Research on Restoration and Reconstruction Technologies of Asphalt Concrete for Very Thin Layers

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Abstract. Due to limited financing there is a search for new ways how to reconstruct the existing road pavements, to protect lower layers from deterioration, and to improve surface properties cheaper and more efficiently both in Latvia and worldwide. It is especially important for roads constructed with EU co-financing. Their resurfacing shall be performed every 6 to 12 years, depending on traffic intensity and applied technology. One of the alternatives is to renew the wearing course with asphalt concrete for very thin layers (AC-TC). Standard LVS EN 13108-2 on asphalt concrete for very thin layers is too general.

The goal of this study is to develop and offer specifications of the asphalt concrete for very thin layers by using analytical and experimental research and experience of other countries. Several experimental mixes for very thin layers were developed and their main qualities and operating properties tested. Shear strength of asphalt concrete composition for very thin layers with different types of asphalt concrete base course – dense asphalt concrete and High Modulus Asphalt Concrete (HMAC) – was evaluated and different emulsions were used between these layers. This research includes several recipes for asphalt concrete for very thin layers, as well as, offers road surface structures incorporating structural layers of asphalt concrete for very thin layers and HMAC.

Key words: asphalt concrete, experimental mixes, asphalt concrete for very thin layers, High Modulus Asphalt Concrete

1. Introduction

Due to limited road financing the available funds have to be used as efficient and rational as possible. The existing budget usually is allocated inefficiently. New roads are constructed or old roads are reconstructed with vast funds while the roads constructed and reconstructed previously deteriorate to such extent when cheap surface renewal methods may not be applied. Therefore timely renewal of bituminous pavements is of utmost importance.

Most often mill and fill is used as the best road preservation method. This method, however, is expensive and sometimes it is used without good reason.

In order to improve the general condition of the road network it should be implemented according to the principle: *Right Treatment for the Right Road at the Right Time* [2]. Pavement preservation is something more than recognition of different renewal methods. It involves long-term thinking and planning both of right renewal methods and attraction of the necessary funding. Often the first and the worst option is chosen. Instead of that the existing assets (recently reconstructed or newly constructed roads) should be protected by performing regular treatment on order to prevent damages. [2]

2. Analysis of renewal of bituminous pavements

In order to perform appropriate renewal of road surface, the monitoring of pavement condition on each road should be done annually. The basis of pavement preventive technical treatment (maintenance) is formed by the concept that periodical and comparatively cheaper surface dressing (renewal) is economically more feasible that seldom (irregular) renovation that requires significant funds. Road pavement maintenance is defined as a measure that should be executed in order to preserve and/or extend the functioning or lifetime of pavement until serious pavement rehabilitation or full reconstruction. Figure 1 shows different renewal technologies for bituminous pavements.

