

Figure 1. The Arand (1987) concept of tensile stress with relaxation and elastic zone [3]

The standard EN 12697-46 recommends to start the test at a temperature of T_0 = +20 °C. At Vienna University of Technology (TU Wien) the TSRST are traditionally carried out at start temperature of T_0 = +10 °C. In the study presented in this paper, it was investigated whether the start temperature T_0 at the TSRST has an influence on the results at low temperatures. Therefore, TSRST was carried out according to standard EN 12697-46 on asphalt concrete AC 8 at starting temperature T_0 = +10 °C and = +20 °C. TSRST was carried out at ZAG Ljubljana Institutes on the asphalt samples with 6.2 m.-% content of bitumen to compare with results of TU Wien. The both Institutes used different equipment manufacturer for TSRST. ZAG Ljubljana Institutes carried out the TSRST on compression-puller manufacturer named "Frank" and TU Wien used the equipment of manufacturer "Wille Geotechnik" from Germany.

2. Tests description

2.1. Test procedure and Equipment

For the TSRST, the asphalt concrete specimen is mounted in a load frame, which is enclosed in a cooling chamber. During the experiment the length of the specimen is kept constant and the temperature is decreased with a constant cooling rate of dT = -10 °C/h. Any movement of the specimen as consequence of thermal shrinkage is monitored by LVDTs, activating a screw jack, to keep the specimen at its original length. This process continues until the tensile stress exceeds the tensile strength and, hence, the specimen fails due to cracking. In standard EN 12697-46, it is recommended to start the test at a temperature of T_0 = +20 °C. The testing machine consists of a load frame, a screw jack, a climate chamber with temperature controller, 4 LVDTs, a specimen-alignment stand and a computer data acquisition and control system [5, 6]. The climate chamber allows to control the temperatures within T = ±40 °C (TU Wien accuracy of ±0.1 °C and ZAG accuracy of ±0.5 °C). The LVDTs are placed outside of the climate chamber (accuracy of 0.2 %). The top and bottom plates and the measurement rods are made of invar steel to avoid a strong influence of temperature changes on the measurement device [5]. Figure 2 shows TSRST equipment of the TU Wien and illustration of setup of the employed testing equipment.

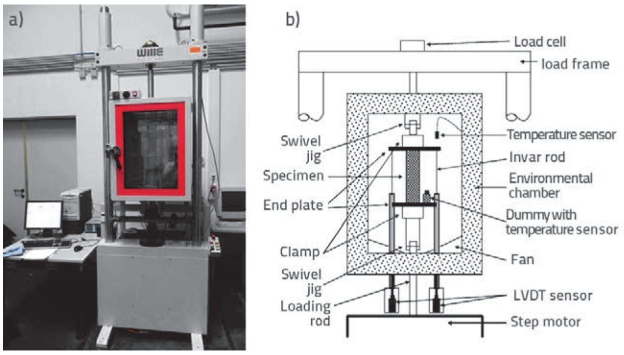

Figure 2. a) TSRST equipment in TU Wien; b) illustration of setup of the employed testing equipment

The results of a TSRST are the progression of the temperature-dependent cryogenic stress $\sigma_{cry}(T)$ [MPa], the failure stress $\sigma_{cry,failure}$ [MPa] and the failure temperature $T_{failure}$ [°C]. The results derived from TSRST on three samples (duplicates) by the same operator shall be considered suspected if they differ by more than 2 °C of the failure temperature and 0.5MPa of the failure stress. The precision highly depends on the range of void content of the samples of the asphalt mixture. An illustration of the test procedure of TSRST is given in Figure 3.

