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Design of poroelastic wearing course with the use of direct shear test

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ABSTRACT: Poroelastic Road Surfaces (PERS) are characterized by porous structure with at least 20% of air void content and stiffness almost 10 times lower than typical asphalt course. Such properties enable noise reduction up to 12 dB in comparison to SMA 11 mixture. However, the main disadvantage of previously used poroelastic mixtures, based on resin type binders, was their low durability, which resulted in raveling and delamination from the lower layer. This paper presents initial results obtained for new type of PERS mixture, based on highly modified bitumen as a binder instead of resin type binder. The direct shear test was applied to estimate resistance of the mixture to raveling as well as to evaluate interlayer bond quality. Observations of first short test sections with different compositions of new PERS mixtures yielded promising results.

1 INTRODUCTION

1.1 *Background*

Poroelastic mixtures for road pavements contain about 20% of crumb rubber and should allow to obtain open (porous) structure of the constructed layer, which is almost exclusively wearing course. Such pavements are referred to as Poroelastic Road Surfaces (PERS). PERS technology originates from Swedish research conducted in the 1970s. From 1994 research efforts concerning poroelastic pavements were also conducted in Japan, where few generations of PERS were developed between 1994 and 2009 (Sandberg *et al.* 2010). First trials resulted in reduction of pavement noise by 5 dB, while further studies enabled a decrease even by 12 dB compared to reference SMA wearing course (Świeczko-Żurek *et al.* 2018). The biggest drawback noted during previous studies was very low durability – the pavement lasted only for a few weeks before deterioration. The sources of insufficient durability of poroelastic mixtures observed in previous studies (Bendtsen 2015) were reveling and debonding from lower layer. Despite excellent properties in noise reduction, the insufficient durability still makes PERS useless. Another unsolved problem is finding proper test method, which would allow to design and assess the quality of PERS mixture and layer efficiently.

1.2 *Objective and Scope*

Presented results were obtained throughout realization of research project called SEPOR, which aims to improve durability of Poroelastic Road Surfaces (PERS). This paper describes investigation phase of poroelastic mixture composition and different types of interlayer bonding techniques. Direct shear test was applied both to estimate resistance to raveling and interlayer bond quality.

2 MATERIALS

2.1 *Poroelastic mixture composition*

During optimization of poroelastic mixtures 13 different mixtures of aggregate and crumb rubber added in dry process with two different highly modified bitumen were evaluated. More details concerning properties and optimization process are described in previous study (Jaskula *et al.* 2019). In this paper the range of results is limited to poroelastic mixture labelled as PSMA (poroelastic SMA). PSMA consisted of mineral and rubber aggregate, limestone filler and highly modified asphalt binder 45/80-80 with at least 7% content of SBS polymer. The proportions of mineral aggregate and crumb rubber are given in Tab. 1. The four contents of bitumen are marked in tab.1 by B1, B2, B3 and B4.

Three mixtures marked as PSMA5 W4 were selected after laboratory testing phase (see 3 p.) to be produced in full scale. While the mineral and crumb rubber composition remained the same for each mixture, the amount of bitumen was slightly different for each composition. PERS mixtures were produced with the use of ordinary asphalt batch plant. Crumb rubber was added to the pugmill by means of additional conveyor which is normally used for adding reclaimed asphalt pavement. Laying and compacting of poroelastic mixture did not require any modifications in the equipment (fig. 1).

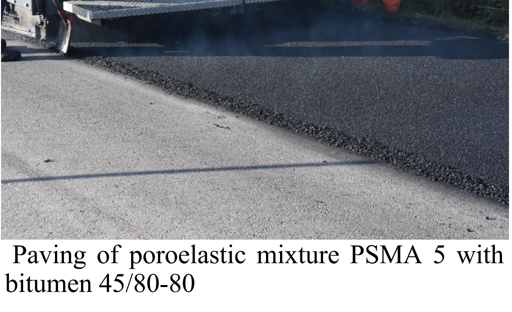

Figure 1. Paving of poroelastic mixture PSMA 5 with highly modified bitumen 45/80-80

Table 1. Composition of the poroelastic mixture PSMA 5 tested at laboratory stage and produced for field trials

Aggregate		Content (% mass of aggregate)			
Type	Sieve [mm]	PSMA5 W3	**PSMA5 W4** 1)	PSMA8 W3	PSMA8 W4
Mineral aggregate (Gneiss)	5/8	0	**0**	0	0
	2/5	60	**72**	72	78
	0/2	10	**6**	6	13
Filler (Limestone)	<0.063	15	**7**	9	9
Crumb rubber	4/7	0	**0**	4	4
	1/4	10	**10**	10	8
	0.5/2	5	**5**	3	3
Bitumen		Content (% mass of mixture)			
45/80-80 (HiMA)	B1	10.0	**9.0**1)	10.0	9.0
	B2	12.0	**11.0**1)	12.0	11.0
	B3	14.0	**13.0**1)	14.0	13.0
	B4	-	15.0	16.0	15.0

1) Combinations produced in full scale.