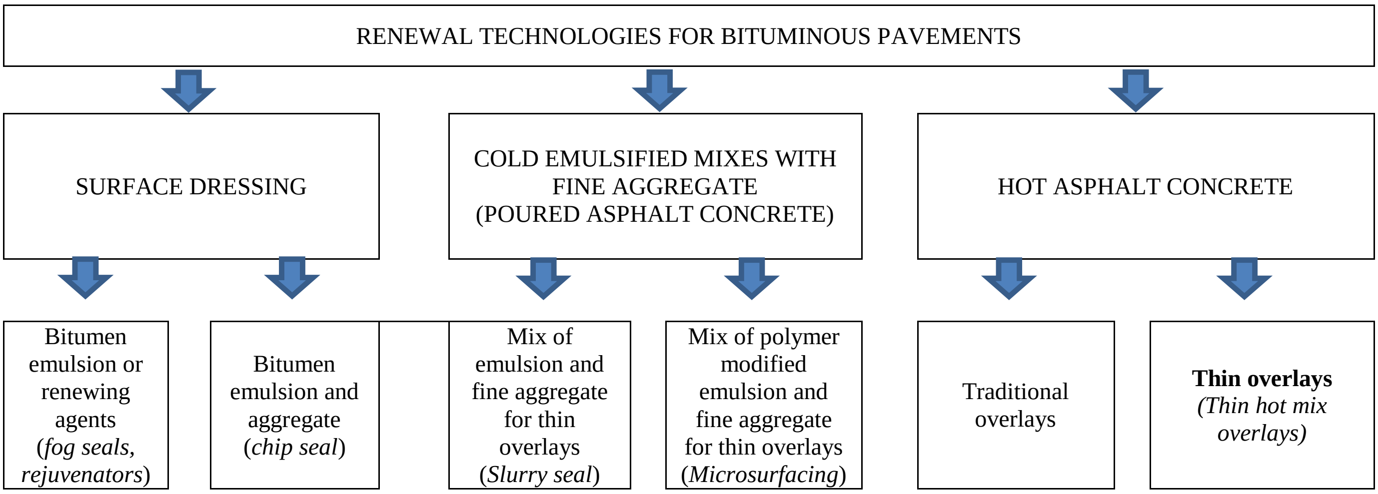

Fig 1. Renewal technologies for bituminous pavements

The main factors that determine the sustainability of the road network are the following:

- its length;
- condition;
- budget;
- time. [2]

It has to be understood that road pavement starts to deteriorate as soon as it is open for traffic. The factors that influence the rate of pavement deterioration are:

- traffic load;
- climate;
- used materials;
- thicknesses of structural layers;
- quality of construction works;
- efficiency of pavement renewal and maintenance. [3]

Asphalt concrete for very thin layers may be mentioned as one of overlay renovation methods. The layer thickness is 20-30 mm, laid on one layer. This reduces the amount of materials needed for overlays, which is economically feasible for countries that lack the natural reserves of high quality aggregate. It has to be noted that SPENS recommendations stipulate the use of asphalt concrete for very thin layers above HMAC (High Modulus Asphalt Concrete) binder course. The use of very thin layer overlay separately or together with HMAC may lead to significant savings in the construction of pavements.

Properties and advantages of asphalt concrete for very thin layers are the following:

1. Smaller amount of materials leading to lower cost and saving of natural reserves of hard and durable aggregate. Costs of asphalt concrete for very thin layers may be up to 45% lower than for alternative types of asphalt concrete. Therefore in case the polymer modified bitumen envisaged for asphalt concrete for very thin layers is used for both mixes then the amount of qualitative but expensive aggregate is reduced by ~40%.
2. Very good pavement surface properties are ensured – texture depth and skid resistance is excellent.
3. Noise reduction by 2-4 dB is ensured.
4. Certain water run-off properties are ensured and water splashing is reduced.
5. Layer / mix has good resistance to rutting.
6. Faster laying in comparison with traditional asphalt concrete.
7. Milling of existing layers in order to avoid the increase of pavement level is not always needed (overlays may be laid on top of existing layers).
8. Evenness of the old pavement may be improved to certain extent, additional levelling course may not be needed.
9. In case of surface maintenance or renewal smaller amounts of bitumen and aggregate are used.

10. Mixing equipment does not need adjusting in order to produce asphalt concrete for very thin layers.
11. Reduced amounts of work. [1]

Advantages of asphalt concrete for very thin layers do not lead to conclusion that it is the most economically feasible surface renewal method. It is necessary to choose the possible renewal technology basing on the type of overlay distress. Table 1 shows potential surface renewal options depending on pavement distress. Potential does not mean the most substantiated or the best as in this stage it is necessary to choose the best possible solution also depending on pavement condition. When the most appropriate options are chosen, another factors, such as climate, geographic conditions, traffic (traffic intensity and share of heavy vehicles) have to be considered for the choice of the best option.

Table 1. Potential options of pavement overlay rehabilitation [4]

Pavement distress		**Thin overlay**	**Milling & overlay**	**Microsurfacing**	**Chip seal**	**Fog seal**	**Slurry Seal**
Roughness	Nonstability related	√	√	√			
	Stability related	√					
Rutting		√	√	√			
Cracking		√	√	√	√	√	√
Flushing/Bleeding			√	√	√		
Ravelling & Wear				√	√	√	√