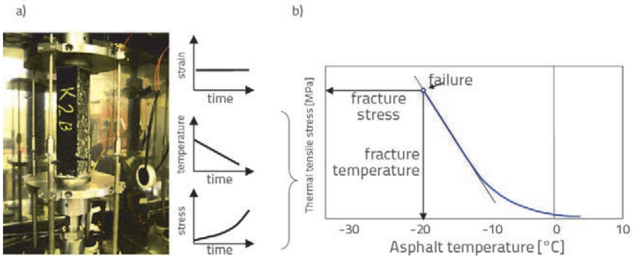

Figure 3. TSRST: a) experimental setup; b) illustration of result [6]

2.2. Material

The tests were carried out on asphalt concrete 0/8 mm (AC 8). The asphalt mixture and test specimens were prepared in the laboratory ZAG Ljubljana. The asphalt mixtures have 6.2 m.-% of bitumen content. Stone fractions used for the stone aggregate mixture are as follows: filler aggregate (grain under 0.125mm) from Stahovica (limestone), mineral aggregate 0/2, 2/4 and 4/8 mm from Ljubešćica (silicate) and for binder we used paving grade bitumen 50/70 by MOL (Hungary). Figure 4 presents grain size distribution for this asphalt mixture 0/8 mm (AC 8). The bitumen and aggregates were heated to prior to mixing at temperature T = 150 °C, for around 0.5 h. Also, prior to compacting, the mixture was conditioned at T = 150 °C, for 0.5 h. For TSRST tests we used a rectangular specimen with cross section dimensions 40 x 40 mm^2 and a length of 160 mm. After trimming, the specimens were conditioned at room temperature T = 20±2 °C and tested in a few days. Table 1 shows properties of used fresh and extracted with trichloroethylene Infratest Asphalt Analyzer (EN 12697-1) paving grade bitumen 50/70. Table 2 presents the results of some basic tests of asphalt mixtures.

Table 1. Properties of paving grade bitumen 50/70

Technical characteristics	Test method	Fresh bitumen	Extracted bitumen
Penetration at 25°C [mm/10]	EN 1426:2007	58	37
Softening point R&B [°C]	EN 1427:2007	50	55,6
Penetration Index PI	EN 12591:2004, dio B4	-0,4	-0,57
Braking point (Fraass) [°C]	EN 12593:2007	-8	-7
Density (in water) [kg/m³]	EN ISO 3838	1020	-
BBR - stiffness S60 [°C]	EN 14771:2005	-15,6	-
BBR – value m-60 [°C]	EN 14771:2005	-17,8	-

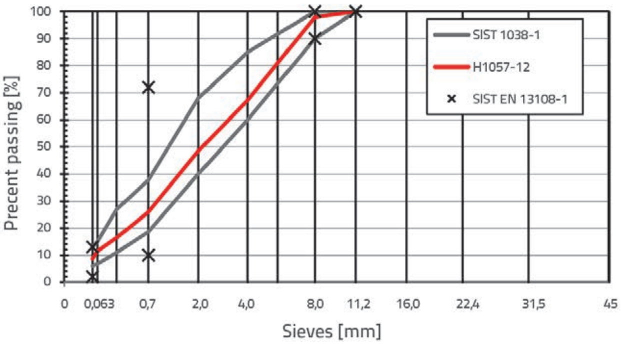

Figure 4. Grain size distribution of AC 8

3. Results and analysis

3.1. Comparison between the two starting temperatures

The results obtained from testing of asphalt concrete AC 8, used for wearing courses on pavements, are presented in Table 3. Three specimens K348A-C have been tested at start test temperature T_0 = +10 °C and the remaining three asphalt samples K348D-G at T_0 = +20 °C. Statistically speaking, all the results of the failure stress showed that the spread between the results slightly above the permitted limit of 0.5 MPa by the standard EN 12697-46. At failure temperature, the results are within the requirements by the standard (<2 °C). If results are looked separately by the start temperature T_0 = +10 °C and T_0 = +20 °C, it can be seen that both cases do not exceed the requirements.

