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Research paper

Use of Tensile Creep Test (TCT) for evaluation of low temperature performance of bituminous mixtures used for bridge pavement

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Abstract: One of the main causes of road pavement distress are low temperatures, and hence the need to thoroughly study the low temperature performance of all bituminous materials used in road construction. The purpose of this study was to determine the performance of alternative and conventional bituminous mixtures in the temperature range between –25°C and –10°C using for this purpose the Tensile Creep Test (TCT). The low-temperature performance data were evaluated using the Burgers model, a tool that is widely used for evaluation of bituminous mixtures. This research focuses on bridge paving mixtures. These included both conventional (mastic asphalt) and alternative (SMA-MA) materials. It was established, based on the test results and their analysis, that low temperature performance of a bituminous mixture is influenced, in the first place, by the characteristics of the asphalt binder it contains. Furthermore, SMA-MA mixtures showed better low temperature performance than conventional, mastic asphalt type mixtures.

Keywords: bridge pavement, tensile creep test, relaxation time

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1. Introduction

In pavements that are not resistant to low temperatures or temperature fluctuations (frequent freeze-thaw cycling) thermally induced cracking and/ or thermal fatigue cracking is bound to occur. Thermally induced distress can take various forms, including block, transverse or irregular cracking. The form of thermal cracking is a function of many factors such as climate, conditions and duration of road operation, the type and thickness of the bituminous layers, the type of the road subgrade and viscous-elastic characteristics of the materials. The type of cracks is also influenced by the characteristics of bituminous mixtures. These characteristics are, in turn, derived from three main factors, in other words the properties of the aggregate and bituminous binder and their proportions in the mixture. The report [1] lists four material-related factors that may influence the bituminous mixture's low-temperature performance under:

- binder type – mixtures made using bituminous binders with a higher penetration grade are less susceptible to thermal cracking,
- aggregate type – the aggregates with high water and frost resistance and low water absorption rate reduce the risk of low temperature cracking,
- bitumen content – a change in the amount of binder content has little effect on the low-temperature performance of bituminous mixtures,
- air voids content – the degree of compaction and the air voids content has no significant effect on low temperature cracking of bituminous mixtures.

The same report also points to environmental factors, including:

- temperature – most low-temperature cracking occurs when the ambient temperature drops below the glass transition temperature of the bituminous mixture.
- temperature drop rate – a more rapid temperature drop increases susceptibility to cracking.
- age of pavement – older surfaces are more susceptible to cracking at low temperatures (due to ageing of bituminous binders).

The type of bituminous binder and aggregate, in terms of low temperature resistance, are the key factors [2–4]. The use of a modified or multi-grade bitumen improves the low-temperature performance of bituminous mixtures [5–11]. However, the results of the tests [12] indicate that it is the base bitumen that has the greatest influence and not the characteristics resulting from its modification. Little effect of the binder content on the low-temperature performance, especially in the TSRST test has been demonstrated in [13–15]. This effect, however, is not unequivocal. Other researchers point to a possible relationship between the air voids content in the mixture and its low-temperature resistance [16, 17]. According to the published research results, the addition of aramid fibres, steel fibres and polymer fibres has a positive effect on the low-temperature performance [18–24], but no effect of cellulose fibres and synthetic fibres has been demonstrated [19]. According to the results of experiments [25, 26], the addition of rubber is also favourable to the resistance to low-temperature cracking. The addition of a natural bitumen (Trinidad asphalt) has a negative effect on the low-temperature performance of mastic asphalt mixtures. [27] The addition of bitumen granulate deteriorates the low-temperature properties of bituminous mixtures [28]. In summary, it is the increase in rigidity [29] with a decreasing temperature that has the greatest effect on its low-temperature performance of bituminous mixtures. This, in effect, reduces susceptibility to deformation, as the material becomes practically rigid.

2. Materials and methods

2.1. The chosen bituminous mixtures

The tests were carried out on four different bituminous mixtures, three alternatives mixes SMA-MA ones and one mastic asphalt (MA) mixture. Mastic asphalt was a reference material for SMA-MA as a standard bituminous mixture used for protection courses on bridges. SMA-MA mixture concepts and examples of their application on a technical scale, along with the proposed specifications are presented in [30–32], these works also compared new and classic mixtures. SMA-MA mixtures were prepared in laboratory, based on the design actually used for production of a bridge protection course. These mixtures varied by the type of bitumen used (ordinary, PmB, highly-modified HiMA). The mastic asphalt mixture was collected during bridge works, part of a project in Zachodniopomorskie province in Poland. The sample was collected directly from the transport boiler for mastic asphalt and, after cooling, transported to the laboratory where test specimens were prepared.

The specifier of the SMA-MA mixture specified basalt grit (#5/8, #2/5), granite sand (#0/2) and limestone filler. Modified bitumen PmB 45/80-65, granular cellulose stabilizer and surfactant were originally specified.

Table 1 summarizes chosen physical-strength parameters and Fig. 1 shows the grain size distribution curve of the designed SMA-MA 8 mixture and MA mixture.

