PAPER • **OPEN ACCESS**

Field investigation of low-temperature cracking and stiffness moduli on selected roads with conventional and high modulus asphalt concrete

To cite this article: Józef Judycki *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **236** 012002

View the article online for updates and enhancements.

You may also like

- A novel SiC power MOSFET with integrated polySi/SiC heterojunction freewheeling diode
Shiwei Liang, Hengyu Yu, Hangzhi Liu et al.

- Blending fishwastes and chicken manure extract as low-cost and stable diet for mass culture of freshwater zooplankton, optimized for aquaculture
E O Ogello, S Wullur and A Hagiwara

- Ion acceleration with few-cycle relativistic laser pulses from foil targets
Sargis Ter-Avetisyan, Parvin Varmazyar, Prashant K Singh et al.

This content was downloaded from IP address 153.19.58.141 on 22/01/2024 at 12:24

IOP Conf. Series: Materials Science and Engineering **236** (2017) 012002 doi:10.1088/1757-899X/236/1/012002

Field investigation of low-temperature cracking and stiffness moduli on selected roads with conventional and high modulus asphalt concrete

Józef Judycki[1], Mariusz Jaczewski[1], Dawid Ryś[1], Marek Pszczoła[1], Piotr Jaskuła[1] and Adam Glinicki[2]

[1]Gdansk University of Technology, Department of Highway Engineering, 11/12 Narutowicza str., 80-233 Gdansk, Poland
[2]General Directorate for National Roads and Motorways, Bialystok Division, 2 Zwycięstwa Str, 15-703 Bialystok, Poland

E-mail: mariusz.jaczewski@wilis.pg.gda.pl

Abstract. High Modulus Asphalt Concrete (HMAC) was introduced in Poland as a one of the solutions to the problem of rutting, type of deterioration common in the 1990s. After first encouraging trials in 2002 HMAC was widely used for heavily loaded national roads and motorways. However some concerns were raised about low-temperature cracking of HMAC. This was the main reason of the studies presented in this article were started. The article presents the comparison of performance of pavements constructed in typical contract conditions with the road bases made of HMAC and conventional asphalt concrete (AC). The field investigation was focused on the number of low-temperature cracks, bearing capacity (based on FWD test) of road sections localized in coldest region of Poland. Also load transfer efficiency of selected low-temperature cracks was assessed. FWD test confirmed lower deflections of pavements with HMAC and two times higher stiffness modulus of asphalt courses in comparison to pavements constructed with conventional AC mixtures. Relation of stiffness of asphalt layers and amount of low-temperature cracks showed that the higher stiffness modulus of asphalt layers could lead to increase of the number of low-temperature cracks. FWD test results showed that the load transfer efficiency of low-temperature cracks on pavements with HMAC presents very low values, very close to lack of load transfer. It was surprising as section with HMAC road base were aged from 2 to 5 years and presented very good bearing capacity.

1. Introduction

1.1. High Modulus Asphalt Concrete in Polish conditions

High Modulus Asphalt Concrete (HMAC) is type of asphalt mixture developed in France [1]. HMAC mixture has several advantages such as higher rutting resistance and improved fatigue life in comparison to typical AC mixtures. HMAC wasintroduced in Poland as a solution to the problem of rutting, type of deterioration common in the 1990s. After first encouraging trials in Poland in 2002, HMAC was widely used for heavily loaded national roads and motorways, especially after encouraging trials and laboratory tests conducted worldwide [1–7]. However between Polish experts

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

MOST WIEDZY Downloaded from mostwiedzy.pl

some concerns were raised about susceptibility to low-temperature cracking of HMAC. Raised concerns were confirmed after winter of 2012 when very high amount of thermal cracks appeared on constructed and existing sections of roads on which HMAC was used in base and binder courses. This issue was described in details in [8–10]. In this article field test results from the coldest region of Poland, where the highest amount of low-temperature cracks appeared, are presented.
High Modulus Asphalt Concrete (HMAC) that was applied in Poland include some modifications in comparison to its French predecessor. It is more dense mixture (from 2% to 4% voids) and has slightly lesser amount of bitumen (usually around 5%, m/m). High value of stiffness modulus (at least 14 000 MPa in 4PB test at 10°C and 10 Hz) is obtained by using neat 20/30 bitumen. The fatigue characteristics remained unchanged and ε_6 is equal to 130 µstrains.

