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Impact of characteristics of asphalt concrete wearing courses on crack resistance at low temperatures

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Abstract

Cracks of various shapes and sizes are among the most widespread damage to road surfaces. The main reason for the formation of cracks in the asphalt layer are increasing tensile and shear stress and strain to the point when exceeds the strength of the material. To evaluate influential factors on strength of the asphalt several laboratory tests of the asphalt mixture AC 8 and AC 11 at low temperatures according to EN 12697-46 were performed. We studied effect on the content of bitumen and void content in asphalt samples on maximum tensile strength reserve and temperature at maximum reserve. The impact of different start temperature and different sample preparation technique on the TSRST test results was evaluated. With statistical analyzes we analyzed effect of the specimen length, and bulk density on maximum tensile strength reserve and temperature at maximum reserve. Main results of our study were recommendations for test conditions and for further research.

Keywords: Asphalt concrete, Low temperatures, Cracks

Résumé

Les fissures de différentes formes et tailles sont parmi les dégâts les plus répandues à la surface de la route. Les principales raisons de la formation de fissures dans la couche d'asphalte sont la traction, la contrainte de cisaillement et la déformation au point où il dépasse la résistance du matériau. Pour évaluer les facteurs influents sur la force de l'asphalte, plusieurs tests de laboratoire sur l'enrobé AC 8 et AC 11 à basse température selon la norme EN 12697-46 ont été effectués. Nous avons étudié l'effet du contenu du bitume et du taux de vide dans des échantillons d'asphalte sur la force de traction maximale et la température maximale. L'impact des différentes températures de départ et la technique de préparation de l'échantillons des tests TSRST a été évaluée. Avec des analyses statistiques, nous avons analysé l'effet de la longueur de l'échantillon, et la densité apparente sur la force de traction maximale et la température maximale. Les principaux résultats de notre étude sont des recommandations sur les conditions de test et pour des recherches antérieures.

Mots-clés: béton bitumineux, les basses températures, fissures.

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Nomenclature

TSRST	Tensile Stress Restrained Specimen Test
UTST	Uniaxial Tensile Strength Test
T_f	fracture temperature at TSRST test
$\sigma_{cry,f}$	tensile stress at TSRST test
$T_{\Delta\beta tmax}$	temperature at tensile strength reserve
$\Delta\beta_{tmax}$	tensile strength reserve

1. Introduction

In nature, most substances including asphalt extend 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 if the maximum tensile strength is reached (Arand, 2002). The low temperature cracking occur as transverse (cryogenic stress) and/or longitudinal (low temperature and traffic loading) and they propagate down from the surface. This paper presents the results of analysis and testing of asphalt concrete 11 surf B50/70 A2/Z2 and asphalt concrete 8 surf B50/70 A2/Z2 at low temperatures as a function of characteristics of asphalt mixture. We have carried out Tensile Stress Restrained Specimen Test – TSRST and Uniaxial Tensile Strength Test – UTST, both tests according to standard EN 12697-46. TSRST test simulates 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 (Fig. 1a). UTST test simulates the resistance of asphalt mixtures at low temperatures exposed to traffic loading. The maximum of critical tensile stress does not occur in the wheel track but in a distance of 30 cm to 90 cm from the location of loading (Fig. 1b) (Spiegl, 2008). The difference between the tensile strength and low temperature stress is known as the tensile strength reserve $\Delta\beta(T)$ and it is the reserve that is available to accommodate additional superimposed stresses (traffic inducted stress) (The Shell Bitumen Handbook, 2003).

Fig. 1. Babno Polje, February 2012: (a) Transversal thermal crack, (b) Longitudinal crack at the wheel tracks.

