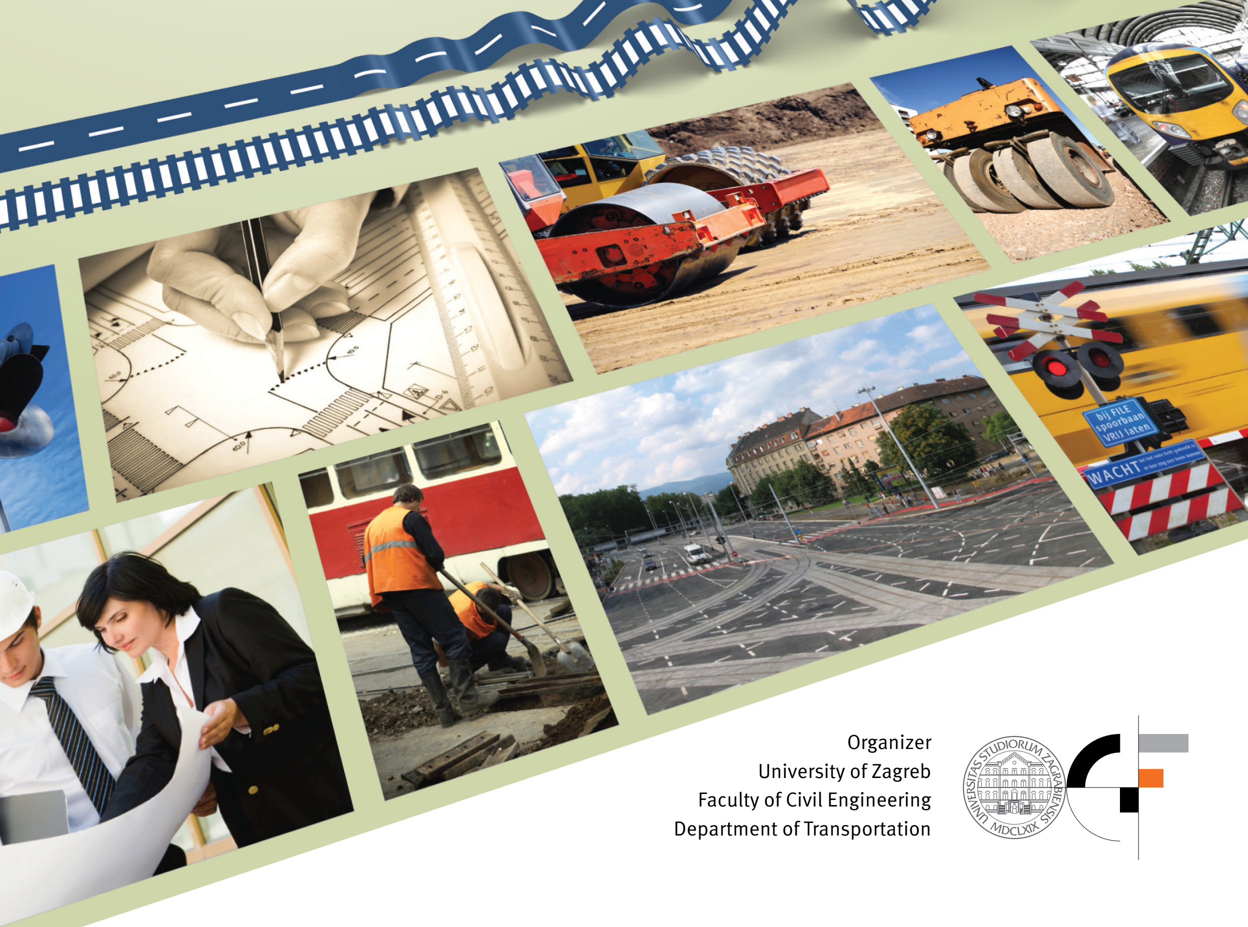
CETRA 2012

2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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RESEARCH OF ASPHALT LAYERS BONDING IN LITHUANIAN PAVEMENT

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Abstract

The bonding of asphalt layers has direct reliance on road pavement structures strength and durability. Because of insufficient bond of pavement layers the slippage and tearing, rutting and cracking emerge and the pavement life cycle becomes shorter. The article describes the research, which was made in 2010-2011 at Vilnius Gediminas Technical University Road Research Institute. In this research the strength of layers bonding was assessed using direct shear (Leutner) test, without normal stress in specimen. The samples were chosen from road sectors in Lithuania with standard asphalt layers, also asphalt layers with geosynthetics interlayer.