1.2. Aim and scope of the paper

The main aim of this study was to evaluate the performance of road sections constructed in the coldest area of Poland with the usage of HMAC mixtures in comparison to the typical Polish pavement structure constructed using conventional Asphalt Concrete (AC) mixtures. For this purpose three aspects were evaluated – low-temperature cracking intensity, bearing capacity of the pavement and load transfer of the thermal cracks on selected test sections.

2. Field investigation

2.1. Characterization of the test sections

Field investigation of selected road sections constructed using HMAC and AC mixtures was one of the major part of the wider study [11,12] prepared for the GDDKiA. Totally in the years of 2012-2014 80 road sections located in Poland were surveyed for thermal cracking and rutting of the pavement. 33 of them were constructed using HMAC base and binder course and 47 using conventional AC mixtures. All of selected sections were new pavement structures, aged 1-12 years, in which the lower base course was made using crushed stone. The localisation of all tested sections is presented on the Figure 1. Sections analysed in this paper are marked in circle.

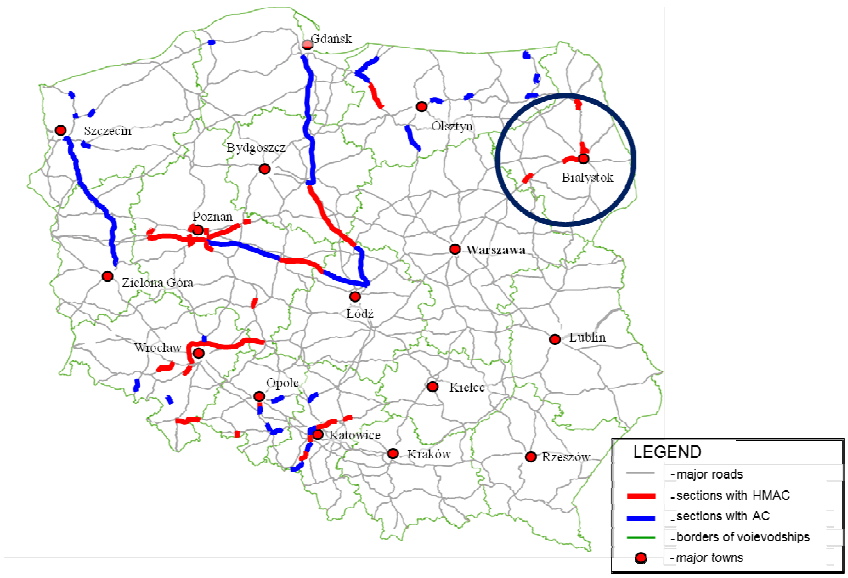

Figure 1. Localisation of tested road sections.

FWD tests were conducted on 3 sections localized along the national road no 8. Due to very heavy transit traffic all of them were dual carriageways. Pavement structures are the same in both cases:

MOST WIEDZY Downloaded from mostwiedzy.pl

sections with AC and sections with HMAC. The typical construction of the upper layers of road section with HMAC comprised of 27 cm of asphalt layers and 22 cm of crushed stone base course. The construction of section with conventional AC comprised of 28 cm of asphalt layers and 20 cm of crushed stone base course. On all analyzed sections all HMAC layers were produced using hard grade 20/30 neat bitumen. Conventional AC mixture was produced using 35/50 neat bitumen. Below the crushed stone base layer in all sections improved subgrade was constructed using cement bound soils. Detailed description of selected test sections along with the amount of low-temperature cracks is given in Table 1.

2.2. Low-temperature cracks investigation

For each selected road section detailed pavement distress survey was conducted according to the Polish SOSN [13] methodology supplemented by FHWA distress manual [14]. The majority of distresses comprised of transverse cracks (Figure 2 and Figure 3), which in most cases originated from the effect of low-temperatures. Mechanism of development of low-temperature cracks is described in details in [15,16]. Nevertheless other distresses were also observed, but their impact on pavement performance was minor or even negligible. What was surprising on very short sections small ruts in the right wheel path were observed, even on sections constructed using HMAC mixtures.

