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Effect of interlayer bonding quality of asphalt layers on pavement performance

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Effect of interlayer bonding quality of asphalt layers on pavement performance

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Abstract. The quality of interlayer bonding at the interfaces between the asphalt layers in flexible pavements affects the overall pavement performance. Lack or partial lack of interlayer bonding between asphalt layers can cause pavement's premature failures such as rutting, slippage of the wearing course, cracking or simply a reduction in the calculated fatigue life of the pavement structure. This paper shows the case studies of investigation of actual or potential premature failure of newly reconstructed and constructed pavements where low quality of interlayer bonding has a dominant meaning. In situ and laboratory tests were performed and followed by analytical calculation of pavement structure where thicknesses of layers and maximum shear strengths obtained from the tests were used. During the investigation it was found out that a low quality of tack coat as well as the same aggregate gradation in the bonded asphalt mixtures were the main reasons behind the weak quality of interlayer bonding. Partial interlayer bonding has a strong influence on reduction of calculated fatigue life of pavement. The summary of the paper includes recommendations on how to avoid the low quality of interlayer bonding of asphalt layers.

1. Introduction

1.1. Background

The problem of lack or partial lack of interlayer bonding quality between asphalt layers is a common reason of dispute between contractor and investor. Poor quality of interlayer bonding causes pavement's premature failures such as rutting, slippage of the wearing course, cracking or simply a reduction in the calculated fatigue life of the pavement structure[1]–[12]. The laboratory test of interlayer shear strength performed in a Leutner device [13] is the standard procedure in Poland for controlling the quality of interlayer bonding. Polish requirements [14] state minimum levels of shear strength for specimens drilled out from pavement. The problem described in this paper concerns three cases of pavements where shear strength obtained for specimens did not fulfill the Polish requirements. The article is focused on the problem of weak interlayer bonding between the asphalt base and the binder course or between two lifts of the asphalt base course. A detailed analysis of fatigue life is presented for one selected case.

The interlayer bonding strength depends on several factors including quantity of tack coat, type of bitumen emulsion used for the tack coat, difference between asphalt mix grading in respective layers, poor compaction of the upper layer etc. [7], [15]–[20]. In some cases when interlayer bonding is

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limited or does not pass the requirements but there is some degree of bonding still, the interlayer bonding can be expected to increase due to aging, traffic load and simply time [21]–[23].

1.2. Objectives
The primary objectives of this study were as follows:

- to reveal how limited interlayer bonding can impact the decreases in calculated fatigue life of pavement structure,
- to show the investigation of three cases of newly constructed pavements where the quality of interlayer bonding did not fulfill Polish requirements,
- to present some recommendation on how to avoid low quality of interlayer bonding of asphalt layers.

2. Case studies
Three cases of different road sections were used in the analysis:

- Road 1 is a newly constructed expressway, the highest (express) technical standard (R1S), for heavy traffic and represents the highest construction standard and investor control.
- Road 2 is a newly constructed national road, the high (highway) technical standard (R2H), for heavy traffic and represents the highest construction standard and investor control.
- Road 3 is a reconstructed city street, the medium (local) technical standard (R3L), for low medium traffic and represents the medium construction standard and investor control.

In roads R1S and R2H the problem of interlayer bonding occurred between two lifts of asphalt base course made from asphalt concrete AC22P with neat bitumen 35/50. The tack coat was applied properly with the usage of bitumen emulsion C60B3ZM (bitumen emulsion dedicated for tack coat of asphalt layers acc. to PN-EN13808) in an amount of bitumen within the range of 0.3–0.5 kg/m^2. In terms of interlayer bonding, the construction process followed good practices. Nevertheless, bonding strength measured in the Leutner test was under the required value of 0.6 MPa at the temperature of +20°C but higher than 0 MPa (see Figure 1). The reason of low interlayer bonding strength was the non-homogenous surface of the bottom base course due to segregation of mixture (see Figure 3) and the same gradation of aggregate used for two lifts of the base course. In consequence the interlocking between two lifts of the asphalt base course was relatively weak.