Table 1. Selected parameters of the designed SMA-MA 8 PmB 45/80-65 mixture

Type of test/Property	Method	Unit	Value
Total binder content B	–	%	8.4
Density of bituminous mixture ρ_{mh}	EN 12697-5	Mg/m^3	2.504
Bulk density ρ_b (after 2x35 blows)	EN 12697-6	%	2.469
Air voids content (after 2x35 blows)	EN 12697-8	%	1.4
Bulk density ρ_b (after 2x50 blows)	EN 12697-6	Mg/m^3	2.478
Air voids content (after 2x50 blows)	EN 12697-8	%	1.0
Water resistance (ITSR)	EN 12697-12	%	97
Binder drain-down D	EN 12697-18	%	0.1
Resistance to permanent deformation PRD$_{\text{AIR}}$ (method B, in air, 45°C, 10,000 cycles)	EN 12697-22	%	13.8
Resistance to permanent deformation WTS$_{\text{AIR}}$ (method B, in air, 45°C, 10,000 cycles)	EN 12697-22	mm/10^3 cycles	0.16

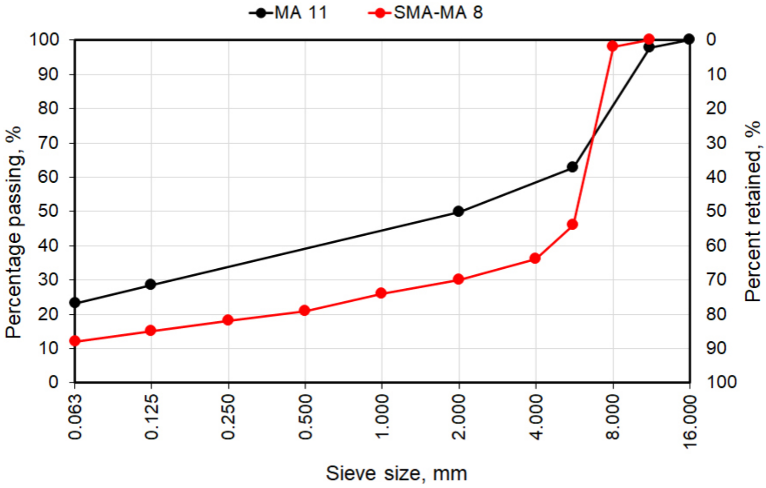


Fig. 1. Grain size distribution curve of alternative SMA-MA 8 mixture and MA11 mixture

Grain size distribution curve of mastic asphalt is shown in Fig. 1, and the physical-strength characteristics are summarised in Table 2.

Table 2. The physical strength properties of mastic asphalt MA 11 PmB 25/55-60

Type of test/Property	Method	Unit	Value
Total binder content B	–	%	6.8
Density of bituminous mixture ρ_{mb}	EN 12697-5	Mg/m^3	
Resistance to permanent deformation	EN 12697-12	–	–
Penetration value		%	2.1
Penetration increase		%	0.4

Four bitumens were used in the experiments. The bitumens used for production of SMA-MA mixtures were: 50/70 pure bitumen, 45/80-65 polymer-modified bitumen (PmB) and 65/105-80 highly modified asphalt (HiMA). Mastic asphalt was produced with PmB 25/55-60 modified bitumen. For comparison purposes, bituminous binder was extracted from the prepared samples. The purpose was to compare changes in the bitumen properties after short-term ageing (SMA-MA – in laboratory, MA – in plant). The obtained results are summarized in Table 3 below.

To prepare the samples for UTST and TCT tests, the mixtures were compacted by means of a compactor (SMA-MA) in 305 × 305 × 100 mm moulds. The moulded slabs were 60 mm thick. Test specimens of 40 × 40 × 160 mm were then cut out from these slabs. The dimensions were measured at eight points (3 times per each longer side and twice the length) and relative compaction was determined. The average relative compaction was 99.9% Average void content was between 1.0–1.5%.

Table 3. Parameters of the base and extracted binders

Binder/ Parameter	50/70		45/80-65		65/105-80		25/55-60	
	Base binder	Extracted binder	Base binder	Extracted binder	Base binder	Extracted binder	Base binder	Extracted binder
Penetration** 0.1 mm	62	49	60	49	89	63	45	35
Softening point* °C	48.6	53	66	73	87	90	63	67

*EN 1426:2015 EN 1427:2015

The sample of mastic asphalt (MA) was taken directly from the job site. It was transferred to the laboratory where it was heated up to 205°C. Hot mastic asphalt mixture was then placed in 305 × 305 × 100 mm moulds, post-compacted with a light compaction hammer and left to cool down. Further on, the test sequence was the same as applied for SMA-MA mixtures.

The preparation of the samples for the stress-strain tests (after cutting) consisted of bonding them to aluminium base plates. Two-component epoxy adhesive was used for this purpose. A jig was used to precisely position the samples. The research program is presented in Figure 2.