Figure 2. Not repaired low-temperature crack.

Figure 3. Repaired low- temperature crack.

Table 1. Description of analysed road test sections.

No.	*Description of road section (year of construction)*	*Pavement construction* [a)]	*FWD test section* [b)]	*No. of low-temperature cracks per km*
1	S8 Expressway, Jeżewo – Białystok (2012)	4 cm SMA 23 cm HMAC 23 cm CS	1) 623+000 – 624+000 L 2) 620+000 – 621+000 R	5,3 1,7
2	S8 Expressway, Zambrów Bypass (2012)	4 cm SMA 23 cm HMAC 23 cm CS	3) 3+000 – 4+000 L 4) 1+500 – 2+500 R	0,7 2,3
3	DK8, Białystok – Katrynka (2009)	4 cm SMA 23 cm HMAC 22 cm CS	5) 649+000 – 650+000 R 6) 648+000 – 649+000 L 7) 649+000 – 650+000 L	8,7
4	One of Polish Motorway section (2008/2010)	4 cm SMA 24 cm AC 20 cm CS	8) 25+000 – 29+000 L 9) 83+000 – 87+000 L	1,7 1,2

Remarks: a) SMA – stone matrix asphalt, HMAC – high modulus asphalt concrete, AC – asphalt concrete, CS – crushed stone
b) L – left carriageway, R – right carriageway

MOST WIEDZY Downloaded from mostwiedzy.pl

2.3. Analysis of the conducted FWD tests

FWD tests were conducted in November 2013 and in October 2014. The average temperatures of asphaltic layers ranged from 8 up to 21°C. Deflection of the pavements with HMAC mixtures were measured on slow traffic line every 25 meters on the selected sections of 1000 meter length. In the case of the motorway structure with conventional AC, the measurements were made every 100 meters on the selected sections of 4000 meter length. Obtained during FWD test pavement deflections were later standardized to the load of 50 kN and the temperature of +20°C.

2.3.1. Load transfer efficiency determination. During determination of deflection using FWD test equipment on two road sections additional test was made, to determine the load transfer efficiency of the low-temperature cracks. Test was conducted on two heaviest cracked sections. The load transfer efficiency factor was calculated using equation (1) given after Polish regulations [17].

$$k = \frac{y_2}{y_1} \tag{1}$$

where: k – load efficiency factor, y_1 – deflection of the loaded edge, y_2 –. deflection of the unloaded edge.

According to [17] the value of k < 0,7 indicates lack of load transfer efficiency, 0,7 < k <0,95 indicates partial load transfer efficiency and k > indicates full load transfer efficiency.

2.3.2. Stiffness moduli back-calculation. For every tested road section on the basis of deflection bowls stiffness moduli were calculated using ELMOD6 program using backcalculation methodology described in details in COST 336 Report [18]. The pavement was modelled as three-layered (asphalt layers, crushed stone base and improved subgrade) half-space, characterized by E – elastic modulus, ν - Poisson's ratio and h – thickness of the layer. The thicknesses of the pavement layers were assumed as stated in the Table 1. Poisson's ratios were assumed as either 0,3 for asphalt layers and crushed stone base or 0,35 for improved subgrade. Calculated stiffness moduli were standardized to the temperature of +10°C using equation 2 [17].

$$E_{10} = E_T \times \left(0.77 + 0.023 \times T\right) \tag{2}$$

where: E_{10} – standardized stiffness modulus (+10°C), T – temperature of the test.

3. Obtained results and discussion

Test results of FWD tests are presented in Tables 2, 3 and 4, respectively standardized deflections, load transfer efficiency factors and standardized stiffness moduli. For each parameters mean values and coefficient of variations COV were calculated.

Table 2. Standardized deflection from FWD test results (T = +20°C, 50 kN load).