Keywords: asphalt layers bonding, bonding strength, Leutner test, asphalt pavement

1 Introduction

The bonding of asphalt layers is a significant factor which directly influences the strength and durability of pavement. The bonding of asphalt layers is influenced by the size of aggregates of asphalt mix, type of asphalt mix and binder, type and amount of bitumen emulsion, as well as the type of construction technology [1], [2]. Due to insufficient bonding between asphalt layers the upper asphalt layer under the effect of shear force can slip in parallel to the asphalt binder layer, and the asphalt binder layer can slip in parallel of asphalt base layer. In that case, corrugation, slippage and transverse cracking occur in the asphalt pavement structure. The pavement distress usually occurs in acceleration/deceleration and turning zones. Because of insufficient bonding of the asphalt layers, the asphalt pavement life cycle become shorter. Sufficient bonding of the asphalt layers assures the necessary bearing capacity, strength, and durability of pavement structure [1], [2]. Sufficient bonding assures that all asphalt layers in pavement work as a monolithic structure, and the largest stress from wheel loads is concentrated at the bottom of asphalt base layer. In that case cracking starts from asphalt base course also. When the bonding is insufficient each asphalt layer operates separately and the maximum stress concentrates in the bottom of each asphalt layer.
The bonding between asphalt layers is conditioned by friction and interlocking of layers. The friction is reduced by an over-large amount of binder between the layers, when is formed a binder coat, which doesn‘t allow to contact of separate asphalt layers. The bonding between asphalt layers depends on friction, bonding and interlocking of the layers. There are three types of asphalt layers bonding [3]:

- Sufficiently bonded –asphalt layers work as a monolithic structure. A large shear stress occurs and no deformations (displacement) are developed. However, this is a theoretical model, because in practice the bonding plane of asphalt layers is always represented by smaller or larger deformation.

- Partially bonded – depends on the strength of interlocking the shear stress and deformations (displacements) of various sizes occurs between layers. In case of strong interlocking occurs large shear stress and small deformation. In case of weak - occurs small shear stress and large deformation.
- Insufficiently bonded – friction and bonding occur only due to the load and the self-weight of layers. Small shear stresses and large deformations occurs between the layers.

K. Schulze [4] obtains that insufficient bonding between asphalt layers can cause corrugation and rutting of pavement. R. Weber [5] stated that cracks in asphalt pavement occur because of insufficient bonding of asphalt layers. J. Eisenmann and U. Neumann[6] reported that optimal bonding is necessary to guarantee asphalt pavement strength to prevent rutting. G. King and R. May [7] determined that deformation in the asphalt pavement layers significantly increases with decrease of layer bonding from 100% to 90%, and results in early asphalt pavement deterioration. C. J. Roffe and F. Chaignon [8] stated that the life cycle of asphalt pavement can decrease by seven or eight years without sufficient asphalt layer bonding. R. Dübner and W. Glet [9] said that insufficient bonding between layers can influence deformation and crumbling on the pavement. L. Tashman and others [10] stated that the asphalt layers bonding strength depend on the surface preparation, the amount of sprayed binder emulsion, the time interval between spraying of binder emulsion and another asphalt layer construction. In 2011, A. Vaitkus et al. [11] declared that there was no difference detected of the asphalt layers bonding strength depending on the sampling location – in the wheel-path or in-between the wheel-path of the same road. The reliance of stress and deformation distribution in pavement construction from transportation overload and climate effects was tested in a specially constructed testing road [12], [13].

2 Determination of asphalt layers bonding strength

The asphalt interlayer bonding strength can be determined by the various methods. Usually is used the Shearing test, less often the Pull–off and Torque tests (Figure 1). Mostly are used Shearing test in order to evaluate the bonding strength between the layers of asphalt. The shearing test can be performed without normal stress (direct shear test) and with normal stress (simple shear test):

1. The Direct shear test: the Leutner test, the Parallel-Layer Direct Shear test, the LBC test, the De Bondt test, the U.S. National Asphalt Technology Center Shearing test (NCAT), the FDOT test, the Iowa test, the Rommanoshi test, the Al-Qadi test, the Asher test, and the SST- Superpave Shear Tester.
2. The Simple shear test: the MCS trial, the ASTRA trial, and the SST trial.