2. Tests on asphalt concrete mixtures at low temperatures

2.1. Materials and tests on AC 11

The low temperature tests were first performed on asphalt concrete AC 11 surf B 50/70 A2/Z2 in the laboratory of the Slovenian National Building and Civil Engineering Institute (ZAG) (Hribar, 2012). We used a rectangular specimen with cross section dimensions 40 x 40 mm and a length of 160 mm. All of asphalt mixtures and test specimens were prepared in the ZAG laboratory. For the stone aggregate mixture were used stone fractions, as follows: filler aggregate (grain under 0.063 mm) from Stahovica (limestone), mineral aggregate 0/2, 2/4, 4/8 and 8/11 mm from Ljubešćica (silicate), for binder we used paving grade bitumen B50/70 by MOL (Hungary). In the laboratory we prepared five different mixtures with bitumen content of 3.9, 4.9, 5.3, 5.6 and 6.0 m.-%. Table 1 shows properties of used fresh and extracted paving grade bitumen B50/70.

Table 1. Properties of paving grade bitumen B50/70

No.	Technical characteristics	Unit	Test method	Fresh bitumen	Extracted bitumen
1	Penetration at 25ºC	mm/10	SIST EN 1426:2007	56	39
2	Softening point, R&B	ºC	SIST EN 1427:2007	52	56.6
3	Fraass braking point	ºC	SIST EN 12593:2007	-15	-13
4	Density (in water)	kg/m^3	SIST EN ISO 3838	1014.2	-

When we vary the content of bitumen at the same sieving curve of stone aggregates then we must vary the content of air voids or the content of filler aggregate. In our research, we decided to try to keep a constant content of filler aggregate in asphalt mixture and to vary air voids. Table 2 presents the results of some basic tests of asphalt mixtures. Nevertheless, the results show that we slightly varied filler content. The maximum deviation from target filler content was found in the asphalt with bitumen content of 5.6 m. -%.

Table 2. Results of some basic tests of asphalt mixtures

No.	Bitumen content	Grain size <0.063 mm	Bulk density of Marshall specimen	Air voids of Marshall specimen	Voids filled with bitumen	Marshall stiffness	Marshall flow
Unit	[m.- %]	[m.-%]	[kg/m^3]	[V.-%]	VFB [V.-%]	[kN/mm]	[mm]
H1006-12	3.9	9.3	2404	8.0	62.8	2.7	4.1
H3893	4.9	9.1	2441	5.0	79.4	2.3	4.7
H3874	5.3	9.0	2461	3.8	86.1	2.1	5.3
H3898	5.6	8.6	2467	2.6	92.5	2.7	4.5
H1115-11	6.0	9.0	2484	1.8	97.9	1.8	6.0

2.2. Materials and tests on AC 8

The low temperature tests on asphalt concrete AC 8 surf B 50/70 A2/Z2 were carried out in the ZAG, Ramtech and TU Wien laboratories. Scheme of tests is presented in Table 3. We used a rectangular specimen with cross section dimensions 40 x 40 mm and a length of 160 mm. All asphalt mixtures and test specimens were prepared in the ZAG laboratory. For the stone aggregate mixture we used stone fractions as follows: filler aggregate (grain under 0.125 mm) from Stahovica (limestone), mineral aggregate 0/2, 2/4 and 4/8 mm from Ljubešćica (silicate), for binder we used paving grade bitumen B50/70 by MOL (Hungary). In the laboratory we prepared five different mixtures with bitumen content of 4.0, 4.9, 5.4, 5.8 and 6.2 m.-%.

Table 3. Program of low temperature test on asphalt concrete AC 8 surf B 50/70

Bitumen content in AC 8 samples	4 m.-%	4.9 m.-%	5,4 m.-%	5,8 m.-%	6,2 m.-%
ZAG Ljubljana (SLO)	x		x		x
ISTU - TU Wien (A)		x		x	x (only TSRST)
RAMTECH Zagreb (HR)		x		x	