Property	*Deflections on sections[μm]*								
	S8 Expressway, Jeżewo – Białystok		S8 Expressway, Zambrów Bypass		DK8, Białystok – Katrynka			One of Polish Motorway section	
no of test section:	1	*2*	3	*4*	5	*6*	*7*	*8*	*9*
Mean ($U_{śr}$)	95	94	108	94	95	103	105	139	161
80% percentile	103	106	114	107	103	118	111	155	174
Reliable (U_m)	115	121	137	121	118	130	131	187	195
CoV, %	10	14	13	14	12	13	12	17	10
No. of points	34	34	34	34	34	34	34	40	40

Remarks: a) Um = $U_{śr}$ + 2σ, where σ - standard deviation
b) CoV – coefficient of variation

MOST WIEDZY Downloaded from mostwiedzy.pl

All nine tested road sections, both with HMAC courses (after 2 and 5 years of service) and AC courses (after 2 and 6 years of service) showed very high homogeneity of measured deflections along the whole length of the test sections. The coefficients of variation of values of deflections on all tested sections are lower than 20%, what according to COST 336 [18] classifies all testes road sections as very homogeneous.

Table 3. Load transfer efficiency factors "k".

Property	Load transfer efficiency factor "k" [-] No. of the test section, (acc. to table 1)		
	2	6	*7*
Mean	0.66	0.73	0.76
CoV, %	29	13	14
No. of points	90	10	30

The load transfer efficiency factors were evaluated only for sections with HMAC layers (see Table 3). On the DK8 national road (no. 6 and 7 test sections; 5 years of service) the results of "k" factor indicate partial load transfer efficiency, but the value is in the lower part of the range, just above the limit of lack of load transfer. On the S8 road (no. 2 test section; 2 years of service) the "k" factor indicates the lack of load transfer. Obtained results are surprising, as all test sections are relatively new and "k" factor should show very high values. The probable reason, responsible for reduction of the "k" values can be higher values of linear coefficient of thermal contraction, due to the usage of higher amount of very hard grade neat bitumen. The lack of load transfer between of low temperature cracks can be big issue in the later service of the road section, as this is the weakest point of the entire pavement, which can cause faster deterioration of the whole pavement [19,20].

Table 4. Standardized back-calculated stiffness moduli (T = +10°C, 50 kN load).

Property	*Stiffness modulus [MPa]*								
	S8 Expressway, Jeżewo – Białystok		S8 Expressway, Zambrów Bypass		DK8, Białystok – Katrynka			One of Polish Motorway section	
no of test section:	1	*2*	3	*4*	5	*6*	*7*	*8*	*9*
Mean	19736	17351	21718	20017	20766	18333	19008	9073	11718
20% percentile	15520	13564	18327	14904	16188	14684	14916	6473	10112
80% percentile	23399	21062	25514	23293	24813	20785	22662	11400	13398
CoV, %	25%	26%	21%	28%	28%	26%	24%	34%	22%
No. of points	34	34	34	34	34	34	34	40	40

20% percentile value in the case of improved subgrade and crushed stone base changed in small range and were similar for every section. Values of elastic modulus ranged from 398 up to 482 MPa in the case of crushed stone base and from 164 up to 259 MPa in the case of improved subgrade.

As for the assessment of the asphaltic layers, apart from mean values also 20% and 80% percentiles were calculated to describe the variability of the obtained stiffness moduli. The results are presented in the Table 4 and in Figure 4. As can be seen, the obtained results for the road sections with HMAC layers differ very much from the values obtained for sections with conventional AC layers. The obtained values for all sections with HMAC layers are two times higher in comparison to the section with AC layers. Additionally in the Figures 5 and 6 authors presented respectively the relation of thermal cracking intensity vs obtained values of stiffness moduli and the relation of thermal cracking intensity vs years of service. Different colors were used to distinguish between different road test sections.

MOST WIEDZY Downloaded from mostwiedzy.pl

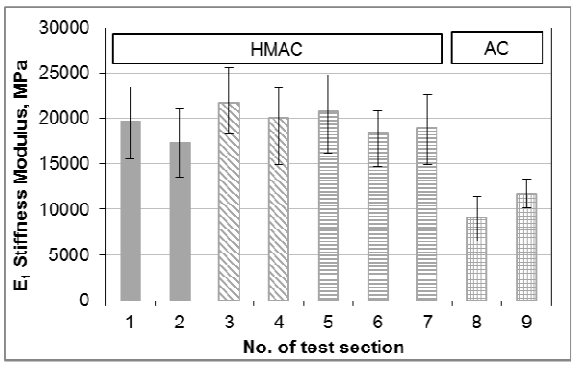

Figure 4. Asphalt layers stiffness moduli obtained from field FWD test (+10°C).