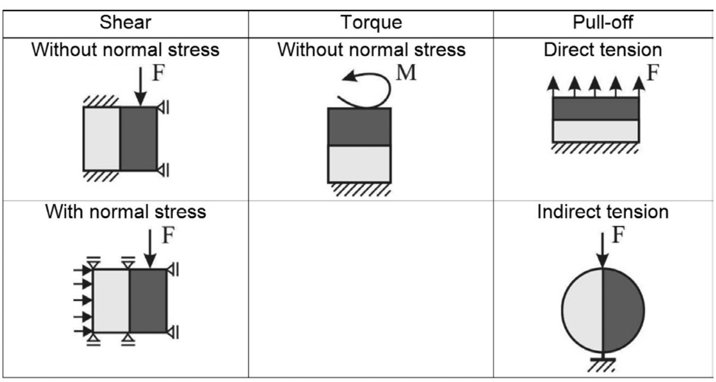

Figure 1 Asphalt layer bonding determination methods [3]

In 1979, R. Leutner described the method of direct shear test for determining the asphalt layer bonding strength [14]. The Leutner test is one of the most commonly used direct shear method. It is used in many countries In Switzerland, Austria, and Germany it has been accepted as the national standard for evaluating asphalt layer strength. The bonding of layers is evaluated according to the measured maximum shear force (kN) and shear flow (mm).
In Germany, the bonding strength of asphalt layers is determined by performing the Leutner test according to the document TP asphalt–StB Teil 80 (Direct shear test). In Germany the minimum value of the asphalt layer bonding strength regulated by the document ZTV Asphalt–StB 07[15]: between the asphalt wearing and binder layers – not less than 15 kN; between all other asphalt layers – not less than 12 kN. The recommended limit values between wearing-binder asphalt layers is 2,0–4,0 mm and between binder-base 1,5–3,0 mm for the shear flow are given in ZTV M–V and Arbit Nr. 60.

3 Experimental research

The experimental research was performed in laboratory of Road Research Institute of the Vilnius Gediminas Technical University in 2010 and 2011. The Direct shear tests were performed on samples prepared in laboratory and on samples (cores) taken from Lithuanian roads and city streets.

3.1 Results from samples made in laboratory

In the laboratory the samples of asphalt wearing and binder layers were prepared with different type and the amount of bitumen emulsion between the layers and different compaction degree of the asphalt wearing layer. The roller compactor was used to compact the samples. The wearing layer was made from AC 11 VN and AC 11 VS hot mix asphalt, and the binder layer – AC 16 AN.
Different types and quantity of bitumen emulsion were sprayed in between the asphalt layers. The emulsion's working temperature was 40°C. For comparison, there were also made asphalt layers slabs without the bitumen emulsion in between the layers. The compaction degree of the asphalt wearing layer was 97% or 100%, and the asphalt binder layer - 97% in all samples. From the each asphalt slab, that had been made, was drilled three 150 mm diameter asphalt cores. The interlayer bonding was measured by the Asphalt technical testing guidelines, Part 80. (German-Technische Prüfvorschriften für asphalt, TP Asphalt–StB Teil 80). The tests were performed in standard Marshall press with shearing form. It was used constant speed static load of 50 mm/min. Before the test, asphalt cores were stored at 20°C temperature for 24 hours. The combinations of samples made in laboratory and the test results are presented in Table 1.
The test results (Fig. 2) showed that the shear force vary in a wide interval, from 14,2 kN to 44,8 kN. The minimum shear force was in combination No. 3 and 4, the samples in which asphalt wearing layer was AC 11 VS with 97% and 100% compaction degree, and no any bonding material were used in interlayer. The maximum shear force was in combination No. 9 (38,17 kN after 2 days and 43,83 kN after 10 days), the samples in which asphalt wearing layer was AC 11 VN with 97% compaction degree, and 150 g/m2 bitumen emulsion in interlayer. Dependent on test performance time the 13% grater shear force was obtained after 10 days. The shear force results of samples with 100% compaction of asphalt wearing layer was 13% (AC 11 VN) and 18% (AC 11 VS) higher comparing with 97% compaction degree. All tested samples, which asphalt wearing layer was from the AC 11 VN, was determined greater value of av. 26% (tested after 2 days) and av. 54% (tested after 10 days) comparing with values of asphalt wearing layer made from the AC 11 VS. In this case the bitumen emulsion wasn't use in the interlayer.