Figure 5.a and 6.a show stress-temperature diagram of the TSRST at start test temperature T_0 = +10 and +20 °C carried out in TU Wien. The both curves have smooth line. Figure

Table 2. Results of some basic tests of asphalt mixtures

Parameters Test	Bitumen content [m.- %]	Grain size <0.063 mm [m.-%]	Maximum density of specimen [kg/m³]	Bulk density of specimen (Marshall) [kg/m³]	Air voids of specimen (Marshall) [V.-%]	Voids filled with bitumen VFB [V.-%]	ITS [kPa]
H1057-12	6.2	8.7	2542	2483	2.3	86.7	1036

Table 3. Results of some basic tests on rectangular specimen and TSRST test

Laboratory	Specimen	Test start temperature [°C]	Bulk density of specimen [kg/m³]	Air voids of specimen [V,-%]	Average width of specimen [mm]	Average length of specimen [mm]	Failure stress $\sigma_{cry,failure}$ [MPa]	Failure temperature $T_{failure}$ [°C]
TU Wien	K348A	+10	2507	1,4	40,40	161	5,44	-31,5
	K348B		2505	1,5	40,59	161	4,82	-31,7
	K348C		2503	1,5	40,29	161	5,05	-30,5
	K348D	+20	2513	1,1	40,64	161	5,07	-31,4
	K348F		2497	1,8	40,44	161	5,50	-31,4
	K348G		2512	1,2	40,27	161	4,99	-30,5
ZAG Ljubljana	001	+20	2509	1,3	40,33	161	4,58	-27,0
	002		2504	1,5	40,42	161	4,45	-24,3
	003		2501	1,6	40,38	161	4,83	-26,8
Average - x			2505,67	1,43	40,42	161,0	4,97	-29,46
Standard deviation - s			5,17	0,21	0,13	0,0	0,35	2,71
Range - r			16	0,70	0,37	0,0	1,05	7,40

5b and 6b presents results of failure stress and failure temperature of the TSRST test at start test temperature T_0 = +10 and +20 °C.

Both stress – temperature curves at start test temperature T_0 = +10 °C (blue line) and +20 °C (red line) are presented in Figure 7a. Practically, the both curves in the relaxation

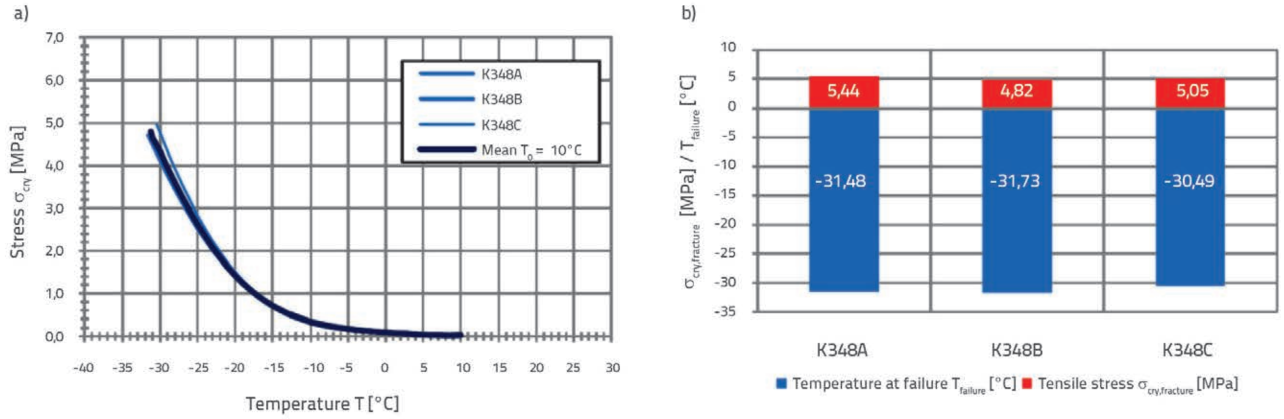

Figure 5. Results of TSRST test at start temperature T_0 = +10 °C: a) cryogenic stress $\sigma_{cry}(T)$; b) failure stress $\sigma_{cry'failure}$ and the failure temperature $T_{failure}$