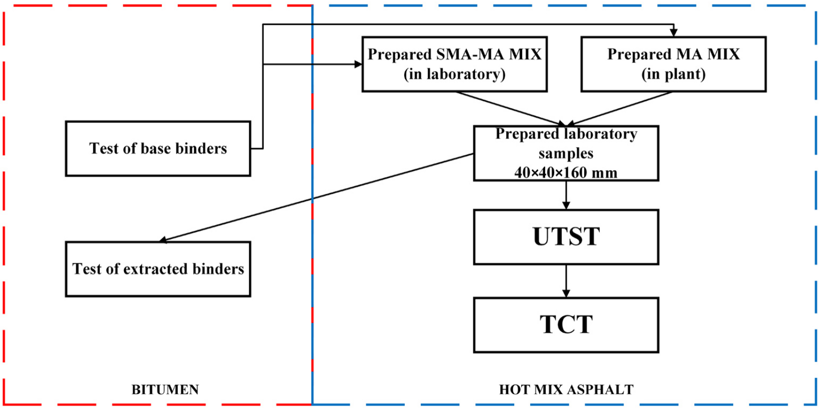


Fig. 2. Research program

2.2. The method

Various tests and loading schemes are used to characterize the behaviour of bituminous mixtures at low temperatures (≤ 0°C) [1, 2, 17, 33–46]. In this paper, to assess the low temperature performance of bituminous mixtures two equal and opposite forces were applied in the uniaxial tension test. The test procedure is described in AASHTO TP10 [47] and EN 12697-46 [48].

Uniaxial Tension Stress Test (UTST)

The purpose of UTST was to determine the loading conditions for the ultimate test, in other words TCT (Tensile Creep Test). In the ultimate test the specimen is tensioned until failure. The specimen was loaded in a way to obtain a constant strain increment of 0.625%/min. The test was conducted at three temperatures: –10°C, –15°C and –25°C. The test principle is presented in Figure 3. In the case of stiff materials, the increase of stress, like strains, is linear. The maximum strain and stress values were recorded during the tests. Based on the test results presented in the graph it was possible to determine the behaviour of the material (elastic, viscoelastic).

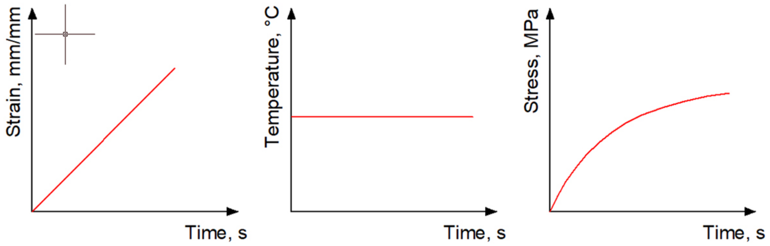


Fig. 3. The principle of UTST

Tensile Creep Test – TCT

The Tensile Creep Test (TCT) consists in loading the specimen with a constant tensile stress (Figure 4). This results in a time history diagram of strain.

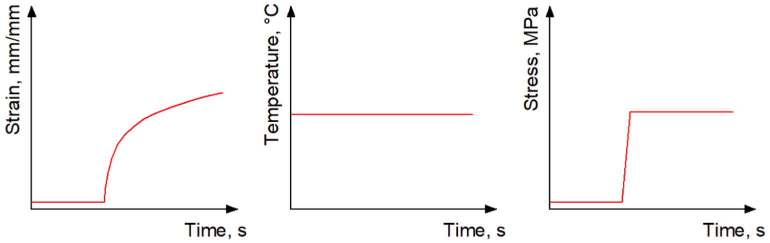


Fig. 4. The principle of TCT

The following loading conditions were specified for the TCT test:

- loading phase – 1.5 MPa;
- unloading phase – 0 MPa.

The loading conditions were determined based on the UTST procedure. The failure stresses obtained in this study were in the range from 4.0 MPa to 6.8 MPa (5.7 MPa on average). Hence the value of 1.5 MPa value is approximately 40% and 25% of the minimum and average failure stress values respectively. The stresses were not varied depending on the test temperature. This allowed for a comparison of deformations at the temperatures of: –10°C, –15°C and –25°C (this being the same temperature range as in the UTST procedure).

The duration of a single test, comprising a single loading/unloading cycle, with 21,600 seconds loading phase and 14,400 seconds unloading phase.

The four-element Burgers model, commonly used to describe bituminous mixtures in constant load tests, also at low temperatures, was used to evaluate the rheological parameters of the tested bituminous mixtures [33, 49–57] (Figure 5).

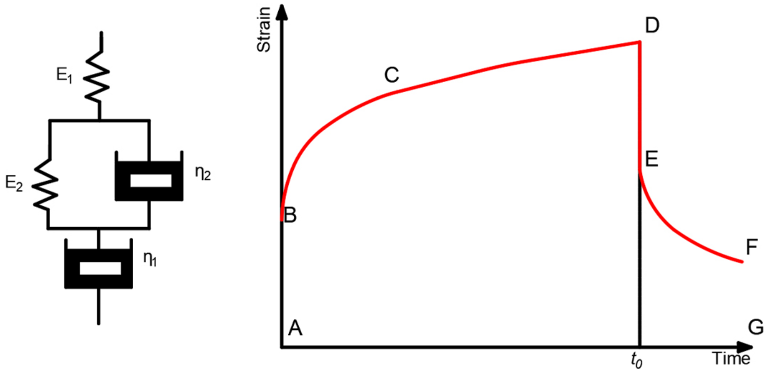


Fig. 5. Burgers Model

Fig. 4 the relationship describing the creep process in the Burgers model is described with equation (2.1):

$$\varepsilon(t) = \varepsilon_H + \varepsilon_N + \varepsilon_{K-V} = \frac{\sigma_0}{E_1} + \frac{\sigma_0 t}{\eta_1} + \frac{\sigma_0}{E_2}\left(1 - e^{\frac{-tE_2}{\eta_2}}\right) \tag{2.1}$$