Table 1 The combinations of samples made in laboratory and the test results

Testing combination	Interlayer bonding material	The quantity of bonding material [g/m2]	The mix of asphalt wearing layer (compression degree [%])	The mix of asphalt binder layer (compression degree [%])	Shear force [kN]		Shear flow [mm]	
					After 2 days	After 10 days	After 2 days	After 10 days
1	–	–	AC 11 VN (97 %)	AC 16 AN (97 %)	21,67	36,73	1,93	2,80
2	–	–	AC 11 VN (100 %)		21,97	41,50	2,93	1,73
3	–	–	AC 11 VS (97 %)		14,23	28,27	2,33	1,70
4	–	–	AC 11 VS (100 %)		14,30	33,53	1,90	1,87
5	C 60 BF 1–S	90	AC 11 VN (97 %)		30,00	44,77	3,10	3,47
6	C 60 BF 1–S	135	AC 11 VN (97 %)		22,83	42,50	2,10	2,57
7	C 60 BF 1–S	200	AC 11 VN (97 %)		32,73	32,73	2,27	2,27
8	C 60 BP 1–S	100	AC 11 VN (97 %)		33,25	36,67	2,81	3,46
9	C 60 BP 1–S	150	AC 11 VN (97 %)		38,17	43,83	3,16	3,00
10	C 60 BP 1–S	250	AC 11 VN (97 %)		35,83	38,42	3,33	4,44

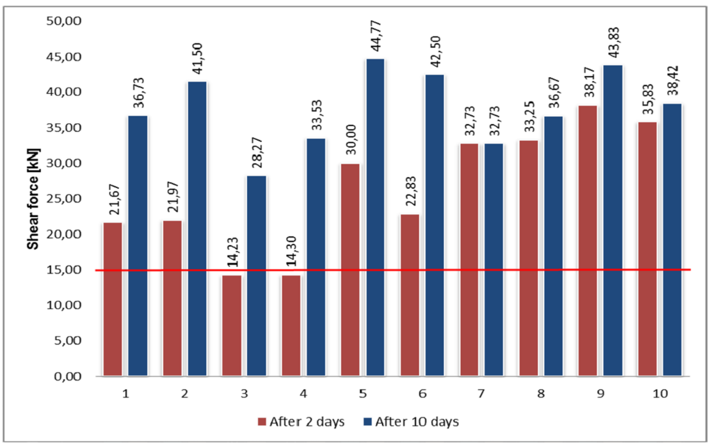

Figure 2 The distribution of shear force between the asphalt wearing and binder layers in samples prepared in laboratory. ▬ - the line shows the lowest allowable limit of bonding strength between the asphalt wearing and binder layers

The bonding strength was about 30% greater with bitumen emulsion C 60 BF 1–S in asphalt interlayer than without (tested after 2 days) and no significant difference tested after 10 days. A significant difference of bonding was defined on comparing the samples tested after 2 and 10 days where the bitumen emulsion wasn't used in the interlayers. In this case, the difference