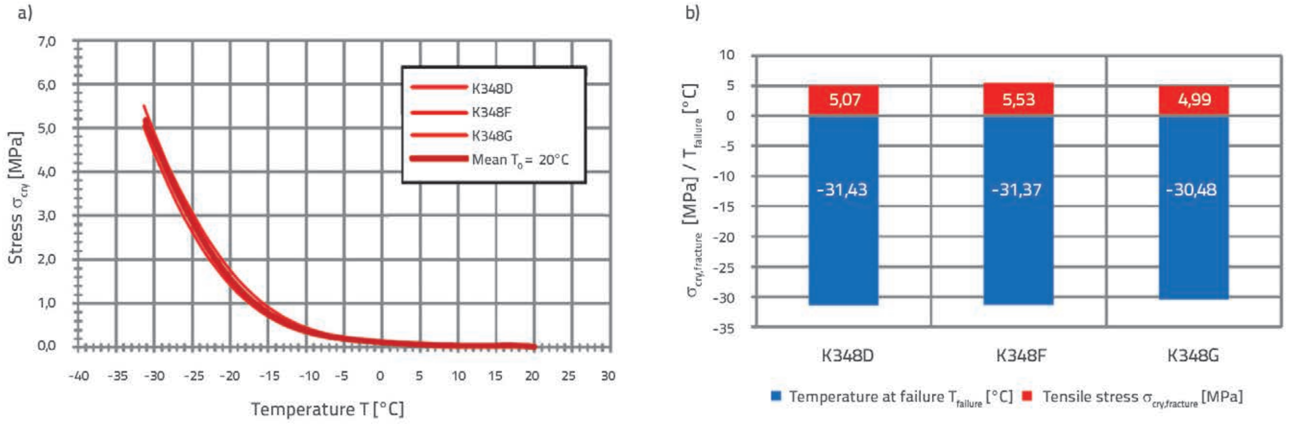

Figure 6. Results of TSRST test at start temperature T_0 = +20 °C: a) cryogenic stress $\sigma_{cry}(T)$; b) failure stress $\sigma_{cry'failure}$ and the failure temperature $T_{failure}$

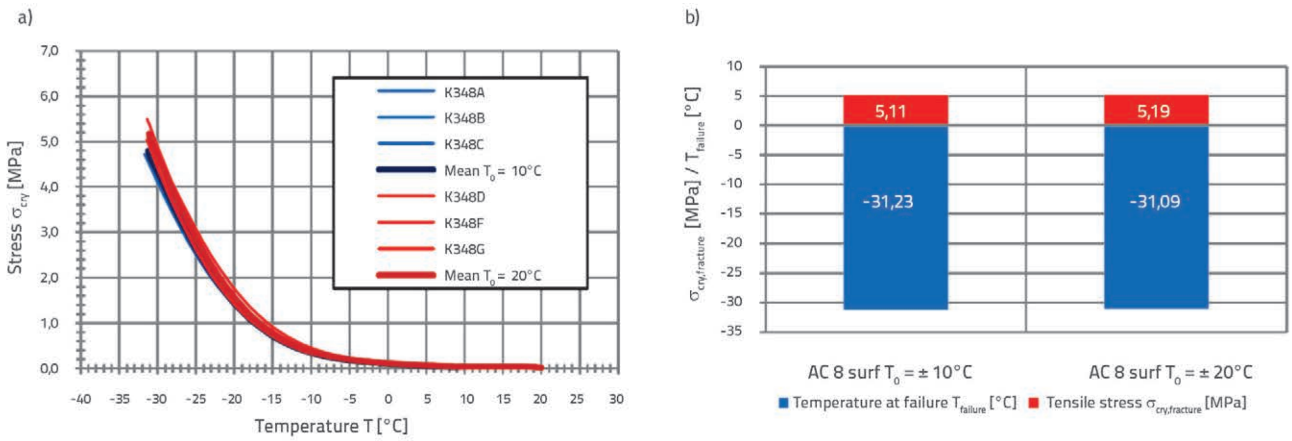

Figure 7. Results of TSRST test at start temperature T_0 = +10 °C and T_0 = +20 °C: a) cryogenic stress σ_{cry}(T); b) failure stress $\sigma_{cry'failure}$ and the failure temperature $T_{failure}$