In the case of road R3L the problem of interlayer bonding occurred between an asphalt base course made from AC22P and a binder course made from AC16W, both with neat bitumen 35/50. In this case shear strengths between two layers were much lower than the required 0.7 MPa at the temperature of +20°C. Additionally, 30% of cored specimens disintegrated during coring, that is the core of the binder course and the base course separated spontaneously, therefore those specimens were marked with 0 MPa of interlayer shear strength (see Figure 2). Unlike in the case of roads R1S and R2H, the reason of weak bonding quality in road R3L was not gradation of aggregate in the asphalt mix, but rather poor quality of the tack coat sprayed in combination with improper compaction of the upper layer – the binder course. Despite the usage of the proper bitumen emulsion C60B3ZM in amount of 0.3–0.5 kg/m^2, the sprayed surface was not homogenous, which is visible in the Figure 4. Another problem identified in road R3L was the insufficient thickness of the asphalt base course, which additionally and ultimately contributed to the decrease in fatigue life of the pavement structure.

In all the aforementioned cases, the unsatisfactory bonding strength was the reason of dispute between the contractor and the investor. On the one hand, lower quality of interlayer bonding contributes to a decrease in fatigue life but, on the other, milling of layers and their subsequent reconstruction causes considerable losses for the contractor. The presented analyses were performed in order to assess whether the existing pavement structure can bear the designed traffic or whether its layers need to be re-built.

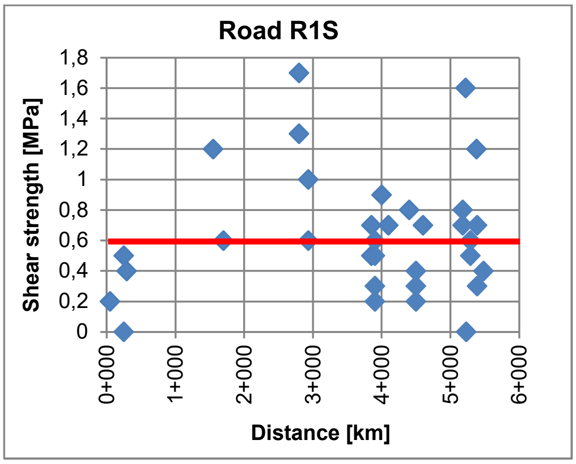

Figure 1. Results of shear strength obtained from the Leutner test between two lifts of the asphalt base course AC22P. Road R1S.

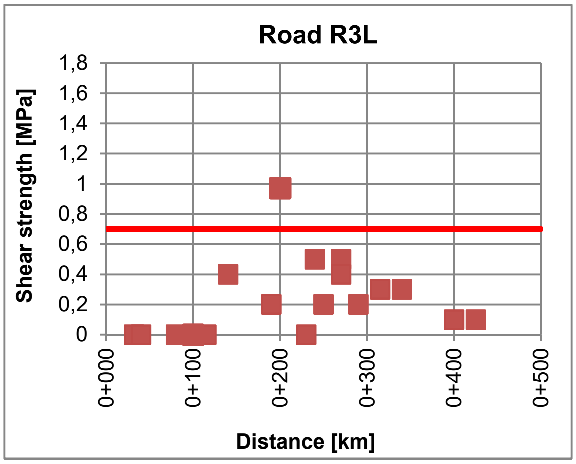

Figure 2. Results of shear strength obtained from the Leutner test between the asphalt base course AC22P and the binder course AC16W. Road R3L.

Figure 3. Surface of the lower asphalt base course AC22P. Non-homogenous surface. Road R1S.

Figure 4. Poor quality and lack of tack coat on the asphalt base course. Road R3L.

3. Mechanistic-empirical analysis of pavement performance

3.1. Pavement structure model

For the sake of analysis the pavement structure is modeled as a multilayer elastic half-space. The scheme of the model is presented in Figure 5. It is assumed that each layer is homogenous, isotropic and elastic. The calculations of stresses, strains and deflections inducted in pavement by a single wheel load were performed in BISAR® software [24].