2.2 *Laboratory tests of interlayer bonding*

Poroelastic mixture was laid on previously prepared slabs made of two typical asphalt mixtures: denser and stiffer for AC16 and more open and less stiff for SMA 11. Two different mixtures for lower layer were used in order to vary the surface texture that would be in contact with poroelastic mixture. Moreover, the effect of grooved texture obtained by milling of the lower layer, and effect of geogrid reinforcement were also considered. Fig. 2 presents four various surfaces of lower layer.

The interface layer was applied as a tack coat over the lower layer. Cationic bituminous emulsions with following bitumens were applied: three SBR-modified bitumens 35/50, 50/70 and 70/100 as well as one neat bitumen 70/100. The amount of residual bitumen equaled from 0.1 to 0.3 kg/m^2. Combinations of interlayer bonding techniques are summarized in tab. 2.

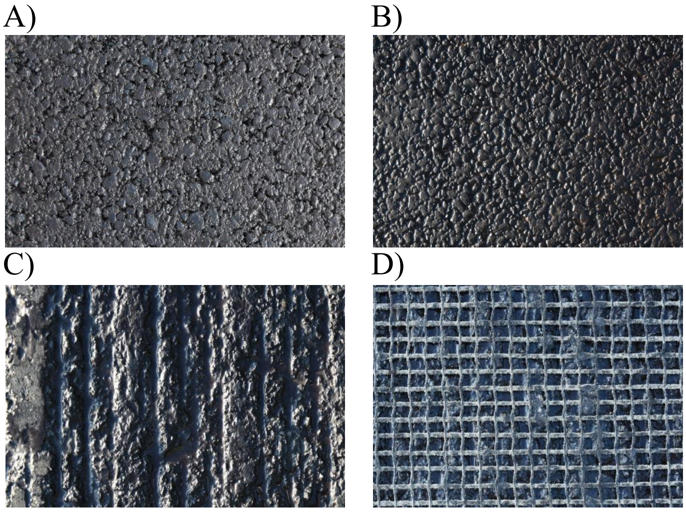

Figure 2. Surfaces of lower layer: A) AC16 B) SMA11 C) SMA11 grooved (after milling) D) SMA11 with geogrid reinforcement

Table 2. Combinations of bonding techniques used in the studies

Type of the lower layer	Type of bitumen used in bitumen emulsion for tack coat	Content of residual bitumen [%]
AC16	35/50+SBR 50/70+SBR 70/100 70/100 + SBR	0.1, 0.2, 0.3 0.1, 0.2, 0.3 0.1, 0.2, 0.3 **0.2**1)
SMA11	35/50+SBR 50/70+SBR 70/100 70/100 + SBR	0.1, 0.2, 0.3 0.1, 0.2, 0.3 0.1, 0.2, 0.3 0.1, **0.2**1), 0.3
SMA11 after milling	70/100 + SBR	0.15, **0.3**1)
SMA11 after milling and with geogrid	70/100 + SBR	0.15, **0.3**1)

1) Combinations which were chosen to be used in full scale.

3 LABORATORY TESTS

3.1 *Specimen preparation*

Cylindrical specimens for direct shear tests were prepared as follows:

1) By compaction with the use of Marshall compactor (specimens for optimization of mixture composition, with a diameter of 100 mm).
2) By drilling out from two layer slabs compacted in laboratory roller compactor (specimens for laboratory interlayer bonding evaluation, with a diameter size of 150 mm). After compaction of the first, lower slab, its surface was covered with bitumen emulsion. After required time needed to obtain emulsion breakdown it was covered with loose poroelastic mixture and the entire set was again subjected to compaction in laboratory roller compactor. Lower slabs of selected specimens were grooved with the use of full-scale milling machine.
3) By drilling out cores from full scale field sections (specimens for field interlayer bonding evaluation, with a diameter size of 150 mm).

