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RESEARCH AND ASSESSMENT OF ASPHALT LAYERS BONDING

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Abstract. The bonding of asphalt layers has direct reliance on road pavement structures strength and durability. Because of insufficient bond between pavement layers the slippage and corrugations, rutting and cracking occur and the pavement life cycle becomes shorter. The article describes the research on bonding of asphalt layers, which was carried out in 2010–2011 at Vilnius Gediminas Technical University Road Research Institute. In this research the strength of layers bonding was assessed using the direct shear (Leutner) test without normal stress in the specimen. The samples were taken from the road sections of Lithuania with standard asphalt layers, also asphalt layers with the geosynthetic interlayer. The research showed that the bonding strength of asphalt layers of the samples taken on the roads of Lithuania in most cases meets the requirements of standard documents, and the use of geosynthetic materials between asphalt layers worsens their bonding strength.

Keywords: adhesion, bonding, bonding strength, shear force, asphalt layers, pavement layers, interlayer shear test, Leutner test, pull-off test.

1. Introduction

The bonding of asphalt layers has direct reliance on road pavement structures strength and durability. The bonding of asphalt layers is affected by the size of aggregates, type of materials, binder (bitumen) of adjacent layers, also by the type of bitumen emulsion, used for the bonding between asphalt layers, and construction technology of asphalt layers (Hu *et al.* 2011; Raab *et al.* 2009). In Lithuania, when laying asphalt pavement from two or more layers, the under layer shall be evenly coated with bitumen emulsion the type and amounts of which depend on the class of pavement structure, properties of the under layer and type of asphalt layer to be laid. In other countries to ensure the bond of asphalt layers the bitumen emulsions of various types are widely used (Harvey *et al.* 1999; Hu *et al.* 2011; Plug *et al.* 2010). Due to insufficient bonding between asphalt layers the upper asphalt layer under the effect of shear force can slip in respect of the lower asphalt layer, and the lower asphalt layer can slip in respect of asphalt base. In that case the corrugations, rutting and cracking occur within the whole pavement structure. The mentioned defects are most frequently formed at the acceleration/deceleration and turning zones. Due to insufficient bonding of asphalt layers the life cycle of asphalt pavement becomes shorter.

The problem of insufficient bonding between asphalt layers is topical for many countries. Already in 1980, the Environmental Dept of Northern Ireland identified asphalt pavement defects on the newly laid road, and they were caused by insufficient bonding of asphalt layers (Hu *et al.* 2011; Shaat 1992). Lepert *et al.* (1992) gave the results of SETRA/DTC research, carried out in 1986, concluding that insufficient bonding of asphalt layers caused 5% of the defects on the road network of France. Sutano (2004) investigated the reasons why on the newly reconstructed road of Indonesia the horizontal deformations and corrugations occur at the acceleration and acceleration zones. Charmot *et al.* (2005) has identified large areas of the slippage of upper asphalt layer, which occurred two months after the overlay project on one of the Nevada State (USA) roads.

The research in the Washington State (USA) indicated that in 10% of the tested asphalt samples, taken from the roads of this State, the upper and lower asphalt layers were separated (Muench, Moonmaw 2008). Because of this problem the asphalt layers were slipped in respect of

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each other and the corrugations, ruts and cracks were evident.

The problem of insufficient bonding of asphalt layers was also analysed in Switzerland. On one of the newly constructed highways the areas of insufficiently bonded base layers were identified. The problem of insufficient bonding of asphalt layers not only occurs between the upper and lower asphalt layers but also between the base layers (Raab, Partl 2004a).

The problems of the slippage of upper layers were investigated and analysed in some Japanese airports. On the airport runways the slippage of upper layer was observed caused by insufficient bonding with the lower layer (Hachiya, Sato 1997). The problem of the slippage of asphalt layers due to insufficient bonding was also analysed and assessed in Newark airport of the New Jersey State (USA) (Bognacki *et al.* 2007). On some airport runways the slippage of upper asphalt layer in respect to the lower asphalt layer was identified.

The ruts, corrugations, slippage of asphalt layers and longitudinal cracks within the whole pavement structure, caused by insufficient asphalt layers bonding, increase maintenance costs (due to repairs) and shorten the life cycle of the pavement. Many European countries, also USA, Canada and others, carry out investigations on the significance of bonding between the upper and lower asphalt layers, and the deeper layers for the life cycle and durability of asphalt pavement. Such countries as USA, Switzerland, Germany and Slovenia have already approved methods for the determination of the bonding strength of layers. Lithuania according to *Automobilių kelių dangos konstrukcijos asfalto sluoksnių įrengimo taisyklės ĮT ASFALTAS 08* [The Installation Rules of the Road Pavement Asphalt Layers "*ĮT ASFALTAS 08*"] also regulates the bonding strength between the upper and lower layers and between the lower and base layers. However, not in all cases this requirement carries an obligatory character and the customer takes the final solution on its necessity.