zone follow the same curve. In the elastic zone curves are slightly apart, but within expectations. The results of failure stress and failure temperature are graphically presented in Figure 7b, where it is seen that the results are comparable. An asphalt mixture, up to a certain temperature is capable of internal movements in the structure without causing a visible change on the outside forms (relaxation phenomenon). Between temperature of +10 °C and +20 °C, these relaxation characteristics of the mixture reduce inducted thermal stress in asphalt specimens and thus that differences between TSRST at start temperatures of +10 °C and +20 °C are negligible.

If a body has one dimension which is much larger than the other two, the two smaller dimensions can be ignored and only the expansion of the length can be looked at. Change of the body length Δx with temperatures change is defined as:

$$\Delta x = \alpha_T \cdot x \cdot \Delta T \tag{1}$$

where is x initial body length, ΔT the temperature change and α_T thermal expansion coefficient of the length.

If input in the equation (1) is given as x =161mm (length of the asphalt specimen), ΔT = +20 °C – (+10 °C) = 10°C and α_T = 2.2 x 10^{-5} [5] as the thermal expansion coefficient of asphalt concrete then change of the specimen length is Δx = 0.0354 mm. According to the required resolution of the LVDTs in EN 12697-46 (0.5 μm = 0.0005 mm), this displacement should be measured and controlled the specimen original length by the test machine. Therefore, equipment does not effect on the results at start temperature T_0 = +10 °C.

3.2. Comparison between the two laboratories

Figure 8 shows the stress-temperature curves of TSRST, which were carried out on prismatic asphalt concrete samples at ZAG Ljubljana (red curve) and TU Wien (blue curve). The curves split in two parts between the temperatures around 5 °C. At colder temperature both curves runs parallel. At tensile stress of 1.0 MPa the temperature difference between curves is between 5-6 °C. The mean curve TU Wien is average of three curves (K384D, K384F and K384G) and the equation reads as follows

$$y_1(x) = -3E\text{-}09x^6 - 6E\text{-}08x^5 + 4E\text{-}06x^4 - 4E\text{-}05x^3 + 0{,}0006x^2 - 0{,}0119x + 0{,}1134 \tag{2}$$

Mean curve ZAG is average of curve 001, 002 and 003 with equation:

$$y_2(x) = -2E\text{-}09x^6 - 8E\text{-}09x^5 + 1E\text{-}06x^4 - 8E05x^3 + 0{,}0029x^2 - 0{,}0365x + 0{,}1962 \tag{3}$$

If we want to get the tangent line equation y(x) = kx + n to a curve at a given point in the elastic zone, it is necessary to derivative the curve function y(x). In this study the tangent is calculated at the brake point V1 (T_f = -31.09 °C, $\sigma_{cry,f}$ = 5.19 MPa) for TU Wien and V2 (T_f = -26 °C, $\sigma_{cry,f}$ = 4.26 MPa) for ZAG. The equation of both tangents is shown on Figure 8. The intersection of the tangent and the curve is the transition temperature T_u. The transition temperature is T_{u1} = -27.2 °C for TU Wien and T_{u2} = -24.1 °C for ZAG. Therefore, the relaxation zone at TU Wien is longer as ZAG. In the elastic zone the curve slope of the results derived at TU Wien (dS/dT = 0.4035) is little higher that at ZAG (dS/dT = 0.2955). Figure 9 shows the results of TSRST test at start temperature T_0 = +20 °C for TU WIEN and ZAG. The difference of the average temperature at failure T_f between TU Wien and ZAG is 5 °C and is outside the permitted range in accordance with EN 12697-46 (<2 °C). The TU Wien samples have higher tensile stress as ZAG (for 0.57 MPa), which is outside the permitted range (<0.5 MPa). The results of the TSRST at TU Wien have better resistance to cracking at low temperatures. All of these differences could be due to various factors as preparing and gluing samples, precision or resolution of LVDTs or differences in the test machine.