3. Results and analysis

3.1. Results on AC 11

The results of cooling test TSRST of asphalt mixture AC 11 surf B 50/70 A2/Z2 show poor correlation between tensile stress σf/bitumen content and fracture temperature Tf/bitumen content (Fig. 2) (Hribar, 2012). On the other hand, the results of tension strength reserve calculations show surprisingly good quadratic correlations between maximum tensile strength reserve Δβ/bitumen content (R^2 = 0.92) and the temperature at maximum tensile strength reserve TΔβ /bitumen content (R^2 = 0.90) (Fig. 3). From those correlations, we think that the strength reserve calculation better describes the influence of bitumen content at low temperatures. Further, the variation of filler content (Table 2) has a greater impact on the results of the cooling test TSRST. Figure 3a presents that with the increase of bitumen content from 4.9 to 6.0 m.-% the maximum tensile strength reserve Δβ increases significantly and the temperature at maximum tensile strength reserve TΔβ is drastically reduced from -6.8 °C to -10.5 °C (Fig. 3b). For asphalt mixtures with bitumen content between 4.0 and 4.9 m.-% both values are almost constant. From these results we can conclude that the bitumen content plays an important role at low temperatures. By increasing the bitumen content over 4.9 m.-% we found a significant improvement in properties of studied asphalt concrete and increased resistance to cracking at low temperatures.

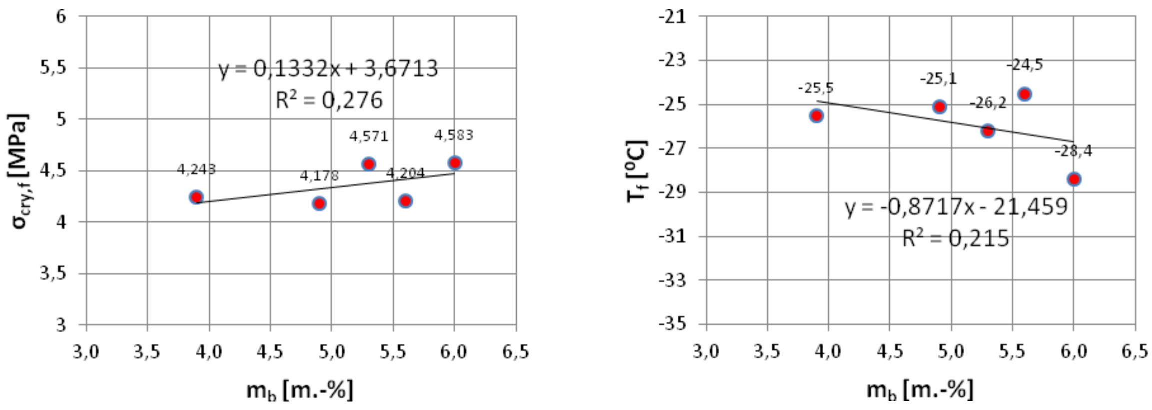

Fig. 2. Results of TSRST cooling test for AC 11 surf B 50/70 A2/Z2 in the dependence of bitumen content m_b [m.-%]: (a) Maximum tensile stress σf, (b) Fracture temperature Tf.