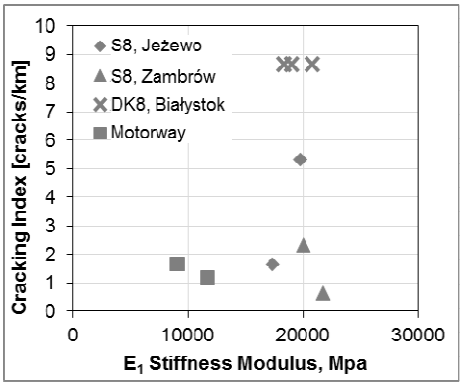

Figure 5. Relation of low-temperature cracking intensity vs FWD E_1 stiffness moduli (mean).

Figure 6. Relation of low-temperature cracking intensity vs years of service.

While there is no clear correlation between stiffness modulus and cracking intensity (R^2 ranges from about 0.1 to 0.2 depending on the used function) some tendencies are visible. The stiffer the asphalt layers of the pavement, the higher number of observed low-temperature cracks. Among the factors which could disturb the correlations probably the most important ones are: small number of test sections, different age of the analyzed pavements (ranged from 2 to 6 years). The last of the factor is quite important as not all winters in the recent years were very harsh with very low temperatures.

More disturbing is relation presented in the Figure 6. Test section with conventional AC layers (represented by gray squares) presents one of the lowest number of low-temperature cracks, despite that this test sections were among the oldest. On the other side, sections with HMAC layers after 2 years of service presents very high number of cracks (range of 0.7 up to 5.3), what are unusually for such new pavements. As it was stated in the introduction, presented results are only a part of the bigger road survey (presented in details in [10]), in which HMAC sections also presented increased cracking intensity in comparison to test sections with conventional AC mixtures.

MOST WIEDZY Downloaded from mostwiedzy.pl

4. Conclusions

On the basis of both field survey and FWD test conducted on the selected road sections it can be stated:

- Test sections constructed using HMAC layers in general presents higher number of low-temperature cracks in comparison to sections constructed with conventional AC layers. In average, the cracking intensity on test sections with HMAC layers is two times higher.
- The FWD test results showed, that all tested sections were constructed according to best practices and are homogeneous in the case of pavement deflections. The bearing capacity of all tested sections is very high.
- The stiffness moduli determined for the asphalt layers is almost two times higher for test sections with HMAC layers in comparison to test sections with conventional AC layers. The elastic moduli of crushed stone base and improved subgrade is almost the same for the all tested layers and their values are around 450 MPa and 200 MPa respectively.
- While there are no strong correlations between E_1 stiffness moduli and cracking intensity, some trends between the cracking index and stiffness moduli of the asphalt layers are visible. The number of low-temperature cracks increases with the increase of the value of the stiffness moduli.
- The cracking intensity of new (2 years of service) road sections constructed with HMAC base is disturbing. The cracking index ranges from 0.7 up to 5.3 cracks per kilometre, what is almost two times higher value than obtained for sections constructed with conventional AC layers, despite their longer time of service.
- The load transfer efficiency on the sections with HMAC layers is poor. Two out of three tested sections presents only partial load transfer, while the last section presents lack of load transfer. This situation can be big issue in the later service of the road section, as this is the weakest spot of the entire pavement, from which the deterioration of the pavement can be accelerated.

Acknowledgements

It is gratefully acknowledge that the field investigation were performed in a research project sponsored by the Polish General Directorate for National Roads and Motorways. Authors would like also to thank the Bialystok Division of General Directorate for National Roads and Motorways for conducting the FWD tests.