The load is a vertical force $Q_V = 50$ kN, applied at a circular contact area and uniform contact pressure q=850 kPa. Two cases of load were considered: a load moving with constant speed and with horizontal force $Q_H = 0$ kN; and a load moving with deceleration and horizontal force $Q_H = 0.6$ kN $Q_V = 30$ kN. The additional horizontal force was considered in the analysis of shear stresses at the interlayer surface.

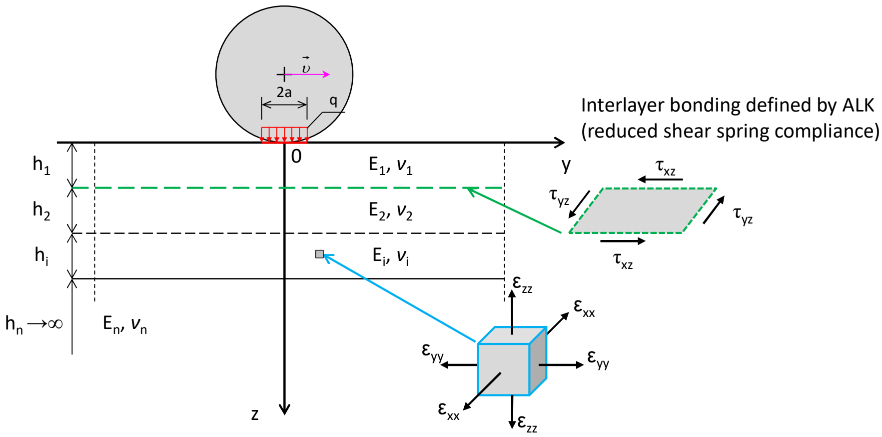

Figure 5. Model of pavement structure assumed for analysis.

Material properties of respective asphalt layers were assumed for two temperatures:

- +20°C for analysis of shear stress (similar to results obtained from the Leutner test),
- +13°C for analysis of fatigue life (the equivalent temperature for Poland [25]).

The detailed mechanical properties of each layer of pavement structure are given in Table 1.

Table 1. Properties of pavement layers.

Layer and material	Thick-ness (cm)	Binder content (%)		Air voids (%)	Stiffness/Elastic modulus E in temperature		Poisson ratio ν in temperature	
		m-m	v-v		+13°C (MPa)	+20°C (MPa)	+13°C (-)	+20°C (-)
1. Wearing course (SMA11 PMB 45/80-55)	4	6.4	16	3.0	7330	3630	0.3	0.38
2. Binder course (AC16W 35/50)	8	4.2	10.5	6.0	10300	6450	0.3	0.38
3. Asphalt base (AC22P 35/50)	Varies from 6 to 12	4.0	10.0	7.0	9820	6190	0.3	0.38
4. Subbase (Crushed stone)	20	-	-	-	400	400	0.3	0.3
5. Subgrade (Improved subgrade)	-	-	-	-	120	120	0.35	0.35

BISAR® software enables modeling of interlayer friction by reduced shear spring compliance ALK [24]. Full bonding between layers occurs when the shear strength of interlayer bonding is close to or a little lower than the shear strength of the used asphalt mixtures, that is when the results of the Leutner test meet the requirements. Full slip between two asphalt layers practically does not occur because of roughness of their surfaces. The modeling of interface parameter for limited bonding requires the performance of a series of calculations with different values of parameters ALK in the range from 0 to 200 m [26], [27], that is, respectively, full bond and full slip (non-bound).

3.2. Effect of reduced interlayer bonding on shear stresses

First stage of mechanistic analysis considered shear stresses on the interface between the asphalt base and the binder course. Calculations were performed for temperature of +20°C, same as in the Leutner test. The results of calculations are given in Figure 6. It can be concluded that for full (100%) bonding (parameter ALK = 0 m) shear stresses obtained from calculations are two times lower than the required 0.7 MPa from the Leutner test. It is also visible in Figure 6, that at low values of bonding, below 30%, the shear stresses are close to 0 MPa. Thus it was assumed that for places where specimens cored out from pavement had disintegrated, the bonding can be assumed as 30% due exclusively to friction at the layer interface. It is visible from comparison of Figures 2 and 6 that shear strength for the majority of specimens is lower than stresses obtained from mechanistic calculations. It means that two layers in pavement will displace horizontally in relation to each other, but interlayer bonding will bear some part of the shear stress, lower than its strength. It is also possible that when the maximum shear stresses caused by the traffic exceed its strength, the two layers will slip. Slip of layers – especially in the case of the wearing course – results in high displacement between them and causes characteristic semi-circular cracks, leading to loss of pavement roughness [4]. The risk of slip is especially high for sections with frequent acceleration and deceleration of vehicles, e.g. within the zones of crossroads. However, layer slipping is more often observed for cases of poor bonding quality between the wearing course and the binder course and it is rather not expected to occur between the binder course and the base or between two lifts of the asphalt base course.