3. Testing programme

Testing programme covers the testing of raw materials for asphalt concrete for very thin layers. Three types of bitumen: PmB-45/80-55, 45/80-65 and 45/80-80 were chosen. Quartz diorite was chosen as aggregate with the fraction size of 0/5, 5/8, 8/11, and filler. Grading was based on Polish specifications for designing asphalt concrete WT-2:2014 [5]. To optimise bitumen contents in accordance with mix design the mixes of asphalt concrete were prepared in the laboratory. The initial (theoretical) bitumen content was assumed to be 5.2%. In order to analyse physical properties in accordance with LVS EN 12697-30 [20] standard method, cylindrical Marshall mix samples were prepared (see Fig 5). Samples were prepared at the temperature of +150°C with 50 blows from each side. Stipulated height of Marshall mix samples is 63.5 ± 2.5mm. Bulk density for Marshall samples was determined according to LVS EN 12697-6 [16] and the acquired value is important to determine void content (compaction) of the mix. Maximum density (density without voids) of asphalt concrete mix was determined according to LVS EN 12697-5 [15].
Air voids (Vm), voids in mineral aggregate (VMA) and voids filled with bitumen (VFB) were determined according to LVS EN 12697–8 [17] standard method.
Thickness of 25 mm was chosen for asphalt concrete for very thin layers. To test the resistance to rutting it was decided to lay the asphalt concrete for very thin layers on a 45 mm thick base course. Table 2 shows the testing programme covering wheel track test, testing of displacement between BBTM and SMA asphalt layers, taking asphalt cores and testing of asphalt concrete slabs.

Table 2. Testing programme to determine resistance to rutting and shear strength

No.	Mix design	No. of prepared slabs	Wheel track test	Displace ment testing	Core testing	Emulsion type	Base course type
1.	9	1	+	-	-	65+3%	SMA
2.		2	+	+	+	65+3%	
3.		2	+	+	+	65+0%	
4		2	+	+	+	60+3%	

3.1. Asphalt mix constituents

The chosen aggregate (quartz diorite) during testing showed high LA value - 11 according to LVS EN 1097-2 [7] and Nordic abrasion value – 8.0 according to LVS EN 1097-9 [8]. Bitumen 45/80-55 chosen for asphalt concrete for very thin layers showed the penetration value of 57.0 according to LVS EN 1426 [9] and softening point of 70.2 according to LVS EN 1427 [10] . Bitumen was tested also for Fraas breaking point according to LVS EN 12593 [11], elastic recovery according to LVS EN 13589 [25], ageing according to LVS EN 12607-1 [12] and other methods. All acquired results were evaluated as appropriate in line with the specifications of several countries for the production of asphalt concrete for very thin layers.

3.2. Asphalt mix design

Table 3 shows the amounts of aggregate fraction sizes used in experimental mixes of asphalt concrete for very thin layers. The amount of fraction size 8/11 depending on experimental mix varies from 35 to 48%, fraction size 5/8 - from 10 to 15%, fraction size 0/5 - from 35 to 53% and filler - from 2 to 7%. Gradation is determined according to LVS EN 933-1 [6].

Table 3. Amounts of aggregate fraction sizes in experimental mixes of asphalt concrete for very thin layers

Materials	Amount, %								
	Mix I [%]	Mix II [%]	Mix III [%]	Mix IV [%]	Mix V [%]	Mix VI [%]	Mix VII [%]	Mix VIII [%]	Mix IX [%]
Crushed quartz diorite 8/11	48	38	32	35	35	35	35	35	35
Crushed quartz diorite 5/8	12	15	15	10	10	10	10	10	10
Crushed quartz diorite 0/5	35	41	46	48	48	48	48	53	53
Filler	5	6	7	7	7	7	7	2	2

Gradation curves for experimental mixes are shown in Figure 2. In total 9 mixes were prepared in order to meet the defined criteria.