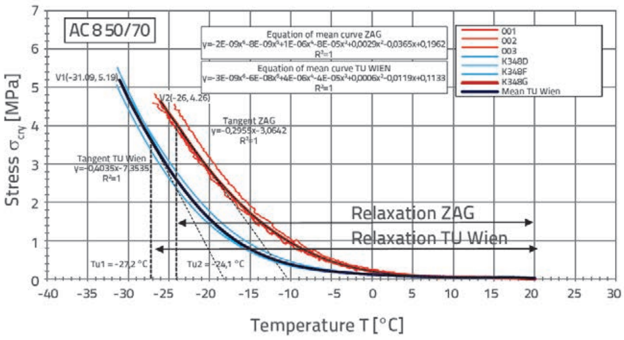

Figure 8. Results of TSRST test at start temperature T0 = +20 °C for TU Wien and ZAG Ljubljana: cryogenic stress σ_{cry}(T)

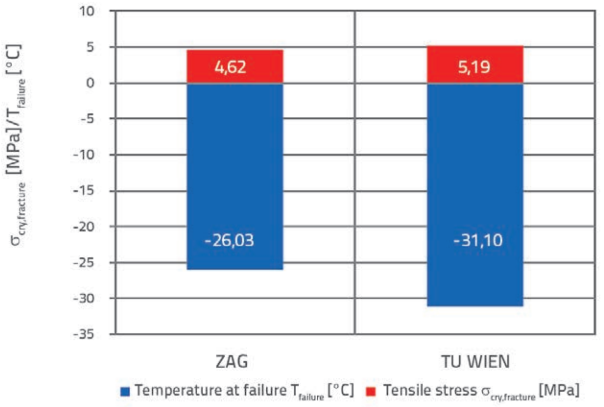

Figure 9. Results of TSRST test at start temperature T_0 = +20 °C for TU WIEN and ZAG Ljubljana: failure stress $\sigma_{cry'failure}$ and the failure temperature $T_{failure}$

4. Conclusion

The result of Tensile Stress Restrained Specimen Tests (TSRST) on specimens of asphalt concrete AC 8 surf with bitumen 50/70 depending of two starting temperatures of T_0 = +10 °C and +20 °C is shown in this paper. The analysis of the results TSRST at TU Wien shows that there is no influence between these two starting temperatures and the results are within the limit of precision given by the standard EN 12697-46. At the University of Nevada Reno found that effect of different starting temperatures (T_0 = +5 °C and +20 °C) is smaller than effect of different cooling rates [7]. In the relaxation zone both curves (T_0 = +10 °C and +20 °C) in the stress-temperature diagram are congruent. In the elastic zone curves are slightly apart, but within expectations. Since at temperature of +10 °C and +20 °C the viscous component in asphalt mixture is dominates and the relaxation characteristics of the asphalt mixture reduce inducted thermal stress, the difference between TSRST at starting temperatures of +10 °C and +20 °C is negligible.

The results of TSRST, comparison between ZAG Ljubljana and TU Wien, shows that there is a considerable difference, although both Institutes carried out TSRST in accordance to the standard EN 12697-46. In this case the both curves TU Wien and ZAG run apart at temperature around 5 °C, but at colder temperature run parallel. At a tensile stress of 1.0 MPa the temperature difference between curves is 5-6 °C. The relaxation zone at TU Wien is longer as ZAG and in the elastic zone the slope of curve is little higher at TU Wien. All of these differences could be due to various factors (etc. gluing samples, equipment).

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