3.2 *Volumetric properties*

Fig. 3 shows comparison of air void content in three mixtures of PSMA 5 compacted in laboratory and full scale conditions. In general, compaction obtained in the field was lower than in the laboratory conditions. Such behavior can be caused by elastic deformation of crumb rubber aggregate and relief of hot mixture compression between passes of roller, while laboratory roller compactor applies constant pressure with less ability to relief of compression of rubber aggregate.

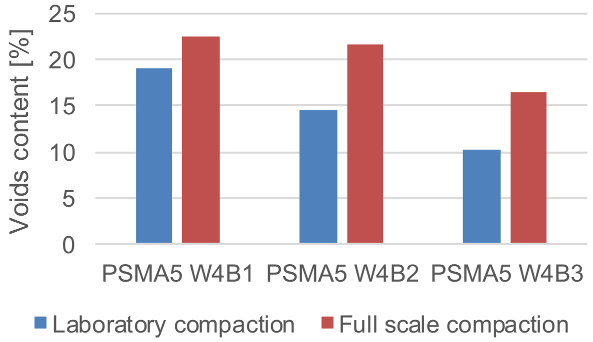

Figure 3. Air void content of the poroelastic mixture PSMA 5 compacted in laboratory and in the field

3.3 *Selected mechanical properties of PERS*

Some tests performed during mixture optimization delivered insufficient results in terms of suspected performance. The Cantabro test, which is commonly used to simulate resistance of porous asphalt mixtures to abrasion and raveling, resulted in very low mass loss, bellow 2% for PSMA 5. Wheel tracking test at 60°C according to EN 12697-22 method B caused extremely fast distress of specimens and the proportional rut depth reached approximately 160 mm after 10000 wheel passes while the result of reference SMA 5 mixture was only 3,4%.. The poroelastic mixture PSMA 5 exhibited much lower stiffness modulus (around 200 MPa) in comparison to 1400 MPa obtained for the reference SMA 5 (IT-CY test at 25°C, according to EN 12697-26). These results implicate that the same performance tests that are used for asphalt mixtures may not be valid for poroelastic mixtures.

3.4 *Direct shear test for PERS*

3.4.1 *Justification of choice of direct shear test for evaluation of PERS*

The loss of aggregate from the pavement surface, which is commonly called as raveling, is mostly unrelated to the pavement structural design, as it primarily depends on surface-contact mechanics and quality of the mixture aggregate skeleton (Huurman *et al.* 2009)(Manrique-Sanchez *et al.* 2018). In the case of typical porous asphalt, the process of raveling can be attributed to the excessive amount of weak rock material in the aggregate. Obviously, replacement of the part of mineral aggregate with crumb rubber in poroelastic mixture has an adverse effect on resistance of the mixture to raveling.

The source of raveling arises from shear stresses caused by vehicle loads and to low internal mixture cohesion. The internal mixture cohesion impact on mixture shear strength too. It can be expected that increase in the internal (inlayer) shear strength will contribute to increase in the resistant to raveling. Direct shear test is also a well known method for evaluation of interlayer bonding quality.

3.4.2 *Test procedure*

Direct shear tests (Leutner 1979) were performed at 20°C, according to EN 12697-48 with constant rate of deformation 50.8 mm/min. For the purpose of this paper, maximum shear strength τ_{max} was considered both as a measure of internal cohesion of mixture and inlayer bonding quality. The difference was the plane of applied shear stress: in the middle of specimen height in case of testing internal cohesion or in joint between two layers in case of testing interlayer bonding quality. The values presented further represents average values calculated for at least two results obtained from test.

3.4.3 *Results of inlayer shear strength of PERS*

The average inlayer shear strength vesrus air void content for various mixture combinations are presented in Fig.4. The shear strength of reference mixture SMA 5 was at the level of 1.81 MPa. By comparing this value with result obtained for PSMA it can be concluded that tested poroelastic mixture has about 2.5 times lower inlayer shear strength than typical asphalt mixtures. It should also noted that air void content above 15% has an adverse effect on inlayer shear strength. The significant variability in the air voids results from bitumen content and its effect on compaction of poroelastic mixture.