The value of the applied stress is designated by the symbol σ_0. The strains in the Burgers model are the sum of the Kelvin–Voigt's and Maxwell's constituent models. E_1 represents the elastic strain, η_1 is the viscous flow, and E_2 and η_2 describe retarded elastic behaviour. The stress-strain curve plot in the Burgers model (after loading and unloading) is divided into the following steps: A–B, which identifies the immediate elastic strain (Hook's law part of the Maxwell model), B–D which covers viscoelastic strains (B–C region of the Kelvin–Voigt's model) and viscous flow (C–D – Newton law part of Maxwell's model). After the load has been removed, elastic recovery takes place (step D–E). In the E–F step, delayed viscoelastic recovery takes place. The last step in this sequence (F–G) concerns permanent deformation resulting from viscous flow.

In the following analyses least squares method (LSM) was employed to determine the parameters of the Burgers model (E_1, E_2, η_1, η_2) from the equation (2.2) on the basis of the strain values obtained in the loading phase of the test. To reduce the number of parameters to be derived from equation (2.1), parameter E_1 was derived from equation (2.3). This parameter describes the behaviour of the material (its immediate strain) immediately after the stress has been applied, i.e., for time $t = 0$ seconds.

$$E_1 = \frac{\sigma}{\varepsilon(0)} \tag{2.2}$$

On the basis of the experimental data, the relaxation time t_r was determined in each case from equation (2.3). This approach was applied also in other research projects [49–51].

$$t_r = \frac{\eta_1}{E_1} \tag{2.3}$$

3. Results and analysis

3.1. Uniaxial tension stress test (UTST)

The uniaxial tension stress test (UTST) was included in this research primarily to determine the ultimate stress and strain values. Two determinations were made for each mixture type. The obtained results are summarized in the Table 4 below.

Table 4. Summary of the results and mean values obtained in UTST (mean values)

Mixture	–10°C		–15°C		–25°C	
	Stress [MPa]	Strain [%]	Stress [MPa]	Strain [%]	Stress [MPa]	Strain [%]
SMA-MA 8 50/70	5.2	0.102	5.0	0.054	4.0	0.0146
SMA-MA 8 PmB 45/65–60	5.4	0.128	5.7	0.120	5.5	0.0228
SMA-MA 8 PmB 65/105–60	5.4	0.485*	6.6	0.144	6.4	0.0332
MA 11 PmB 25/55–60	6.4	0.043	6.8	0.032	6.1	0.0128

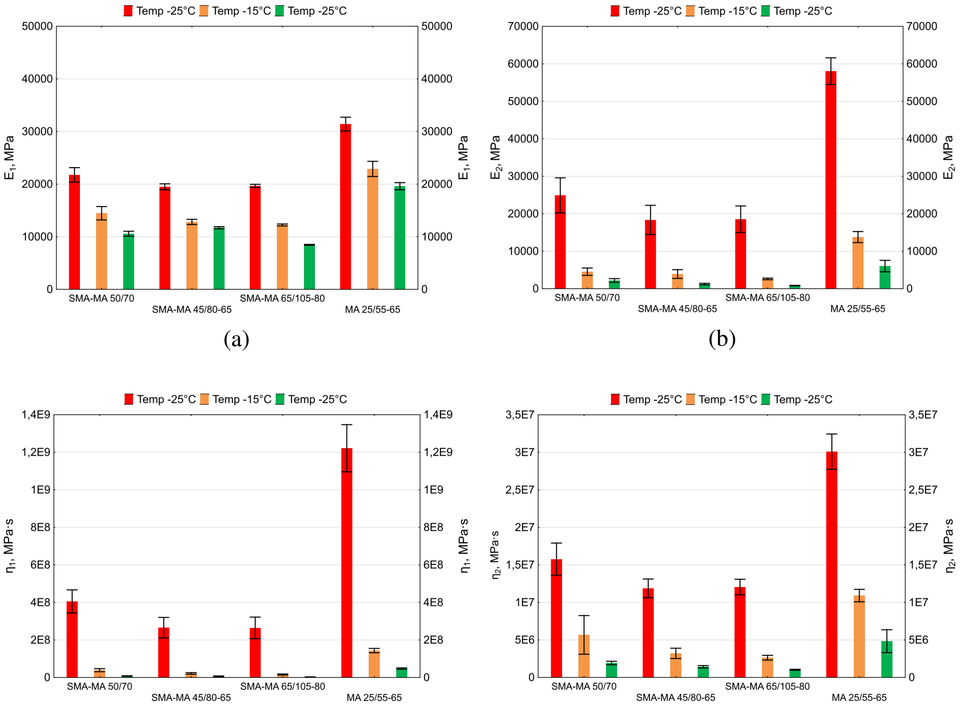
*visco-flow behaviour

An analysis of the stress-strain relationship from the UTST, indicates that at –10°C the mixture containing HiMA 65/105-80 exhibits viscoelastic behaviour. At the final phase of the test, strains increase at constant stress levels (flow behaviour). At the same temperature (–10°C) mastic asphalt type of mixture was characterised by the smallest strain values (Table 4) and the fastest increase of stress, which indicates the highest stiffness of this material. Therefore, elastic-brittle behaviour can be assumed for mastic asphalt mixtures over the entire temperature range of the performed tests. The maximum strains were found to decrease along with the decrease in the test temperature in all the tested mixtures.