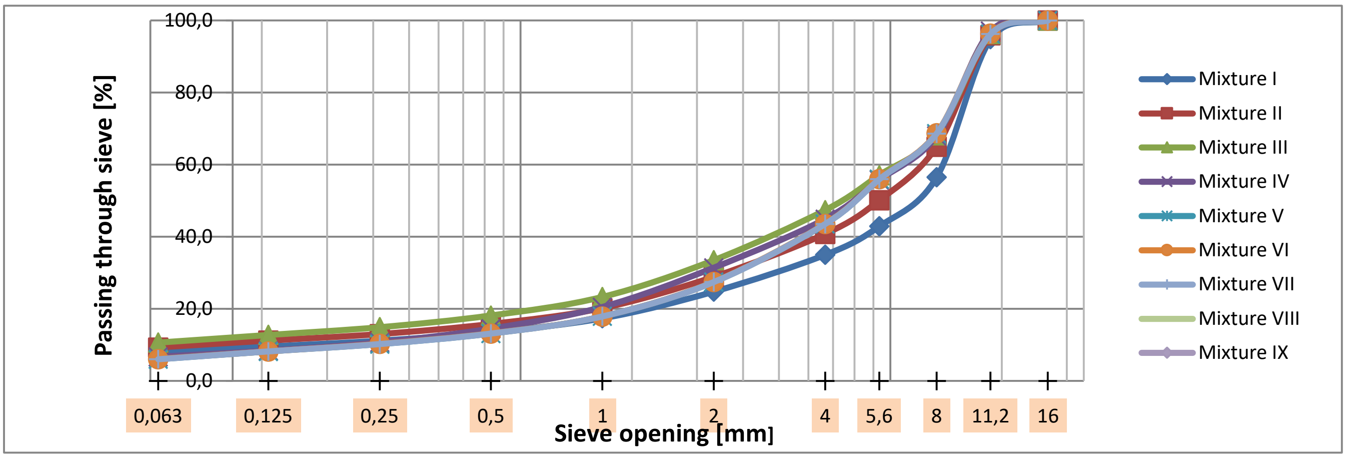

Fig. 2. Gradation curves for experimental mixes of asphalt concrete for very thin layers

Figure 3 shows the amounts of PMB 45/80-55 used in the mixing of each experimental mix of asphalt concrete for very thin layers. Optimum results were achieved with the bitumen content of 5.5%.

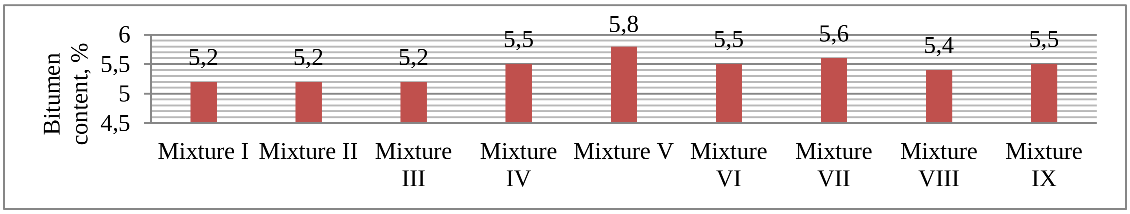

Fig. 3. Bitumen content in experimental mixes of asphalt concrete for very thin layers

3.3. Mix production

In order to optimise bitumen content asphalt concrete samples were produced in laboratory conditions according to mix design in accordance with LVS EN 12697-35 [23] (see Figure 4). It was assumed that the initial (theoretical) bitumen content is 5.2%.

Fig.4. Asphalt concrete mixing equipment for optimising bitumen content

To carry out the analysis of physical properties in accordance with LVS EN 12697-30 [20] standard method, cylindrical Marshall samples were produced as shown in Figure 5.

Fig.5. Marshall samples for optimising bitumen content

The production of samples was carried out at the temperature of +150°C with 50 blows from each side. Stipulated height of Marshall samples is 63.5 ± 2.5mm. Bulk density for Marshall samples was determined according to LVS EN 12697-6 [16] and the acquired value is important to determine void content (compaction) of the mix. Maximum density (density without voids) of asphalt concrete mix was determined according to LVS EN 12697-5 [15]. Air voids (Vm), voids in mineral aggregate (VMA) and voids filled with bitumen (VFB) were determined according to LVS EN 12697–8 [17] standard method.

3.4. Testing results

Table 4 shows the summary of physical properties of produced samples.