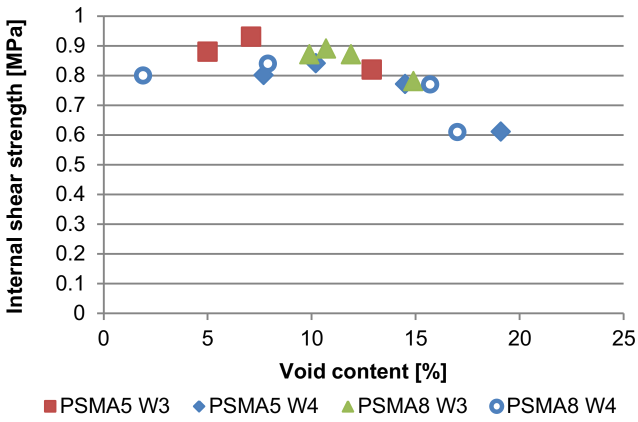

Figure 4. Impact of air void content of poroelastic mixture on inlayer shear strength

Fig.5 presents comparison of inlayer shear strength obtained for specimens compacted in laboratory and full scale conditions. Inlayer shear strength of mixture compacted in the field is significantly lower which can be caused by higher air void content (compare to Fig. 3 and 4).

After several months of service raveling was observed only on section with PSMA 5 W4B1, with 9,0% of binder content. It confirms that mixtures with lower inlayer shear strength are more vulnerable to raveling. Further field observations will allow to verify what is the acceptable level of inlayer shear strength.

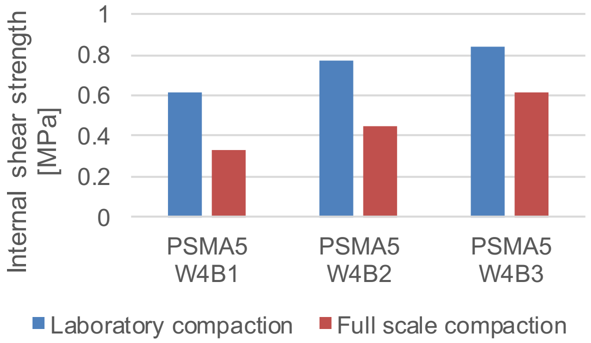

Figure 5. Inlayer shear strength of the poroelastic mixture PSMA 5 compacted in laboratory and full scale conditions

3.5 *Results of interlayer bonding*

The results of interlayer bonding strength are presented in Fig. 6 and Fig. 7., for specimens prepared in laboratory and full scale conditions respectively.

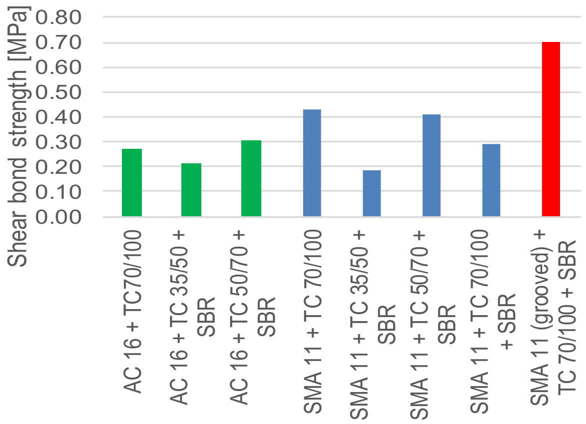

Figure 6. Interlayer bonding shear strength of specimens prepared in laboratory (TC – tack coat)

Results (Fig 7) indicate that obtaining similar interlayer bonding quality in the field as in laboratory conditions can be problematic, despite properly prepared lower layer and application of tack coat. However, after several months of service of trial sections any distresses caused by delamination of PSMA layer have not been observed.

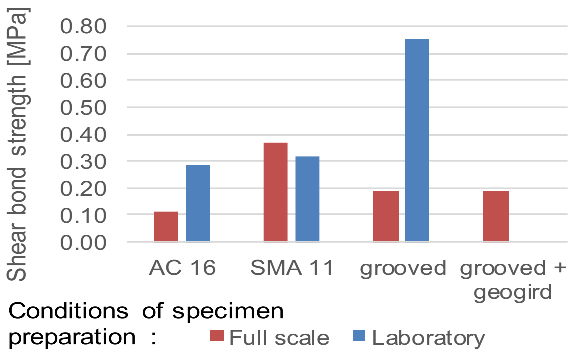

Figure 7. Interlayer bonding shear strength of specimens prepared in full scale and in laboratory

4 SUMMARY

Highly polymer-modified asphalt binders are promising in terms of obtaining reliable and durable poroelastic mixtures.

While Cantabro test and wheel tracking test did not provide reasonable results, direct shear strength test can be used both to assess internal cohesion, resistance to raveling of poroelastic mixtures and interlayer bonding quality.

The problem of raveling occurred on one out of three full scale test sections. Poroelastic mixture used in this section had the lowest bitumen content (9% by mass) and lowest shear strength (0.33 MPa) simultaneously.

The problem of debonding of poroelastic layer was not reported on full scale sections regardless of type of the layer beneath.

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