After the analysis of UTST results, it was decided to carry out the tensile creep test (TCT) at a constant stress of 1.5 MPa, regardless of the test temperature and mixture type. (1.5 MPa stress corresponds to about 25% of the limit stress in the conducted tests). With this approach it was possible to compare all the obtained results, both in terms of the differences between individual mixtures and in terms of the test temperatures of the subsequent tests. This is in accordance with EN-12697 standard.

3.2. Tensile creep test (TCT)

A total of thirty-six determinations were made in the tensile creep test (TCT). In each case the least squares method was used to determine the Burgers model parameters (E_1, E_2, η_1, η_2). The calculations were based on the loading phase test data. The equations (2.2) and (2.3) were used to that end and the relaxation time t_r was determined from equation (3.1). The calculation results are compiled in the Figures 6 and 7. Based on the residual analysis the obtained fit of results should be considered satisfactory and useful for further analyses.



(a) (b)

(c) (d)

Fig. 6. Burgers model parameters a) E_1 b) E_2 c) η_1 d) η_2

The analysis of the results obtained indicates that the mastic asphalt mixture (MA 11 PmB 25/55-60) at each of the temperatures at which the tests were carried out is significantly stiffer (as compared to SMA-MA mixtures) and characterised by elastic-brittle behaviour. This is manifested by the highest values of the Burgers model parameters and small strains obtained in the tests, as well as by the predominance of elastic strains (described by the Hook's law part ε_H). The shares of the respective strains are given in Table 5. The strain values were obtained from the Burgers model parameters.

For assessing the low-temperature performance mineral-asphalt mixtures the most relevant values are E_1 and η_1 [2]. A higher value of modulus E_1 (responsible for elastic

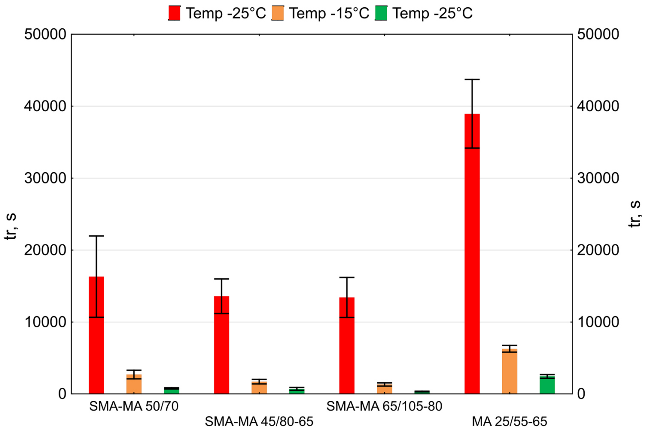
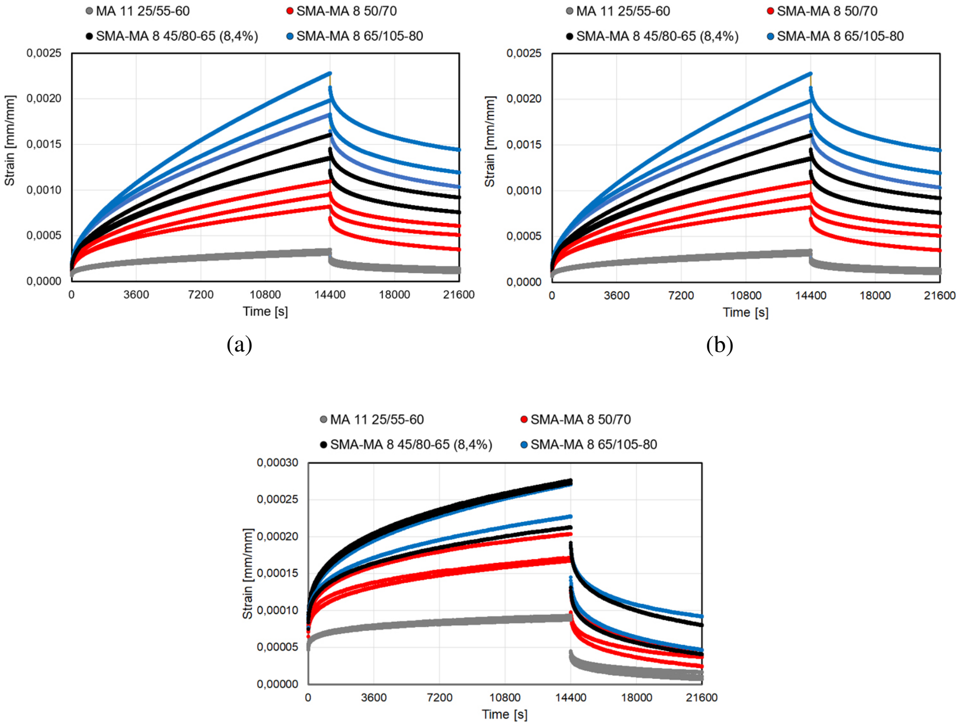