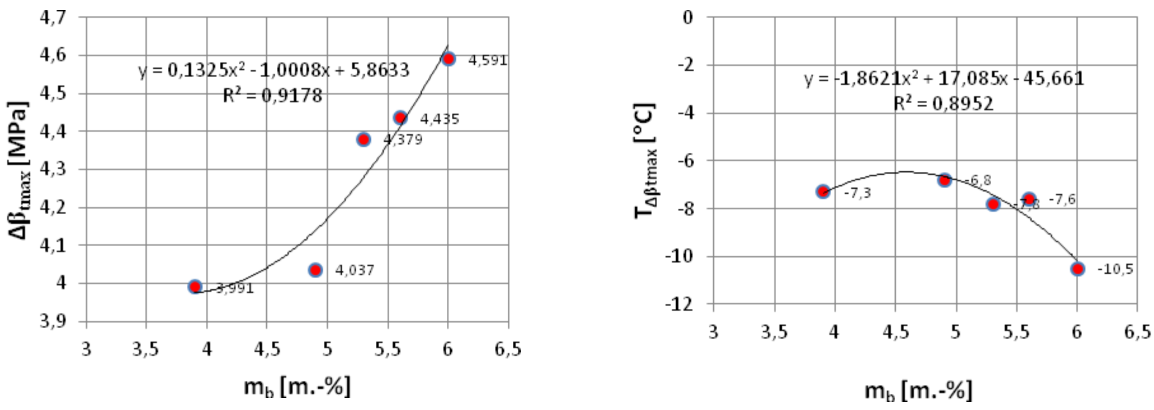

Fig. 3. Results of cooling test for AC 11 surf B 50/70 A2/Z2 (a) Maximum tensile strength reserve Δβ in the dependence of bitumen content m_b[m.-%], (b) Temperature at maximum tensile strength reserve $T_{\Delta\beta}$ in the dependence of bitumen content m_b [m.-%].

3.2. Results on AC 8

From he results of cooling test TSRST of asphalt mixture AC 8 surf B 50/70 A2/Z2 we found poor correlation between tensile stress σf/bitumen content and fracture temperature Tf/bitumen content). Also at tensile strength reserve calculations we found poor correlations between maximum tensile strength reserve Δβ/bitumen content (R^2 = 0.10) and the temperature at maximum tensile strength reserve TΔβ /bitumen content (R^2 = 0.14). Reason for such differences in results of low temperature test between two similar asphalt mixtures as AC 8 and AC 11 could be low reproducibility of tests in different laboratories. From numerical results presented in table 4 we concluded that there must be systematical difference between performance of low temperature test in TU Wien laboratory and other two laboratories.

Table 4. Results of TSRST and tensile strength reserve low temperature tests

Laboratory	Bitumen content	$T_{f\,(TSRST)}$	$\sigma_{cry,f(TSRST)}$	$T_{\Delta\beta tmax}$	$\Delta\beta_{tmax}$
Unit	[m.- %]	[ºC]	[MPa]	[°C]	[MPa]
ZAG*	4.0	-27,4	4,73	-7,4	4,448
TU WIEN**	4.9	-30,5	4,28	**-10,4**	**5,013**
RAMTECH*	4.9	-26,0	4,39	-4,6	3,311
ZAG*	5.4	-25,5	4,74	-5,6	3,905
TU WIEN**	5.8	-31,7	4,09	**-12,6**	**5,435**
RAMTECH*	5.8	-30,7	4,69	-7,6	3,878
ZAG*	6.2	-26,0	4,62	-9,0	4,609
TU WIEN*	6.2	-31,1	5.19	No result	No result
TU WIEN**	6.2	-31,2	5.10	No result	No result

* TSRST test starts at +20°C.
** TSRST test starts at +10°C.

At first it was assumed that cause for the difference is in different stating temperature of TSRST test in TU WIEN laboratory. In TU WIEN TSRST test starts at +10°C, in other laboratories according to EN 12697-46 starting temperature is +20°C. In TU WIEN for one sample TSRST test was additionally performed with starting temperature +10°C (Hribar, 2013). From results in Table 4 we concluded that difference between TSRST results in different laboratories is not due to different starting temperatures. We checked the dimensions of used specimens and we found out they were uniform and inside the requirement of the standard. The only difference we found between laboratories was different type of glue and bigger quantity of glue used in TU WIEN. We compared the results of UTST test (Table 5) and we found out that tensile strengths (β_t) are significantly higher at -10 ºC and -25 ºC and lower at +5 ºC in TU WIEN. The other problem is that generally in this laboratory UTST test at +20 ºC is not performed. Graphically this can be seen in figure 4. It is logically that this difference leads to different calculation of maximum tensile strength reserve (Fig.5).