The bonding of asphalt layers is affected by many factors. They altogether determine the strength and durability of asphalt pavement. Due to the gradually increasing traffic volume and traffic loads the higher and higher requirements are raised for asphalt pavements. In order to achieve the highest possible strength and durability of asphalt pavements a large attention is paid to the research in the physical and *mechanical* properties of individual asphalt layers and their mixtures (Bulevičius *et al.* 2010; Čygas *et al.* 2011; Motiejūnas *et al.* 2010). However, it should be emphasized that not only the materials of different asphalt layers but also the bonding between them is a very important factor seeking to prolong pavement performance and to prevent the occurrence of defects (Hu *et al.* 2011; Raab *et al.* 2004b).

2. The principles of bonding between asphalt layers

Sufficient bonding between asphalt layers ensures the required bearing capacity, strength and durability of asphalt pavement (Raab *et al.* 2009). Under sufficient bonding the asphalt layers function as a monolithic structure and the largest stresses from vertical load are concentrated at the bottom of the structure. When the bonding is insufficient each asphalt layer functions separately and such pavement is able to carry lower loads compared to the pavement the layers of which are sufficiently bonded.

The bonding between asphalt layers is conditioned by friction, bonding and interlocking of the layers. Asphalt layers can be (Frohmut, Ascher 2007) (Fig. 1):

– fully bonded – in that case they work as a monolithic layer. On their bonding plane large shear stresses occur and no deformations (displacements) are developed. However, this is a theoretical model since in practice the bonding plane of asphalt layers is always represented by smaller or larger deformations;
– partially bonded (interlocked) – depending on the strength of interlocking the shear stresses and deformations (displacements) of various sizes are developed at the interlayer. In case of strong interlocking large shear stresses and small deformations (displacements) occur, in case of weak – on the contrary, small shear stresses and large displacements. An intermediate variant is also possible. Besides interlocking, the bonding is influenced by the layers friction, though, the effect of friction is getting lower with the increasing bonding area;
– fully slipped – between the layers only friction and bonding occur due to the load and the self-weight of layers. Very small shear stresses and very large deformations (displacements) are developed.

According to Dr Metelmann (ADLER Baustoff und Umwelt LABOR GmbH, 2004. *Anforderungen an den Asphalteinbau, Schichtenverbund und Lebensdauer von Asphaltkonstruktionen*) the bearing capacity of asphalt pavement, depending on the bonding of asphalt layers in a three-layer structure, is distributed as follows: all three lay-

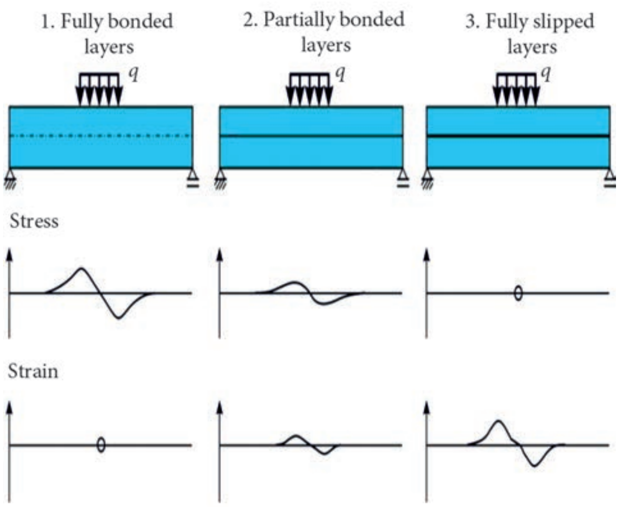

Fig. 1. Distribution of shear stresses and deformations (displacements) depending on the bonding level between the layers (Frohmut *et al.* 2007)

ers are bonded – 100%, there is no bonding between the upper and lower layers – 70%, there is no bonding between the lower and base layers– 40% and there is no bonding between all three layers – 3%.

At the joining of two asphalt layers (interlayer) horizontal load generates the shear and tensile stresses. The shear stresses occur in the wheel and pavement contact zone between asphalt layers.

Insufficient bonding between asphalt layers are determined by the following factors (West *et al.* 2005): the non-use of materials to improve bonding (bitumen, bitumen emulsion), improper use of materials to improve bonding, the use of improper asphalt mixtures to ensure a proper bonding between asphalt layers (it is of significant importance at the acceleration/deceleration and turning zones), the use of asphalt mixtures with a large content of sand filler, the improper application of technology to prepare the under layer surface or the non-compliance with the technology (insufficient cleaning when preparing the layer, dust, water, the uneven and (or) in too small contents spreading of bitumen or bitumen emulsion).