References

[1] Corté J F 2001 Development and Uses of Hard-Grade Asphalt and of High-Modulus Asphalt Mixes in France *Perpetual Bitum. Pavements, Transportation Research Circular* pp 12–31
[2] De Backer C, Glorie L and Reynaert R 2008 Test Section in High-Modulus Asphalt: A Comparative Experiment with Ten Variants *Proc. 4th Eurasphalt Eurobitume Congr. (Copenhagen)*
[3] De Visscher A, Vansteenkiste J and Vanelstraete S 2008 Test Section in High-Modulus Asphalt: Mix Design and Laboratory Performance Testing *Proc. 4th Eurasphalt Eurobitume Congr. (Copenhagen)*
[4] Rohde L, Ceratti J A P, Nunez W P and Vitorello T 2008 Using APT and Laboratory Testing to Evaluate the Performance of High Modulus Asphalt Concrete for Base Courses in Brazil *Third Int. Conf. Accel. Pavement Testing. APT 2008 (Madrid)*
[5] Wielinski J C and Huber G A 2011 Evaluation of French High Modulus Asphalt (EME) in Pavement Structural Design (MEPDG) *Journal of the Association of Asphalt Paving Technologists* **80** pp 697–718
[6] Carbonneau X, Michaut J P, Andersen T, Thorup C and Ladehoff L 2008 High Modulus GAB II: A Danish Experiment *Proc. 4th Eurasphalt Eurobitume Congr. (Copenhagen)*

MOST WIEDZY Downloaded from mostwiedzy.pl

[7] Lee H J, Lee J H and Park H M 2007 Performance evaluation of high modulus asphalt mixtures for long life asphalt pavements C*onstruction and Building Materials* **21** pp 1079–87
[8] Judycki J, Jaskuła P, Dołżycki B, Pszczoła M, Jaczewski M, Ryś D and Stienss M 2015 Investigation of low-temperature cracking in newly constructed high-modulus asphalt concrete base course of a motorway pavement *Road Materials and Pavement Design* **16** (sup 1) pp 362–88
[9] Judycki J, Jaskuła P, Dołżycki B, Pszczoła M, Jaczewski M, Ryś D and Stienss M 2016 The Impact of Homogeneity of High Modulus Asphalt Concrete Layer on Low-Temperature Crackin, *8th RILEM Int. Conf. Mech. Crack. Debonding Pavements (Nantes)* pp 319–26
[10] Ryś D, Judycki J, Pszczoła M, Jaczewski M and Mejłun Ł 2017 Comparison of low-temperature cracks intensity on pavements with high modulus asphalt concrete and conventional asphalt concrete bases C*onstruction and Building Materials* **147** pp 478–87
[11] Judycki J, Pszczoła M, Jaczewski M, Mejłun Ł and Ryś D 2014 *Research on the Effect of Application of High Modulus Asphalt Concrete (HMAC) in Pavement Structures on Low - Temperature Cracking and Decrease of Permanent Deformations (in Polish)* (Gdansk University of Technology)
[12] Jaczewski M 2016 *The influence of high modulus asphalt concrete on low temperature cracking of pavements - Ph.D. Thesis* (Gdansk University of Technology)
[13] General Directorata for National Roads and Motorways (GDDKiA) Warsaw 2002 Evaluatuion of pavement condition system *(SOSN 2002)*
[14] Miller J S and Bellinger W B 2003 Distress Identification Manual for the Long-Term Pavement Performance Program FHWA-RD-03-031 (Federal Highway Administration)
[15] Judycki J 2016 A new viscoelastic method of calculation of low-temperature thermal stresses in asphalt layers of pavements *International Journal of Pavement Engineering* (in press)
[16] Zofka A and Braham A 2009 Comparison of Low-Temperature Field Performance and Laboratory Testing of 10 Test Sections in the Midwestern United States Transportation Research Record *Journal of the Transportation Research Board* **2127** pp 107–114
[17] GDDP 2001 *Catalogue of reinforcement and reconstruction of flexible and semi-rigid pavements*
[18] Beuving E 2005 Falling Weight Deflectometer *COST 336 Final report of the action*
[19] Mackiewicz P 2013 Fatigue Tests of Bituminous Mixtures with Inclusion of Initial Cracks *Journal of Materials in Civil Engineering* **25** pp 140–147
[20] Mrugała J and Chomicz-Kowalska A 2017 Influence of the Production Process on the Selected Properties of Asphalt Concrete *Procedia Engineering* **172** pp 754–59

MOST WIEDZY Downloaded from mostwiedzy.pl