Table 5. Results of tensile strength β_t at UTST low temperature tests

Laboratory	Bitumen content	tensile strength β_t	tensile strength β_t	tensile strength β_t	tensile strength β_{tt}
	[m.- %]	+20 ºC	+5 ºC	-10 ºC	-25 ºC
TU WIEN	4.9	No result	2.307	**5.360**	**5.067**
RAMTECH	4.9	0.579	2.833	4.004	3.769
TU WIEN	5.8	No result	1.987	**5.647**	**5.803**
RAMTECH	5.8	0.784	2.997	4.497	4.156

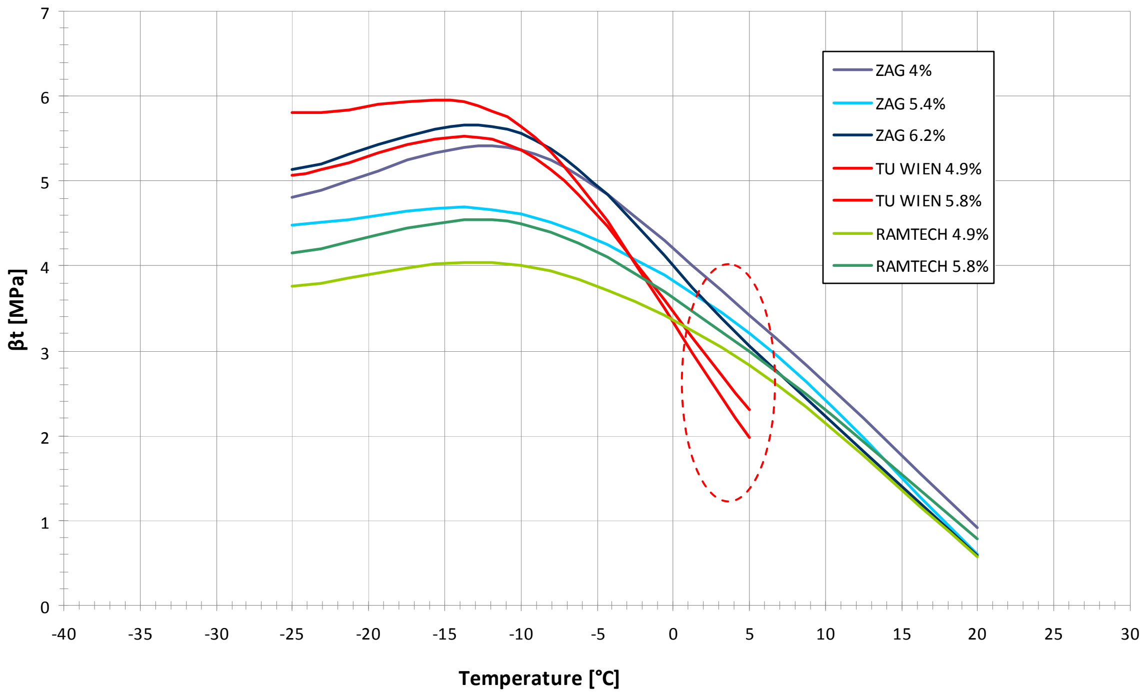

Fig. 4. Results of UTST cooling test for AC 8 surf B 50/70.