3. Methods for the determination of asphalt layers bonding and requirements for bonding values

The bonding strength between asphalt layers could be determined by various testing methods. In recent years many European countries, as well as USA and Canada, have validated methods and devices used to perform the testing of bonding strength between asphalt layers. (Raab *et al.* 2009).

To determine the bonding strength between asphalt layers most frequently the shear tests are carried out, more seldom the pull-off of torque tests (Fig. 2). The shear tests are performed by applying normal stresses in the sample or without their application, the pull-off tests are direct or indirect (Frohmut, Ascher 2007; Raab *et al.* 2009).

The shear tests, performed without applying normal stresses in the sample, are also called direct, and the shear tests performed with normal stresses – the simple. The most world widely used are various modifications of the direct shear test. Those are static tests without the application of normal stresses in the sample during which the force with constant displacement is transferred to only one of the layers parallel to the shear plane. Another layer remains fixed. A cylindrical sample (asphalt core, Marshall sample or similar) is fixed in a perpendicular direction to the cross-section, i.e. laid. The obligatory parameters for the direct shear test are testing temperature, loading speed, dimensions of samples, gap between fixation and shearing rings. In many countries the tests are essentially similar only using different testing parameters and the slightly modified shearing rings, and the bond between the layers is usually assessed according to the measured destructive shear force and shear flow (Frohmut, Ascher 2007; Raab *et al.* 2009).

Fig. 2. Asphalt layers shearing mould fixed in the Marshall press

The bonding force between asphalt layers by a direct tensile test is world widely determined by the same principle only under different conditions, i.e. by laboratory and field tests. The edges of 50 mm, 100 mm or 150 mm diameter samples are glued with special glue to steel or aluminium testing disks and are tracked in an axial direction with constant force one from each other until their destruction. In this way, at the selected temperature, for example 15 °C, the max force is determined at which the sample fails. It should be mentioned that the failure zone of the sample is not always identical to the interlayer plane. The indirect tensile test of asphalt layers is carried out by the method of wedge-shaped crack. The bonding point of separate layers of rectangular or cylindrical samples is pressed by a special wedge, fixed in the wheels, until the sample fails (Frohmut, Ascher 2007).

Using the non-destructive test methods to detect the bonding condition between asphalt layers the piezoelectric acceleration detectors are used to measure and record vibrations induced by the impulse (from the falling weight) to the pavement surface. The curves of vibrations of sufficient and insufficient bonding differ, and thus the bonding between asphalt layers is detected without destructing the pavement.

A plenty of tests are worldwide used to determine the bonding strength between asphalt layers (Bondt 1999; Canestrari, Santagata 2005; Frohmut, Ascher 2007; Kruntcheva *et. al.* 2004; Raab *et al.* 2009; Recasens *et. al.* 2003; Sholar *et. al.* 2004; Tashman *et al.* 2006):

- shear tests: direct shear test (without normal stresses) – Leutner, Layer–Parallel Direct Shear, LBC, de Bondt, NCAT, FDOT, Iowa, Rommanoshi, Al-Qadi, Asher, Superpave shear tester (SST) or simple shear test (by inducing normal stresses in the sample) – MCS, ASTRA, SST;
- tensile tests: direct tensile test – UTEP Pull–Off Test, MTQ; indirect tensile test – Tschegg;
- torque tests – Attacker and Torque bond test;
- non-destructive tests – load impulse test; Falling weight deflectometer (FWD) test.

In Europe, the bonding strength between asphalt layers is mostly measured by testing cylindrical core samples with the diameter of 100 mm or 150 mm taken from the asphalt pavement. Using the modified direct shear device (Layer parallel direct shear LPDS) the bonding between asphalt layers can be also measured for prismatic samples. The test of bonding strength is usually performed at a 20–25 °C temperature.

The Leutner shear test is widely used in many countries, and in Switzerland, Austria and Germany has been accepted as a national standard to detect the bonding strength of asphalt layers. European countries, using the Leutner method, have slightly modified its principle scheme and adapted to their needs. The test is performed on a 150 mm or 100 mm diameter cylindrical sample composed of two layers. One tested part (lower layer) is fixed by mechanical clamping and another part (upper layer) is provided with the static load at a constant 50 mm/min speed. Between the fixing plate and force transfer plate a 1 mm gap is left. The test is performed at a temperature of 20 °C (Leutner 1979).