It should be noted that the direct comparison of shear strength derived from the Leutner test with the stresses from mechanistic calculations is a considerable simplification due to different shape of the load. There is still a gap of knowledge pertaining to relation between the results of laboratory tests and the mechanistic calculations. Nevertheless, it is certain that at the level of stress between 0 and 0.3 MPa the interlayer bonding takes on values lower than 100% but the full slip between layers does not occur, and it is expected that interlayer bonding is greater than 30%.

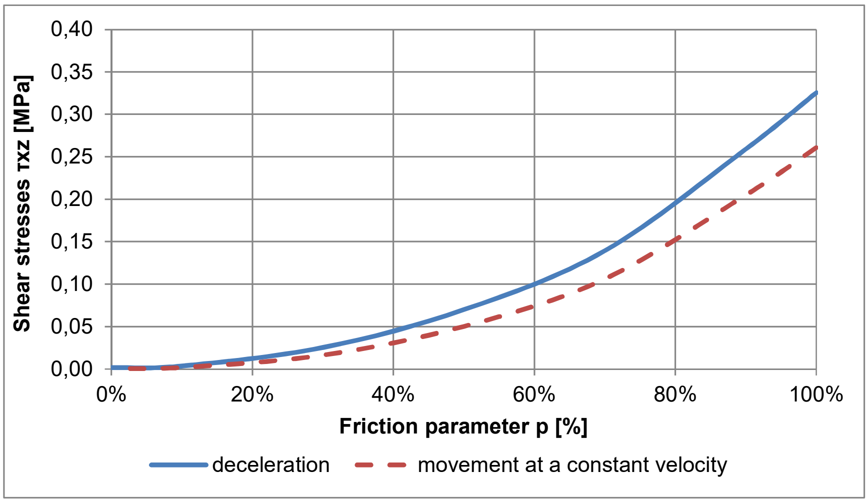

Figure 6. Effect of reduced bonding on shear stresses at the layer interface level.

3.3. Effect of reduced interlayer bonding on fatigue life of pavement structure

The analyses of fatigue life were performed for properties of asphalt mixtures obtained for equivalent temperature of +13°C, used for design of flexible pavements in Poland [25]. Calculations were performed for different levels of interlayer bonding from 0% (full slip) to 100% (full bonding) and for 4 thicknesses of asphalt layers from 18 cm to 24 cm. Two criteria were considered: bottom-up fatigue cracking of asphalt mixtures acc. to AASHTO 2004 [28] and the Asphalt Institute criterion of subgrade permanent deformation [29]. The fatigue life of pavement structure is represented by the minimum value obtained from the criteria of fatigue asphalt cracking and subgrade permanent deformation. The results of calculations are given in Table 2 for thickness of asphalt layers equal to 24 cm, and in Figure 7 for 4 thicknesses from 18 to 24 cm.

Reduced bonding (<100%) between asphalt base and binder course causes the increase in strains at critical points in pavement structure. For the AASHTO 2004 bottom-up fatigue cracking criterion the

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critical point is determined directly under wheel load at the level where the horizontal strains ε_{xx} in asphalt layers reach their maximum. For full bonding of asphalt layers the critical point (maximum ε_{xx}) occurs at the bottom of all asphalt layers in the asphalt base course. With the deterioration of quality of interlayer bonding between the base and the binder course, strains at the bottom of the asphalt base and strains at the bottom of the binder course increase simultaneously. For a limited level of bonding (parameter 0<ALK<200 m) strains at the bottom of the binder course are higher than at the bottom of the asphalt base and, therefore, fatigue cracks will be initiated in the binder course (see Table 2). However, for the considered case of pavement structure in R3L the fatigue life obtained from permanent deformation criterion is lower than fatigue life obtained for bottom-up cracking initiated in the binder course.