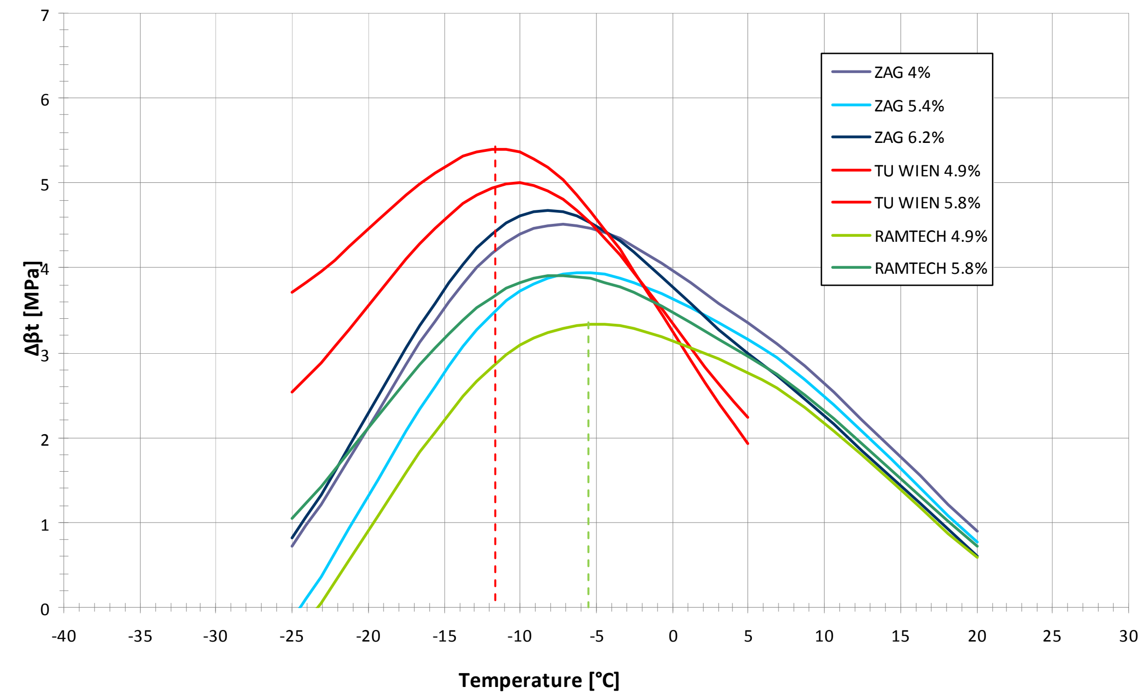

Fig. 5. Results of tensile strength reserve for AC 8 surf B 50/70 A2/Z2

4. Conclusions

The results of the tests at the low temperature on the asphalt concrete 11 surf B 50/70 A2/Z2 as a function of the bitumen content are presented in the first part of the paper. We have performed the cooling test (Tensile Stress Restrained Specimen Test – TSRST) and uniaxial tensile test (Uniaxial Tensile Strength Test – UTST) in one laboratory. The analysis of results has shown better correlation between the properties of bituminous mixtures and UTST test results, than between the properties of bituminous mixtures and TSRST test. Due to limited number of samples it is not clear if the reason for this phenomenon is in testing error or is it a more general rule. What is especially visible is a good correlation between the results in the maximum reserves of tensile strength and temperature at the maximum reserve tensile strength as a function of the bitumen content. From those correlations, we concluded that the influence of bitumen content at low temperatures is better described with the UTST test. Further, the variation in the filler content has bigger impact on the results of TSRST cooling test. By increasing the bitumen content over 4.9 m.-% we found a significant improvement in the properties of asphalt concrete and increased resistance to cracking at low temperatures.

The results of the tests at the low temperature on the asphalt concrete 8 surf B 50/70 A2/Z2 as a function of the bitumen content are presented in the second part of the paper. We have performed the cooling test (Tensile Stress Restrained Specimen Test – TSRST) and uniaxial tensile test (Uniaxial Tensile Strength Test – UTST) in three laboratories and differences between laboratories were significant. 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 was analysed. 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.

The comparison between results of UTST test in RAMTECH and TU Wien laboratories shows that there is a considerable difference, although both Institutes carried out UTST in accordance to the standard EN 12697-46. We found out that tensile strengths (βt) are significantly higher at -10 °C and -25 °C and lower at +5 °C in TU WIEN. We checked the dimensions of used specimen and we found out they were uniform and inside the requirement of the standard. Differences in results could be due to various factors (etc. gluing samples, equipment). We assumed that the main reason was different glue and bigger quantity of glue used in TU WIEN.
From the study we can recommend that type of glue and quantity of used glue must be more precisely specified in the standard. Starting temperature of TSRST test can vary between +10°C and +20°C without any significant impact on the results.

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