The direct bonding strength of asphalt pavement layers can be determined by the peel test. In Germany, this test is aimed at determining the bonding between thin asphalt layers and is performed according to the *Forschungsgesellschaft für Sraßen- und Verkehrswesen "Technische Prüfvorschriften für asphalt, TP Asphalt-StB Teil 81" 2009* [Research Society for Srasse and Transportation "Technical Test for Asphalt, Asphalt-StB part TP 81st" 2009]. During the test the edges of samples (cores) are glued by special glue to the steel or aluminium testing disks and are tracked in axial direction with constant force one from each other until their destruction. At the selected temperature the largest destructive force is detected. It should be mentioned that the failure zone is not always identical to the interlayer bonding plane. The test can be performed in the laboratory or on-site.

The bonding condition between asphalt layers could be assessed by using the falling weight deflectometer. This device induces the load impulse, simulating traffic loading, and pavement deflections are recorded by the piezoelectric acceleration detectors. Knowing the properties of pavement materials and based on the back-calculation method the bonding between the layers are determined. For this purpose the parameters, influencing the layers bonding, are changed until the calculated surface deformations coincide with those measured. This method does not enable to determine the direct bonding parameters between asphalt layers (bonding strength or shear flow). Due to an extremely large amount of parameters, influencing calculation results, the use of this method for the determination of asphalt layers bonding is rated as poor (Frohmut, Ascher 2007).

In Germany, the min values of the bonding strength between asphalt layers, regulated by the document ZTV Asphalt–StB 07 are: between the upper and lower asphalt layers not less than 15 kN and between other layers or partial layers not less than 12 kN.

ZTV Asphalt–StB 07 does not regulate the values of shear flow, and the recommended limit values for the shear flow are given in ZTV M–V and Arbit No. 60 (Table 1).

Table 1. The recommended values for the shear flow of asphalt layers

Name of document	ZTV M–V	Arbit No. 60
Underlayer	Shear flow, mm	
Between the upper and lower asphalt layers	2.0–4.0	2.0–5.0
Between the lower and base layers	1.5–3.0	1.0–4.5

4. Experimental research

The first stage of experimental research on the bonding of asphalt layers was carried out at the Road Scientific Laboratory of the Vilnius Gediminas Technical University Road Research Institute in September and October 2010. The samples were taken from the streets of Vilnius City. The research consisted of the taking of asphalt samples (cores) from the selected streets and roads and the laboratory testing of bonding between asphalt layers in the samples (cores) that were taken. The samples were taken in five locations (Table 2), at the outer track of the first traffic lane. In all sampling locations, under the lower asphalt layer (in Savanorių pr. and Kalvarijų g. between the upper and lower asphalt layers) a geosynthetic material was laid or a special asphalt mix.

Taking of asphalt samples (cores) to be tested was carried out according to the standard *LST EN 12697–27:2002 "Bituminiai mišiniai. Karštojo asfalto mišinio bandymo metodai. 27 dalis. Ėminių ėmimas"* [Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 27: Sampling], and the bonding condition of asphalt layers was determined according to the document *TP Asphalt–StB Teil 80 Technische Prüfvorschriften für Asphalt* [Technical Regulations for Asphalt Testing, Part 80]). This was based on the fact that the *ĮT ASFALTAS 08* points out namely to this document for the determination of the bonding of asphalt layers.

In the laboratory the bonding of asphalt layers was determined for those layers between which the geosynthetic material (geogrid) was laid, i.e. between the lower layer and the layers of the old asphalt pavement (in most cases) or between the upper and lower asphalt layers, also between the layers where no geogrid was laid to compare the bonding strength between the layers. The bonding strength between the upper or lower asphalt layer and the underlying layer, laid from the special stress-absorbing asphalt mixture VIASAF 0/5, was also determined.

Prior to the shear test of asphalt layers each of the asphalt samples (cores) was marked with the traffic direction, since the shear of asphalt layers was made parallel to the driving direction. The bonding test was performed according to the principle scheme of the Leutner shear test. The asphalt cores of 150 mm diameter were tested. For the transfer of shear load and for the recording of destructive force and shear flow the standard Marshall press, generating a static load, was used. The shear was made by a special shearing mould (Fig. 2) which was fixed in the Marshall press. During the test the lower layer was fixed