of bonding strength was in range from 69% to 134%, depending on the type of asphalt mix used on the wearing layer, and the degree of compaction. It was obtain that the shear force is much higher in samples with bitumen emulsion C 60 BP 1–S than samples with bitumen emulsion C 60 BF 1–S. The difference in results 2 days after compaction varies from 10% to 60%, but no significant difference obtained in samples tested 10 days after compaction.
It was determined that the asphalt layer shear flow values changed from 1.7 mm to 4.5 mm. The samples with bitumen emulsion C 60 BF 1–S shear flow varied from 2.1 mm to 3.5 mm. The greatest values determined in the samples with 90 g/m2 emulsion, tested after 10 days. The samples with bitumen emulsion C 60 BP 1–S shear flow varied from 2.8 mm to 4.5 mm. The greatest value was determined in the samples with 250 g/m2 emulsion, tested after 10 days. The analysis of the asphalt layer bonding strength results shows that after 10 days of asphalt compaction, the bonding strength in all cases was greater than 25 kN and the shear flow was greater than 1.5 mm. It should be stated that the use of bitumen emulsion leads to sufficient bonding of asphalt layers, but only right amount of bitumen emulsion ensures the good bonding and the allowed shear flow. The polymer modified emulsions C 60 BP 1–S shows much more promising results than bitumen emulsion C 60 BF 1–S.

3.2 Results from samples taken from roads and city streets

The research was composed from taking asphalt cores from selected roads and laboratory testing the bonding strength of asphalt layers. The samples were taken in the wheel-path and between the wheel-path of selected roads and streets. A range of the samples were with geosynthetics interlayer, stress absorbing membrane interlayer (SAMI) or bitumen emulsion interlayer. The testing combinations and results from laboratory testing are presented in Table 2. The asphalt cores sampled according to the LST EN 12697–27:2002 standard and the asphalt layers bonding strength determined according to the Asphalt Testing Technical Directive-Part 80 (German-Technische Prüfvorschriften für asphalt, TP Asphalt–StB Teil 80). The asphalt layers bonding strength distribution dependent on testing combination presented in Fig. 3.
Analyzing the asphalt layer shear force distribution was determined that 88% of the testing combinations (22 out of 25), the shear force was greater than 15 kN. The remaining 3 testing combinations results distributed: the shear force in 6.1. and 8.1 combination was 21% less than required (15 kN) and in 5.2 was 20% less than the required (12 kN). The maximum shear force identified for combinations 10.1 and 10.2 were taken from the wheel-path of road Nr. 102 where the asphalt wearing layer was made from the SMA 11 S. Whereas, the minimum shear force was identified in combination 5.2 taken from the wheel-path of Eisiskių street. From samples taken at Plytines street, were determined that the shear force is 85% greater (3.2. testing combination) without geosynthetics interlayer than with it (3.1. testing combination). Testing of samples selected from Eisiskiu street showed about 30% greater shear force samples without geosynthetics (5.1. testing combination) than with geogrid Hatelit C 40/17 (5.3. testing combination), and even a 2.7 times greater shear force (5.2. testing combination) than with geogrid Armatex RSM 50/70. Insufficient asphalt layer bonding strength also has been identified from selected samples at road Nr. 153, Nr. 130 and Nr. 143.
It was determined that the shear flow changes independently from testing combination, but the flow is influenced by the material used in the interlayers. Shear flow in 72% of testing combinations (18 out of 25) was within the range from 2.0 mm to 4.0 mm. From samples taken at Plytines street, were determined that the shear flow is 35% lower with geosynthetics interlayer than without it. Meanwhile testing of samples selected from Eisiskiu street showed about 40% greater shear force samples without geosynthetics than with geogrid Hatelit C 40/17 (5.1. testing combination), and with geogrid Armatex RSM 50/70 (5.2. testing combination).
A relatively high and exceeding the ZMT M-V recommended shear flow range was identified in samples 1, 2 and 13.1. In sample 1 and 2, a special asphalt mix SAMI 0/5 was used for the interlayer and SMA 11 S for 13.1. It can be noticed that chosen testing combinations with

asphalt wearing layer SMA 11 S (10.1, 10.2 road Nr. 102 and 13.1, 13.2 road Nr. A14) the shear flow wasn‘t significantly higher compared to other types of asphalt wearing layer shear flow. It was obtained that the shear flow changes independently from place of sample taking, wherever the sample was taken in the wheel-path or between it.