The reduction of interlayer bonding also results in the increase in vertical strains ε_{zz} at the top of subgrade. For full interlayer bonding and relatively thick pavements the criterion of permanent deformation provides higher fatigue life than the criteria of fatigue cracking and the pavement reaches the critical level of fatigue cracks first. It was revealed in the analysis that for low values of bonding the criterion of permanent deformation provides lower fatigue life. Finally, the minimum values of fatigue life were obtained for the criterion of fatigue cracking of the asphalt base and the binder course, as well as for the criterion of permanent deformation of subgrade. The minimum fatigue life values are highlighted in Table 2 and the critical criteria are marked in graphs in Figure 7. Figure 7 also shows the trend of impact of bonding level and asphalt layers thickness on the type of critical fatigue criteria.

Table 2. Fatigue life in millions of 100 kN ESAL's calculated for respective fatigue criteria. Road R3L with total asphalt layers thickness 24 cm.

Interlayer bonding (%)	Fatigue life (millions of 100 kN ESAL's)		
	Bottom-up cracking initiated in		Permanent deformation of subgrade
	asphalt base	binder course	
0%	8.00	5.91	**4.13**
10%	7.96	6.21	**4.28**
30%	8.17	10.41	**6.46**
50%	**9.77**	27.93	12.71
70%	**13.48**	130.89	26.03
100%	**28.72**	>>200	66.82

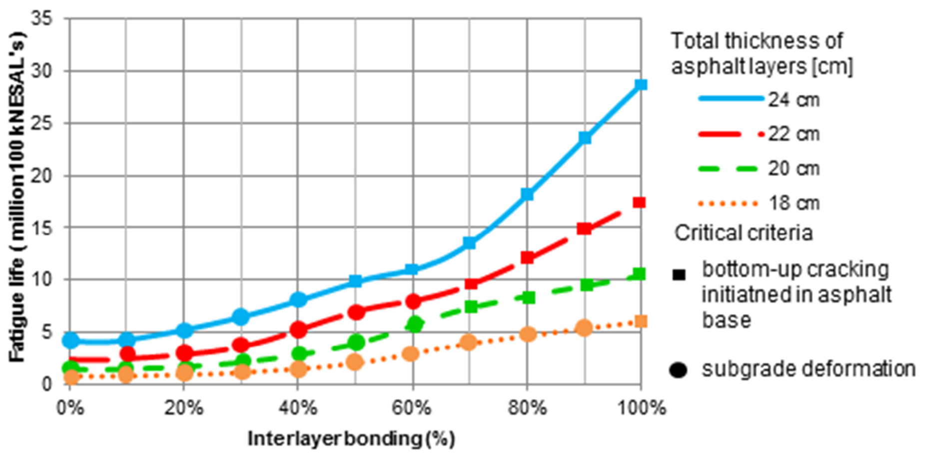

Figure 7. Effect of reduced interlayer bonding and total thickness of asphalt layers on fatigue life of pavement structure.

It is visible in the Figure 7 that a slight decrease in interlayer bonding causes a significant decrease in fatigue life, and this decrease is higher for thicker pavements. For example, with total asphalt layers thickness of 24 cm, slight decrease in interlayer bonding from 100% to 70% causes significant decrease in fatigue life by 50%. Further decrease to 30%, which represents zero shear strength, causes decrease in fatigue life by almost 85%. It can be concluded from Table 2 and Figure 7 that lack of interlayer bonding cannot be accepted by the investor and rebuilding of pavement layers is necessary. Partial lack of interlayer bonding, shown by shear strength in the Leutner test below required values, but above the maximum shear stress actually present in the pavement, can be accepted, provided that the quality of the asphalt mix and layer thicknesses fulfill all the other requirements.

4. Summary and recommendations

As shown by means of mechanistic-empirical analysis, lack or partial lack of interlayer bonding between asphalt layers can cause reduction in fatigue life of pavement structure.