Table 2. Sampling locations in the Vilnius City

Sampling location		Number of asphalt samples (cores), units	Type of geosynthetic material or special asphalt mix in the interlayer
The Vilnius City Western By-pass, Oslo g.	STA 28+15 left side	2	*VIASAF 0/5* (under the lower layer)
	STA 37+12 right side	2	
Savanorių pr.	7.0 m from the road sign (Kaunas 92, Klaipėda 303) in Kaunas direction, right side	3	*VIASAF 0/5* (under the upper layer)
Plytinės street, behind the turn to the Plytinės cartodrome, in Dvarčionys direction	Numbered in schemes included into the testing protocols No. 1-2322 and 1-2323	3	*Pavegrid G100/100* (under the lower layer)
		3	–
Kalvarijų g., from Žvalgų g. in Ozo g. direction	21.0 m from the 1st entrance to the petrol station Alauša, left side	2	–
	3.0 m in front of the entrance to the petrol station Alauša, right side	2	*Pavegrid G100/100* (between the upper and lower layers)
Eišiškių road	Numbered in schemes included into the testing protocols No. 1-2324, 1-2325, 1-2326, 1-2327	3	*HATelit C 40/17* (under the lower layer)
		3	
		3	*Armatex RSM 50/50* (under the lower layer)
		3	–

by mechanical clamping and the upper layer was provided with the static load at a constant 50 mm/min speed. Before the test, asphalt cores were stored at a 20 °C temperature for 24 hours, then the diameter of samples and the thicknesses of the sheared layers were measured and the joining boundary of asphalt layers was marked with a special marker to ensure a more precise fixing of the sample. Totally, 2 or 3 asphalt cores were tested (depending on the sampling location). After the test the remains of adjoining layers were recorded.

The second stage of experimental research on the bonding of asphalt layers was carried out at the Road Scientific Laboratory of the Vilnius Gediminas Technical University Road Research Institute from October 2010 to January 2011. The bonding tests were performed using methodology identical to the first research stage. First of all, on different roads of Lithuania the asphalt samples (cores) were taken, then the shear test of the upper asphalt layer was performed (Table 3). The asphalt cores were taken at the first track and also in-between the tracks to compare the bonding strength between the layers. Two asphalt cores were taken from each location.

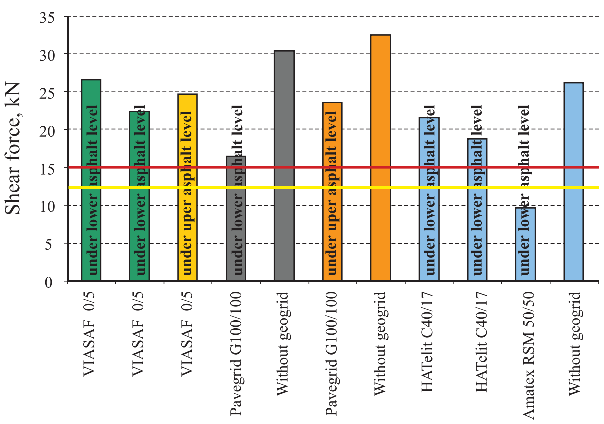

Fig. 3. Distribution of the bonding strength of asphalt layers depending on geosynthetic material or special asphalt mix in the interlayer: —— – the lowest permissible bonding strength between the upper and lower asphalt layers —— – the lowest permissible bonding strength between all the other layers according to *ĮT ASFALTAS 08*

5. Analysis and assessment of research results

The first stage of laboratory tests of the bonding between asphalt layers in the samples found that the max shear force in asphalt layers varies depending on the geosynthetic material used (Fig. 3).

In all cases, for the samples without geogrid at the interlayer a larger max shear force was determined compared to the samples the interlayer of which was equipped with geosynthetic material. It was found that the max shear force in the samples without geogrid (between the lower and the old asphalt pavement layers), taken from the Plytinės g., was 85% higher than in the samples taken from the same street but having the geogrid *Pavegrid G100/100* (between the lower and the old asphalt pavement layers). The similar results were also obtained in Kalvarijų g. where the bonding strength of the samples without geogrid (between the lower and the old asphalt pavement layers) was 38% higher compared to the samples with the geogrid *Pavegrid G100/100* (between the upper and lower asphalt pavement layers). The histogram of Fig. 3 shows that the max shear force in the samples without geogrid (between the lower and the old asphalt pavement layers), taken from the Eišiškių road, is about 30% higher than in the samples with the geogrid *HaTelit C 40/17* (between the lower and the old asphalt pavement layers) and even 2.7 times higher than in the samples with the geogrid *Armatex RSM 50/70*. It should be mentioned that the bonding strength in the samples with the geogrid *Armatex RSM 50/70* between the lower and the old asphalt pavement layers is 20% lower than it is required by the article 86 of *ĮT ASFALTAS 08* (9.6 kN < 12.0 kN). The bonding strength in all other samples (with and without the geogrid between the upper and lower layers and between the lower and the old asphalt pavement layers) is higher than the required. The testing showed that the bonding between a pavement layer from the special asphalt mixture VIASAF 0/5 and the lower or upper asphalt layers is relatively large and in all tested cases reached more than 22.0 kN.