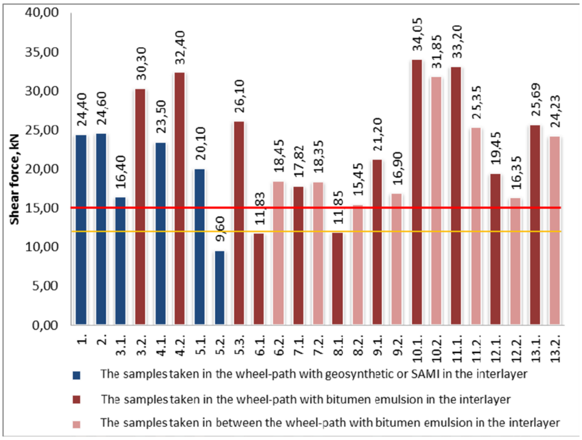

Figure 3 The distribution of shear force between asphalt layers in samples cored in roads and city streets.
- the lowest allowed limit of shear force between the asphalt wearing and binder layers (15 kN).
- the lowest allowed limit of shear force between all other asphalt layers (12 kN)

4 Conclusions

1 The analysis of the asphalt layer bonding strength results shows that after 10 days of asphalt compaction, the bonding strength in all cases was greater than 25 kN and the shear flow was greater than 1.5 mm.

2 The shear force results of samples with 100% compaction of asphalt wearing layer was 13% (AC 11 VN) and 18% (AC 11 VS) higher comparing with 97% compaction degree.

3 All tested samples, which asphalt wearing layer was from the AC 11 VN, was determined greater value of av. 26% (tested after 2 days) and av. 54% (tested after 10 days) comparing with values of asphalt wearing layer made from the AC 11 VS. In this case the bitumen emulsion wasn’t use in the interlayer.

4 Experimental research has indicated that the bonding strength between asphalt layers decreases from 20% to 50% when the geogrid is laid between asphalt layers. The use of geosynthetics also influence on shear flow reduction.

5 It was also determined that the amount of bonding emulsion C 60 BF 1–S influence on asphalt layers shear force and its values were distributed from 22,8 kN to 32,7 kN (tested after 2 days) and from 32,7 kN to 44,8 kN (tested after 10 days). The bonding strength was about 30% greater with bitumen emulsion in asphalt interlayer than without (tested after 2 days) and no significant difference tested after 10 days.

Table 2 The testing combinations and results from laboratory testing of samples taken from roads and city streets

Testing combination	Paving year	Sampling location		The mix of asphalt wearing layer	The type of material in the interlayer	Shear force [kN]	Shear flow [mm]
1.	2010	Oslo str., Vilnius	In the wheel-path	AC 16 AS	SAMI (under binder layer)	24,40	5,90
2.	2005	Savanoriu str., Vilnius	In the wheel-path	SMA 11 S	SAMI (under wearing layer)	24,60	6,10
3.1.	2006	Plytines str., Vilnius	In the wheel-path	AC11VS	Pavegrid G100/100 (under binder layer)	16,40	2,20
3.2.			In the wheel-path		Without geogrid	30,30	3,40
4.1.	2007	Kalvariju str., Vilnius	In the wheel-path	SMA11S	Pavegrid G100/100 (under wearing layer)	23,50	2,80
4.2.			In the wheel-path		Without geogrid	32,40	3,50
5.1.	2007	Eisikių str., Vilnius	In the wheel-path	SMA 11 S	Hatelit C 40/17 (under binder layer)	20,10	1,80
5.2.					Armatex RSM 50/50 (under binder layer)	9,60	1,70
5.3.					Without geogrid	26,10	1,00
6.1.	2008	Road Nr. 153	In the wheel-path	AC 11 VS	Without geogrid	11,83	1,78
6.2.			Between the wheel-path			18,45	2,00
7.1.	2010	Road Nr. 143	In the wheel-path	AC 11 VN	Without geogrid	17,82	2,55
7.2.			Between the wheel-path			18,35	2,70
8.1.	2010	Road Nr. 130	In the wheel-path	AC 11 VS	Without geogrid	11,85	2,05
8.2.			Between the wheel-path			15,45	2,78
9.1.	2010	Road Nr. 128	In the wheel-path	AC 11 VS	Without geogrid	21,20	2,08
9.2.			Between the wheel-path			16,90	2,25
10.1.	2010	Road Nr. 102	In the wheel-path	SMA 11 S	Without geogrid	34,05	4,03
10.2.			Between the wheel-path			31,85	3,95
11.1.	2010	Road Nr. 2828	In the wheel-path	AC 11 VN	Without geogrid	33,20	3,35
11.2.			Between the wheel-path			25,35	4,05
12.1.	2010	Road Nr. A4	In the wheel-path	AC 11 VS	Without geogrid	19,45	3,95
12.2.			Between the wheel-path			16,35	2,70
13.1.	2009	Road Nr. A14	In the wheel-path	SMA 11 S	Without geogrid	25,69	5,53
13.2.			Between the wheel-path			24,23	3,43

References

[1] Raab, C.; Partl, M. N.; Halim, A. E. 2009. Evaluation of interlayer shear bond devices for asphalt pavements, The Baltic Journal of Road and Bridge Engineering 4(4): 186–195 a.