Table 4. Physical properties of asphalt concrete for very thin layers

Parametre	Standard	Results										
		Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7			Mix 8	Mix 9
								Test				
								No. 1	No. 2	No. 3		
Bulk density, Mg/m^3	LVS EN 12697-6	2.313	2.371	2.390	2.396	2.422	2.388	2.409	2.399	2.386	2.394	2.396
Maximum density, Mg/m^3	LVS EN 12697-5	2.566	2.569	2.550	2.557	2.529	2.535	2.544	2.539	2.538	2.539	2.531
Air voids, %	LVS EN 12697-8	9.9	7.7	6.3	6.3	4.2	5.8	5.3	5.5	6.0	5.7	5.3
Voids in mineral aggregate, %	LVS EN 12697-8	22.1	18.8	18.5	19.2	18.0	18.9	18.0	18.4	18.8	17.7	17.6
Voids filled with bitumen, %	LVS EN 12697-8	55.2	59.3	65.9	67.1	76.6	69.1	70.4	70.3	68.3	68.0	70.1
Height of Marshall samples , mm	LVS EN 12697-30	65.9	62.6	64.2	63.0	61.8	64.4	62.9	62.7	63.3	63.8	63.5
			Conformity				Non-conformity					

Wheel tracking test plays an important role in designing asphalt concrete overlays. It is performed in order to determine the resistance of asphalt concrete to rutting at high temperatures. The test in laboratory conditions simulates road loading in the hottest summer days when the temperature of asphalt concrete reaches +55°C in Latvia. This test is widely used in Europe to determine the rutting. Wheel tracking test is performed in accordance with LVS EN 12697-22 [18]. Samples are produced in accordance with LVS EN 12697-33 [21]. The produced samples are cast in plaster and the prepared samples are embedded in metal forms. The necessary sample height is 40-100 mm. Tracking load is 705 N. In total 20000 wheel tracking cycles are performed per each test sample. Depth of wheel track is determined with the help LVDT displacement indicators. Testing time is 6 hours (see Figure 6).

Fig. 6. Wheel tracking test equipment

The cut slab of sample for wheel tracking test is shown in Figure 7.

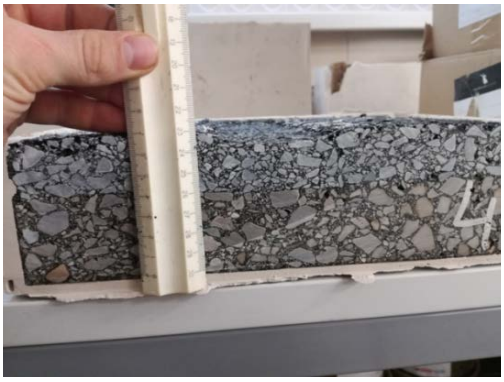

Fig. 7. Cut slab of sample for wheel tracking test

Already tested samples of asphalt concrete available in the laboratory were chosen as base courses for asphalt concrete for very thin layers. The chosen samples have increased resistance to rutting therefore the acquired results reflect the durability of overlay objectively. Table 5 also shows the WTS value for base course which directly influences the resistance of overlay to rutting.

Table 5. Properties of asphalt concrete for very thin layers and chosen base courses

Parametres \ Mix No.	1.	2.	3.	4.
Mix design	**9**			
Base course type	SMA	SMA	SMA	SMA
Base course individual WTS_{air} value [mm/1000]	0.11	0.05	0.06	0.06
Base course thickness	45mm	45mm	45mm	45mm
Air voids, overlay *	-	4.35	4.35	4.4
Maximum density, overlay (Mg/m^3) *	-	2.516	2.507	2.514
Bitumen content in overlay after recovery **	-	5.15	5.15	5.15
Overlay thickness	25mm	25mm	25mm	25mm
WTS_{air} [mm/1000]	0.18	0.12	0.12	0.16
Rut depth	4.7	3.7	2.9	4.1
Prop. rut depth [%]	6.7	5.3	4.2	5.8

* average between the values of 100mm and 150mm.
** taken from asphalt concrete mix tests – Mix No. 9

As the rolling compactor produces samples close to real conditions (during the designing of BBTM mixes the compaction was determined for Marshall samples) therefore the compaction was also determined for core samples taken from asphalt concrete slab. Table 6 shows the results of compaction of core samples with the diametre of 100 mm and 150 mm which fall within the limits stipulated for the compaction of asphalt concrete for very thin layers (3-6%). The compaction of core samples conforms to the compaction of Marshall samples.