Fig. 7. Relaxation time (from Burgers model)

Table 5. Distribution of the elastic, viscoelastic and viscoplastic strains derived from the Burgers model

HMA type	–10°C			–15°C			–25°C		
	$(\varepsilon_h/\varepsilon_{\max})\cdot 100$ [%]	$(\varepsilon_{K\text{-}V}/\varepsilon_{\max})\cdot 100$ [%]	$(\varepsilon_N/\varepsilon_{\max})\cdot 100$ [%]	$(\varepsilon_h/\varepsilon_{\max})\cdot 100$ [%]	$(\varepsilon_{K\text{-}V}/\varepsilon_{\max})\cdot 100$ [%]	$(\varepsilon_N/\varepsilon_{\max})\cdot 100$ [%]	$(\varepsilon_h/\varepsilon_{\max})\cdot 100$ [%]	$(\varepsilon_{K\text{-}V}\varepsilon_{\max})\cdot 100$ [%]	$(\varepsilon_N/\varepsilon_{\max})\cdot 100$ [%]
SMA-MA 8 50/70	4.1	19.2	76.7	11.0	29.8	59.2	38.4	31.8	29.8
SMA-MA 8 PMB 45/80-65	3.5	24.3	72.2	8.2	21.1	70.7	30.7	36.6	32.7
SMA-MA 8 HiMA 65/105-80	1.8	18.3	79.9	6.1	26.8	67.1	31.2	32.5	36.3
MA 11 PMB 25/55-60	10.3	29.1	60.6	20.6	32.1	47.3	52.9	27.4	19.7

strain) translates into an increase in the thermal stress with a decreasing temperature. Lower values of viscosity index η_1 are desirable because of a faster stress relaxation in the bituminous mixture. For SMA-MA mixtures, the values of Burgers model parameters are significantly lower compared to MA. It is only at –25°C that the differences, although still existing, become significantly smaller (for SMA-MA mixtures E_1 is about 20 GPa, while for MA it is ca. 50% larger at over 31 GPa). The strain time history curves are shown in Figs. 8 At the temperature of –10°C (Fig. 8a) the creep curves of the SMA-MA 8 HiMA 65/105-80 mixture differ from the creep curves for the other SMA-MA (and MA) mixtures. The recorded strains are much larger. The combined range of elastic and viscoelastic strains is approximately 20%. Different behaviour is observed for the MA 11 mixture. The strains are small (compared to SMA-MA mixtures) and to a greater extent, ca. 40% in total, occur in the elastic and viscoelastic regions. The other two SMA-MA mixtures (containing 50/70 bitumen and PmB 45/80-65) are characterised by a similar level of creep strain, with combined elastic and viscoelastic strains at the level of 23% to 28%.



(a)

(b)

(c)

Fig. 8. Time history diagram of strain in a creep test at a) –10°C; b) –15°C; c) –25°C

At the temperature –15°C, the proportion of viscoplastic strains (at the expense of elastic and viscoelastic strains) in each of the analysed mixtures is reduced. In the case of SMA-MA mixtures containing modified bitumens (PmB 45/80-65, HiMA 65/105-80), viscoplastic strains constitute 70% as compared to 47% in the case of mastic asphalt.

As the test temperature gets further reduced to –25°C, the proportion of elastic and viscoelastic strains in each of the analysed mixtures increases to over 50%. In SMA-MA mixtures viscoplastic strains constitute approximately 30% (bitumen 50/70) and 36% (HiMA 65/105-80). In the case of the MA mixture, the proportion of viscoplastic strains drops to less than 20%.

The differences between the maximum strains are the most pronounced at the temperature –10°C. This also applies to SMA-MA mixtures containing highly modified bitumen (HiMA 65/105-80) and other binders (50/70, PmB 45/80-65). At –15°C, the differences in creep strains are no longer that significant in all SMA-MA mixtures, also those containing HiMA 65/105-80. Similar values of strain in the creep test in SMA-MA mixtures were obtained at –25°C. Based on the above data, it can be concluded that the use of soft highly modified asphalt HiMA 65/105-80 is justified, and that the drop of the temperature (below –25°C) increases the stiffness of the bituminous mixtures (containing binder and mastic) with predominance of elastic and viscoelastic behavior.

Analysing the test results for mixtures at subsequent test temperatures, consideration should also be given to the differences between the levels of strain (on a vertical scale) recorded at the subsequent test temperatures. The maximum strains recorded in the creep test at –15°C and –25°C are considerably smaller than the strains at –10°C. At –15°C the strains were 4 times smaller, while at –25°C they were about 20 times smaller.