[2] Raab, C.; Partl, M. N. 2009. Interlayer Bonding of Binder, Base and Subbase Layers of Asphalt Pavements: Long-term Performance, Journal Construction and Building Materials, 23 (2009) 2926–2931 p.

[3] Frohmut, W.; Ascher, D. 2007. Untersuchungen zur Wirksamkeit des Haftverbundes und dessen Auswirkungen auf die Lebensdauer von Asphaltbefestigungen, Schlussbericht zum AiF-Projekt Nr. 13589 BR/1, Technische Universität Dresden.

[4] Schulze, K. 1979. Asphaltbeton mit erhöhtem Füller-Bitumen-Verhältnis und dichter Belagsstruktur, Straßen- und Tiefbau Heft 11.

[5] Weber, R. 1991. Rißbildungen in Asphaltstraßen als Folge mangelhaften Schichtver-bundes, Dissertation TU München.

[6] Eisenmann, J.; Neumann, U. 1993. Auswirkungen von Verbundstörungen auf die Spurrinnenbildung, Forschungsbericht Nr. 1444 (FE 07.151 G 91 K), Prüfamt für Bau von Landverkehrsflächen der TU München.

[7] King, G, and R. May. 2003. New Approaches to Tack Application, presentation made to the 83rd Annual Meeting of the Transportation Research Board, Washington, D. C.

[8] Roffe, J. C., and Chaignon, F., "Chatacterisation Tests on Bond Coats: Worldwide Study, Impact, Tests, and Recommendations", 3rd International Conference Bituminius Mixtures and Pavements, Thessaloniki, 2002.

[9] Dübner, R.; Glet, W. Unterhaltung von Asphaltstraßen Arbeitsgemeinschaft der Bi-tumen-Industrie, e.V., Hamburg, 1993.

[10] Tashman, L.; Nam, K.; Papagiannakis, T. 2006. Evaluation of the Influence of Tack Coat Construction Factors on the Bond Strength Between Pavement Layers, Report# WCAT 06-002, Washington Center for Asphalt Technology.

[11] Vaitkus A., Žilionienė D., Paulauskaitė S., Tuminienė F., Žiliūtė L. 2011. Research and Assessment of Asphalt Layers Bonding, The Baltic Journal of Road and Bridge Engineering 6(3): 210-218. ISSN 1822-427X (print), ISSN 1822-4288 (online). (Thomson ISI Web of Science).

[12] Vaitkus, A.; Puodžiukas, V.; Motiejūnas, A.; Vitkienė, J.; Vorobjovas, V.; Paliukaitė, M. 2010. Long Term Research of Experimental Asphalt Pavement Structures, in Transport Research Arena Europe 2010, Brussels: Selected papers (2010, Brussels, Belgium).

[13] Čygas, D.; Laurinavičius, A.; Vaitkus, A.; Perveneckas, Z., Motiejūnas, A. 2008. Research of asphalt pavement structures on Lithuanian roads (I), The Baltic Journal of Road and Bridge Engineering 3(2): 77-83. ISSN 1822-427X (print), ISSN 1822-4288 (online). (Thomson ISI Web of Science).

[14] Leutner, R. 1979. Untersuchungen des Schichtenverbunds beim bituminösen Oberbau Investigation of the Adhesion of Bituminius Pavements], Bitumen 3: 84–91.

[15] Forschungsgesellschaft für Straßen- und Verkehrswesen, Zusätzliche Technische Vertragsbedingungen und Richtlinien für den Bau von Verkehrsflächenbefestigungen aus Asphalt ZTV Asphalt–StB 07. 2007.