Table 6. Compaction of core samples of asphalt concrete for very thin layers

Mix No. 2	**100mm***	**150mm****
Bulk density (Mg/m^3)	2.394	2.420
Maximum density (Mg/m^3)	2.524	2.507
Air voids, %	5.2	3.5
Mix No. 3	**100mm***	**150mm****
Bulk density (Mg/m^3)	2.384	2.413
Maximum density (Mg/m^3)	2.506	2.508
Air voids, %	4.9	3.8
Mix No. 4	**100mm***	**150mm****
Bulk density (Mg/m^3)	2.412	2.394
Maximum density (Mg/m^3)	2.506	2.521
Air voids, %	3.8	5.0

* the acquired results are average between two 100 mm core samples
** the result is acquired from one 150 mm core sample

In total displacement was tested for 3x150 core samples according to *TP Asphalt-StB R1* [26] with different emulsions between layers. The highest result was achieved with emulsion C65BP (mod. 3%). The acquired results conform to *Road Specifications 2017* (see Table 7).

Table 7. Summary of displacement results

Parametre	Mix No. 2		Mix No 3		Mix No 4	
Used emulsion	C65BP (mod. 3%)		C65B		C60BP (mod 3%)	
Sample diametre (mm)	149		149		149	
Sample layer thicknesses (mm)	25	45	25	45	25	45
Shear strength (kN)	17.919		12.770		17.300	
Shear distance (mm)	5.157		2.447		3.114	
	conformity to Road Specifications 2017					

Conclusions

1. After the analysis of data on applied technologies and their lifetime a conclusion may be drawn that asphalt concrete for very thin layers similar to traditional asphalt concrete ensures the greatest extension of road structure and pavement lifetime – 8-12 years.
2. The experience of using asphalt concrete for very thin layers in Europe shows that this pavement type is economically feasible as its cost is up to 45% lower than alternative asphalt concrete types.
3. Some drawbacks of asphalt concrete for very thin layers have to be noted, namely it may be laid only in good weather conditions as the thin layer cools down quickly; manual laying is not possible; quality of aggregate has to be high (it may be difficult to find such aggregate); efficiency of noise reduction decreases in time. Another disadvantage of asphalt concrete for very thin layers is the fact that only high quality magmatic rock aggregate has to be used for its production. In accordance to the requirements set in *Road Specifications 2017*, Table 6.2-7, the strength class of mineral aggregate shall be S-I. Because of high LA (Los Angeles value) and AN (Nordic abrasion value) values local materials such as dolomite or gravel are not suited for asphalt concrete for very thin layers.
4. This research has summarised the recommendations for using asphalt concrete for very thin layers, as well as, cases when its use is not recommended, such as areas with fatigue or alligator cracking and patches above 20% of pavement area; rut depth above 1.27cm; rut width above 1cm; areas where there is a risk of layer displacement or deterioration of unbound layers.

5. In this research magmatic rock – crushed quartz diorite (Class S-I) – was chosen for the design of asphalt concrete. Such aggregate in Latvia is used for laying Stone Mastic Asphalt (SMA) and dense asphalt concrete (AC) on roads with AADT > 3500.
6. To produce asphalt concrete for very thin layers PMB bitumens modified with elastomers with high elastic recovery value (≥ 70%) have to be used. In accordance with LVS EN 14023 the following classes of PMB may be used: PMB 45/80-55, PMB 45/80-65 and PMB 45/80-80. It has to be noted that elastic recovery value of traditional PMB bitumens used for the production of traditional SMA and AC mixes may be lower (≥ 50 %).
7. Basing on Polish specifications WT-2 the research has resulted in the production of asphalt concrete mixes with excellent operation properties (WTSair 0,12 - 0,18), produced from crushed quartz diorite (LA-11, AN-8) and polymer modified bitumen PMB 45/80-55.
8. After the analysis of changes in shear strength of traditional asphalt concrete and asphalt concrete for very thin layers with different emulsions (consumption of 0.3l/m^2), the acquired results conform to the requirements set in *Road Specifications 2017* by exceeding the stipulated value of 8 kN for 1.5 - 2.5 times.
9. After performing this research and comparing asphalt concrete for very thin layers with other surface renewal methods it may be concluded that this material has more advantages than other methods though it is more expensive. Therefore in order to acquire the best results from the society's point of view the principle *Right Treatment, Right Road, Right Time* has to be followed.

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