Stress relaxation time is determined for all the tested SMA-MA mixtures containing three different bitumen types and for the MA 11 PmB 25/55-60 mixture. The stress relaxation time for the MA 11 PmB 25/55-60 mixture at each test temperature was significantly longer than in the case of SMA-MA mixtures. The shortest relaxation times were recorded for the SMA-MA 8 HiMA 65/105-80 mixture at each test temperature. At –10°C, the average relaxation time of the next mixture (SMA-MA 8 PmB 45/80-65) was almost two times longer. Along with the decreasing temperature (to –15°C), the difference decreased to approximately 40%. The spread of values was the greatest at the test temperature –25°C for all the respective tests.

A variance analysis (ANOVA) was performed to compare the respective means. Before the Tukey test, a distribution normality analysis and the Levene's variance uniformity test were performed. The conditions for the variance analysis were satisfied. The results are compiled in the Tables 6–8. Several conclusions to be drawn upon analysing these values. The primary conclusion is that at each test temperature the MA 11 PmB 25/55-60 mixture differs significantly from the other mixtures. At –10°C, the differences between SMA-MA mixtures containing modified bitumens become statistically insignificant. SMA-MA mixture containing 50/70 unmodified bitumen forms a second group with the mixture containing 45/80-65 bitumen. At –15°C, the use of modified bitumen, both HiMA 65/105-80 and PmB 45/80-65, reduced the stress-relaxation time, compared to the mixture containing 50/70 bitumen. At the lowest test temperature of –25°C, the differences between all SMA-MA mixtures become statistically insignificant.

Table 6. Tukey test results for TCT relaxation time (–10°C)

Mixture	Relaxation time Mean [s]	1	2	3
SMA-MA 8 HiMA 65/105-80	333.475591	****		
SMA-MA 8 PmB 45/80-65	698.434222	****	****	
SMA-MA 8 50/70	770.400222		****	
MA 11 PmB 25/55-60	2442.57776			****

Table 7. Tukey test results for TCT relaxation time (–15°C)

Mixture	Relaxation time Mean [s]	1	2	3
SMA-MA 8 HiMA 65/105-80	1311.15148	****		
SMA-MA 8 PmB 45/80-65	1698.11818	****		
SMA-MA 8 50/70	2699.65181		****	
MA 11 PmB 25/55-60	6270.3862			****

Table 8. Tukey test results for TCT relaxation time (–25°C)

Mixture	Relaxation time Mean [s]	1	2
SMA-MA 8 HiMA 65/105-80	13412.2521	****	
SMA-MA 8 PmB 45/80-65	13590.0018	****	
SMA-MA 8 50/70	16309.3193	****	
MA 11 PmB 25/55-60	38934.6032		****

Further, a correlation was sought between the parameters of extracted bitumens and the relaxation time in the tensile creep test. Such a relationship was found for penetration. The function described by the formula (3.1) was used for description:

$$t_r = e^{a\mathrm{PEN}+b} \tag{3.1}$$

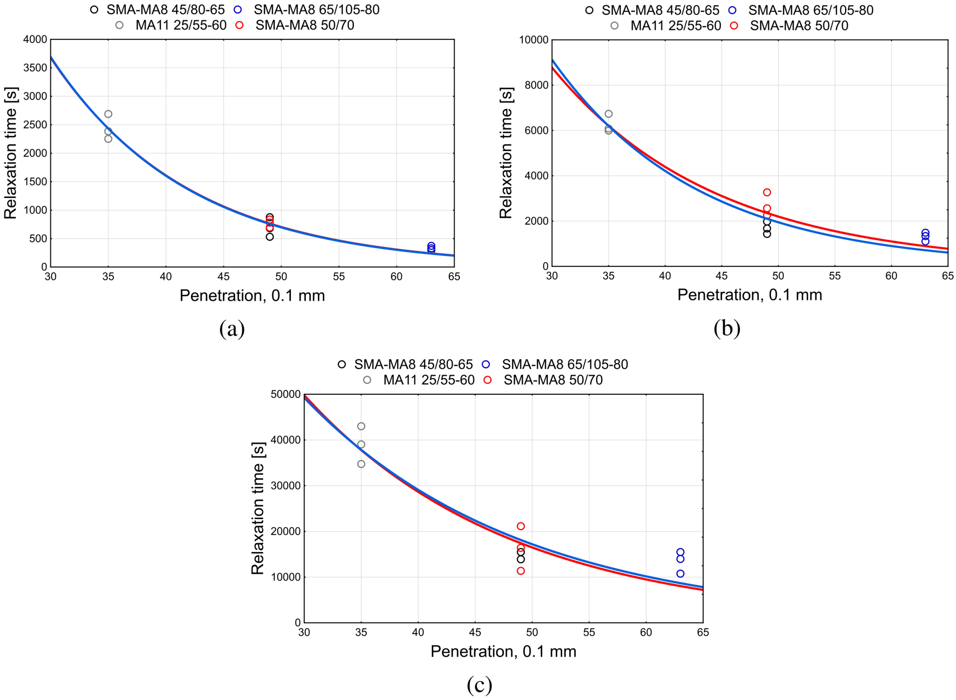
where: t_r – relaxation time, s, PEN – penetration grade of extracted bitumen, ×0.1 mm; a, b – factors of the function to be found.