The shear flow (deformation) of asphalt layers varies subject to the geosynthetic material used (Fig. 4). It could be noticed that the shear flow in the samples with the geogrid *Pavegrid G100/100* is lower than that in the samples without geogrid, and in the samples with the geogrid *HaTelit C 40/17* and *Armatex RSM 50/70* to the contrary – higher.

It was found that the shear flow in the samples with the geogrid *Pavegrid G100/100* (between the lower and the old asphalt pavement layers), taken from the Plytinės g., was 35% lower than in the samples without geogrid, and the shear flow in the samples taken from the Kalvarijų g. with the identical geogrid between the upper and lower layers was 20% lower than in the samples without geogrid.

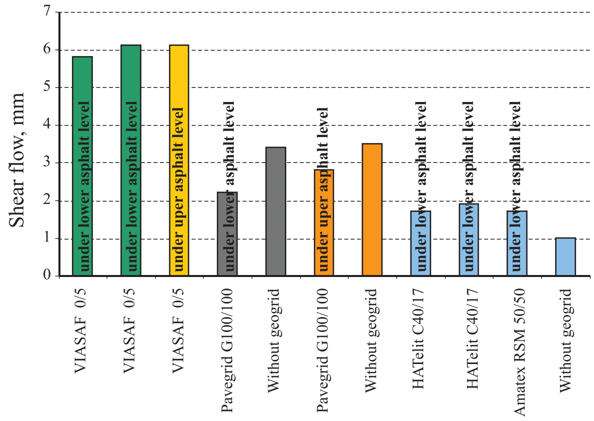

Fig. 4. Distribution of the shear flow of asphalt layers depending on geosynthetic material or special asphalt mixture at the interlayer

Table 3. Sampling locations

Sampling location			The mix of asphalt upper layer
Road No. 153 Joniškis–Žagarė	1.6 km, left side, 2.2 m from the road axis	in the track	AC 11 VS
	1.4 km, right side, 2.2 m from the road axis	in the track	
	1.1 km, right side, 1.6 m from the road axis	in-between the tracks	
Road No. 143 Jonava–Žasliai–Kalniniai–Mijaugonys	17.0 km, left side, 2.4 m from the road axis	in the track	AC 11 VN
	16.0 km, left side, 1.4 m from the road axis	in-between the tracks	
	15.7 km, right side, 2,2 m from the road axis	in the track	
	15.7 km, right side, 2,2 m from the road axis	in the track	AC 11 VS
	15.7 km, right side, 2.2 m from the road axis	in-between the tracks	
Road No. 130 Kaunas–Prienai–Alytus	34.0 km, left side, 2.6 m from the road axis	in the track	AC 11 VS
	33.9 km, left side, 1.7 m from the road axis	in-between the tracks	
	22.95 km, left side, 2.7 m from the road axis	in the track	
	22.85 km, left side, 1.7 m from the road axis	in-between the tracks	
Road No. 128 Valkininkai railway station–Daugai–Alytus	26.0 km, in the track, 2,6 m from the road axis	in the track	AC 11 VS
	26.05 km, left side, 2,7 m from the road axis	in the track	
	25.95 km, left side, 1.9 m from the road axis	in-between the tracks	
Road No. 102 Vilnius–Švenčionys–Zarasai	48.06 km, left side, 2.4 m from the road axis	in the track	SMA 11 S
	48.11 km, left side, 1.5 m from the road axis	in-between the tracks	
	48.16 km, left side, 2.3 m from the road axis	in the track	
Road No. 2828 Alanta–Naujasodis–Svobiškelis	1.0 km, left side, 1.8 m from the road axis	in the track	AC 11 VN
	1.05 km, left side, 1.2 m from the road axis	in-between the tracks	
	1.1 km, left side, 1.8 m from the road axis	in the track	
Road No. A4 Vilnius–Varėna–Gardinas	48.0 km, right side, 2.3 m from the road axis	in the track	AC 11 VS
	48.1 km, right side, 1.7 m from the road axis	in-between the tracks	
	48.25 km, right side, 2.3 m from the road axis	in the track	
Road No. A14 Vilnius–Utena	12.0 km, right side, 7.1 m from the road axis	in the track	SMA 11 S
	12.3 km, right side, 6.3 m from the road axis	in-between the tracks	
	13.0 km, right side, 7.1 m from the road axis	in the track	
	14.4 km, left side, 2.1 m from the road axis	in the track	
	14.2 km, left side, 2.9 m from the road axis	in-between the tracks	
	14.17 km, left side, 2.1 m from the road axis	in the track	

Meanwhile, the shear flow in the samples with the geogrid *HaTelit C 40/17* and *Armatex RSM 50/70* (between the lower and the old asphalt pavement layers) was about 40% higher compared to the samples without geogrid. The relatively high shear flow (> 5 mm) was determined between a layer from the special asphalt mixture *VIASAF 0/5* and the lower or upper asphalt layers compared to the other tested samples.

The analysis of results of the 1st research stage enables to assume that the use of geosynthetic materials at the interlayer reduces the bonding strength between asphalt layers. Also, the bonding strength between asphalt layers depends on the type of geosynthetic material. The use of geosynthetic material, and especially of the special stress-absorbing asphalt layer, increases the shear flow at the asphalt pavement interlayers.

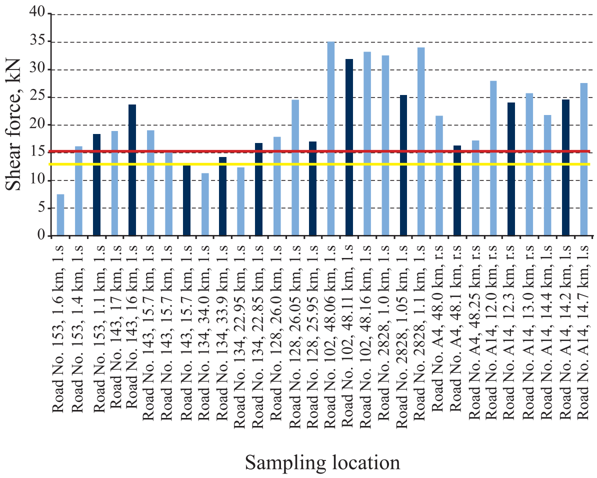

Fig. 5. Distribution of the bonding force between the upper and lower asphalt layers depending on the sampling location: – the samples taken in the first track, – in-between the tracks, – the lowest permissible bonding strength between the upper and lower asphalt layers, – the lowest permissible bonding strength between all other layers according to *ĮT ASFALTAS 08*

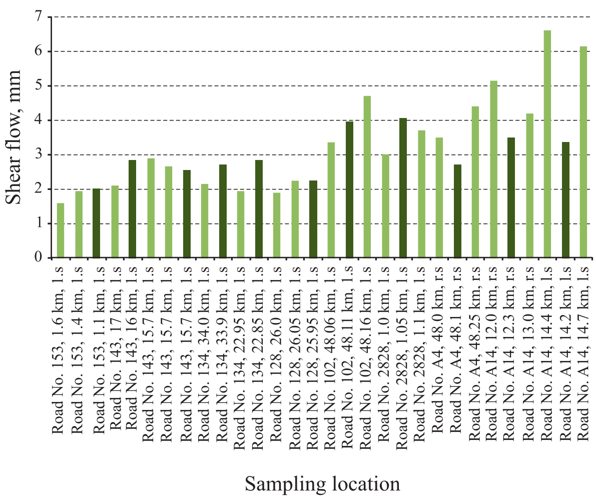

Fig. 6. Distribution of the shear flow between the upper and lower asphalt layers depending on the sampling location: – the samples taken in the first track, – in-between the tracks

The analysis of results of the second research stage showed that the samples from 83% of the sampling locations (25 from 30) had the max shear force higher than 15 kN (Fig. 5). The max shear force in the samples of the remaining 4 locations was < 25% lower than the required (15 kN), and the shear force the samples of 1 location was 2 times lower than the required. The highest shear force was determined in the samples taken from the road No. 102. The samples were taken in the track, the upper asphalt layer was laid from the mixture SMA 11 S. Meanwhile, the lowest shear force was determined in the samples taken from the road No. 153. The samples were taken at the track, the upper asphalt layer was laid from the mixture AC 11 VS. It could be noticed that the samples from 50% of the sampling locations had the max shear force higher than 20 kN.

Fig. 5 shows that the bonding strength in the samples, taken from the road No. 102, is higher than 30 kN. The upper asphalt layer of this road was laid from the mixture SMA 11 S. The relatively high shear force was also determined in the samples taken from the road No. A14 (in all cases > 22 kN), here the upper asphalt layer was also laid from the mixture SMA 11 S. When analysing the bonding strength between the upper and the lower layers of the pavement of road No. 130, it should be mentioned that in 4 from 5 sampling locations the samples had no required 15 kN shear force. It was determined that the bonding strength was on average 16% lower than the required. The insufficient bonding between asphalt layers was also determined in the samples taken in 1.6 km of the road No. 153, and in the samples taken in 15.7 km of the road No. 143. The results of the bonding strength in the samples, taken in the 1st track and in-between the tracks, suggest no concrete assumptions. During the testing no significant difference was detected between the shear force in the samples, taken in the track, and in those taken in-between the tracks of the same road.