The least squares method was used to determine the factors of the function to be found (a, b). The obtained results are summarized in the Table 9 below. The model fit was performed in two variants. In one variant the results with unmodified bitumen 50/70 were considered, in the other variant the results of the tests for this bitumen were not included. The curves representing the obtained function are shown in Fig. 10. The results show that the bitumen penetration value (at 25°C) correlates with relaxation time in the tensile creep test. Leaving out bitumen 50/70 changes the fit curve only slightly and both curves coincide at –10°C. At other test temperatures (–15°C, –25°C) these differences are not significant. The resulting graphs also show that above a certain penetration value (50 × 0.1 mm in the case under analysis), the change in the relaxation time with an increase of penetration is asymptotic. Further studies should be carried out to find a better relationship between the penetration grade (or other binder parameters).

Table 9. Results of the least squares method

Temp.	Curve	Par.	Rating	Error	t-value	p	Lower confidence limit	Upper confidence limit
–10°C	with 50/70	a	–0.08283	0.005571	–14.8684	0.000000	–0.09524	–0.07042
		b	10.69606	0.211306	50.6189	0.000000	10.22524	11.16688
	w/o 50-70	a	–0.08336	0.008233	–10.1259	0.000020	–0.102829	–0.06389
		b	10.71463	0.302628	35.4053	0.000000	9.999025	11.43023
–15°C	with 50/70	a	–0.06920	0.007079	–9.77581	0.000002	–0.08497	–0.05343
		b	11.15605	0.276655	40.32477	0.000000	10.53962	11.77247
	w/o 50/70	a	–0.07723	0.009466	–8.15868	0.000080	–0.09961	–0.05484
		b	11.43551	0.351266	32.55514	0.000000	10.60490	12.26612
–25°C	with 50/70	a	–0.05529	0.008214	–6.73038	0.000052	–0.07359	–0.03698
		b	12.47488	0.333614	37.39310	0.000000	11.73154	13.21822
	w/o 50/70	a	–0.05260	0.009488	–5.54431	0.000865	–0.07504	–0.03017
		b	12.38245	0.373253	33.17439	0.000000	11.49985	13.26506

Confidence level: 95.0% ($\alpha = 0.050$)



(a)

(b)

(c)

Table 10. Stress relaxation time in the tensile creep test depending on the penetration grade of the extracted bitumen, red with 50/70 bitumen, blue without 50/70 bitumen, a) –10°C b) –15°C c) –25°C

4. Conclusions

This article assesses the low temperature performance of bituminous mixtures used for bridge paving, based on the tensile creep test (TCT) results. The most important conclusions drawn from the tests are as follows:

- At extremely low temperatures (below –25°C), the type of the binder used in SMA-MA mixtures is of little importance.
- MA mixture containing binder PmB 25/55-60 is characterised by a much longer relaxation time compared to SMA-MA mixtures, regardless of the test temperature,
- The benefit of using HiMA 65/105-80 is particularly evident at –10°C and as the temperature drops, the differences in the relaxation times obtained decrease.
- The authors analysed, inter alia, the influence of bitumen penetration the properties of bituminous mixtures at low temperatures, and the experiments and analyses showed a high correlation between bitumen penetration and low temperature parameters.
- SMA-MA mixtures, in which soft bitumen could be used showed better performance (relaxation time) than mastic asphalt mixtures, which contain relatively hard binders.
- The results obtained at different test temperatures can be compared relatively easily in creep test with axial tension, assuming a constant level of stress independent of the test temperature.
- The TCT relaxation time strongly correlates with the penetration of extracted bitumens. The exact relationships of bitumen penetration (or other properties) are yet to be established as part of further studies.
- Based on the conducted research, it can be concluded that the SMA-MA mixture is better low temperature performance than the MA mixture.

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Ocena mieszanek mineralno-asfaltowych stosowanych na obiektach mostowych w niskich temperaturach z wykorzystaniem testu TCT

Słowa kluczowe: nawierzchnie mostowe, tensile creep test, czas relaksacji

Streszczenie:

Niska temperatura jest jedną z przyczyn powstawania uszkodzeń nawierzchni drogowych, zatem ocena parametrów niskotemperaturowych powinna być przedmiotem pogłębionych badań materiałów asfaltowych stosowanych w drogownictwie. Celem przeprowadzonych badań było określenie parametrów MMA w zakresie temperatur od –25°C do –10°C, z wykorzystaniem badania pełzania przy rozciąganiu (Tensile Creep Test – TCT). Do oceny parametrów niskotemperaturowych wykorzystano szeroko stosowany do oceny mieszanek minerlano-asfaltowych model Burgersa. Analizie poddano mieszanki stosowane na obiektach mostowych. Badania przeprowadzono zarówno na mieszankach klasycznych stosowanych na obiektach (asfalt lany) jak i alternatywnych mieszanek SMA-MA. Na podstawie uzyskanych wyników i przeprowadzonych analiz stwierdzono, że na parametry niskotemperaturowe kluczowy wpływ mają parametry lepiszcza asfaltowego stosowanego w mieszance. Stwierdzono również, że mieszanki w typie SMA-MA cechują się lepszymi parametrami niskotemperaturowymi niż klasyczne mieszanki w typie asfalt lany.

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