The analysis of results of the shear flow of the upper and lower asphalt layers showed that the shear flow varies irrespective of the sampling location. The histogram of Fig. 6 shows that in the samples taken from 63% of locations (19 from 30) the shear flow varied from 2.0 mm to 4.0 mm. The results of the remaining 11 sampling locations were as follows: the shear flow in the samples taken from 4 locations was slightly lower than 2 mm, in the other 7 – higher than 4 mm. It could be noticed that the shear flow in the samples taken from the roads the upper layer of which was laid from the mixture SMA 11 S (the roads No. 102 and No. A14) was slightly higher compared to the shear flow in the samples taken from other roads. The research showed that the shear flow varies irrespective of the fact if the samples were taken in the track or in-between the tracks.

The analysis of results of the bonding strength between asphalt layers in the samples, taken from different roads of Lithuania, showed that the samples from 83% of the sampling locations (25 from 30) had the max shear force higher than 15 kN, and in the samples taken from 63% of locations (19 from 30) the shear flow varied from 2.0 mm to 4.0 mm. In most cases, the bonding between the lower and upper asphalt layers on different roads of Lithuania corresponds to the current requirements, thus, it could be assumed that the asphalt underlayer has been prepared properly. It should be also mentioned that the highest bonding values between the upper and lower asphalt layers were recorded in those cases where the upper layer was laid from the asphalt mixture SMA 11 S. In those cases, the bonding strength value, required by the *ĮT ASFALTAS 08,* is exceeded even up to two times. The higher shear flow was observed where the upper asphalt layer was laid from the asphalt mixture SMA 11 S.

6. Conclusions and recommendations

In the result of analysis and assessment of theoretical principles of the bonding between asphalt layers, research methods, worldwide experience and of the results of experimental research, carried out in Lithuania, the following conclusions and recommendations are given.

1. Sufficient bonding between asphalt layers ensures the functioning of asphalt pavement as of the monolithic structure, and the largest stresses from vertical loads are concentrated at the bottom of the monolithic structure. In case of insufficient bonding between asphalt layers the largest stresses occur at the bottom of each layer. Such pavement structure can carry lower loads compared to that having sufficient bonding between asphalt layers.

2. Due to insufficient bonding of asphalt layers, deformations developed within asphalt pavement (tearing, corrugations, slippage of layers, longitudinal cracks) worsen the driving conditions, reduce pavement life cycle between repairs, increases pavement maintenance costs. Due to insufficient bonding of asphalt layers the plastic pavement deformations occur – ruts, and pavement durability can decrease to 7 or 8 years.

3. Experimental research has indicated that the bonding strength between asphalt layers decreases from 20% to 50% when the geogrid is laid between asphalt layers.

4. The use of stress-absorbing asphalt layer between asphalt pavement layers allows achieving the relatively high bonding between asphalt layers. Experimental research showed that the bonding of asphalt layer, constructed from this mixture, and the lower or upper asphalt layers in all tested cases is higher than 22.0 kN under the relatively high shear flow ≥ 5 mm.

5. It was determined by the testing of asphalt pavement samples, taken from different roads of Lithuania, that the bonding between the upper and lower asphalt layers in most cases (83%) corresponds to the requirements of *ĮT ASFALTAS 08* and is higher than 15 kN. The bonding values higher than 20 kN were detected at 50% of all studied locations. The assumption could be made that the attainment of the required bonding values between asphalt layers of the studied roads depend on a proper preparation of underlayer, protection against pollution and the use of optimum amount of bitumen emulsion.

6. During experimental research no difference was detected in the bonding strength of asphalt layers depending on the sampling location – in the track or in-between the tracks of the same road.

7. The bonding values for asphalt pavement layers, regulated by the normative documents of Lithuania *ĮT ASFALTAS 08* and *ĮT APM 10*, ensure sufficient bonding of layers in respect of road pavement strength and durability. However, it is recommended to supplement those normative documents with the requirement when accepting works to control the bonding strength of asphalt layers and the volume of control tests, also to supplement the *ĮT ASFALTAS 08* with the requirements for the control of the bonding of asphalt layers when for the interlayers of asphalt pavement the geosynthetic materials are used. In that case, the control tests on the bonding between asphalt layers shall be obligatory for each object.

8. For the determination of the bonding between asphalt layers the shear test is recommended (without applying normal stresses). For the determination of bonding between thin layers and the underlayer it is recommended to use the peel test (direct tension). The German testing methodologies are recommended to be used.

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