Case studies included analyses of three road sections. Despite proper technical specification and technology of construction the shear strength of interlayer bonding did not fulfill the requirements. Potential reasons of unsatisfactory interlayer shear strength obtained in the Leutner test are as follows:

- Lack or low quality of an interlayer tack coat.
- Too low or too high quantity of bitumen emulsion for spraying a tack coat.
- Non-homogenous surface of the lower layer and weak interlocking due to insufficient compaction of the upper layer or the same gradation of bonded layers.

These reasons – in case of an otherwise good practice – would imply the main recommendations for contractors willing to reduce the risk of limited or zero interlayer bonding between asphalt layers.

Reduction of interlayer bonding between the asphalt base and the binder course or two lifts of the asphalt base course will result in:

- Premature initiation of fatigue cracks both on the bottom of asphalt layers in the base course and in the binder course, which accelerates the distress of pavement.
- Much faster occurrence of critical level of asphalt fatigue cracks for thicker pavements.
- Faster occurrence of permanent deformation rather than fatigue cracks for thinner pavements.
- For very low quality of interlayer bonding critical level of permanent deformation of thick asphalt pavement can occur before fatigue cracks.

References

[1] Uzan J, Livneh M, and Eshed Y 1978 Investigation of adhesion properties between asphaltic-concrete layers *Journal of AAPT* **47** pp 495–521

[2] Judycki J 2003 Sczepność między warstwami asfaltowymi nawierzchni *Drogownictwo* **9** pp 275–279

[3] Jaskula P 2006 Ocena sczepności między warstwami asfaltowymi nawierzchni *Drogownictwo* **12** pp. 412–414

[4] Romanoschi S A and Metcalf J B 2001 Effects of Interface Condition and Horizontal Wheel Loads on the Life of Flexible Pavement Structures *Transp. Res. Rec. J.* **1** pp 123–131

[5] Romanoschi S A and Metcalf J B 2002 The characterization of pavement layer interfaces *Ninth International Conference on Asphalt Pavements* pp 1–18

[6] Zofka A, Maliszewski M, Bernier A, Josen R, Vaitkus A and Kleiziene R 2015 Advanced shear tester for evaluation of asphalt concrete under constant normal stiffness conditions *Road Materials and Pavement Design* **16** (sup1) pp 187-210

[7] Al-Qadi I L, Hasiba K I, Cortina A S, Ozer H, Leng Z, Parish D C and Worsfold S J 2012 *Best practices for implementation of tack coat: Part 1 Laboratory study* (Springfield)

[8] Ozer H, Al-Qadi I L, Wang H and Leng Z 2012 Characterisation of interface bonding between

hot-mix asphalt overlay and concrete pavements: modelling and in-situ response to accelerated loading *Int. J. Pavement Eng.* **13**(2) pp 181–196

[9] Raab C and Partl M N 1998 Shear strength properties between asphalt pavement layers *Arch. Civ. Eng.* **3** pp 353–365

[10] Raab C and Partl M N 2004 Effect of tack coats on interlayer shear bond of pavements *8th Conference On Asphalt Pavements For Southern Africa* p 9

[11] Górszczyk J and Malicki K 2012 Influence of the tack coat material on interlayer bonding properties in asphalt layers system *Proceedings of the 4th European Pavement and Asset Management Conference EPAM*

[12] Judycki J, Jaskula P, Dolzycki B, Pszczola M, Jaczewski M, Rys D and Stienss M 2015 Investigation of low-temperature cracking in newly constructed high-modulus asphalt concrete base course of a motorway pavement *Road Mater. Pavement Des.* **16**(1) pp 362–88

[13] Leutner R 1979 Untersuchung des Schichtenverbundes Oberbau *Bitumen* **3** pp 84–91

[14] Jaskula P 2014 *Instrukcja laboratoryjnego badania sczepności międzywarstwowej warstw asfaltowych wg metody Leutnera i wymagania techniczne sczepności* (Politechnika Gdańska Poland) p 12

[15] West R C, Zhang J and Moore J 2005 *Evaluation of bond strength between pavement layers* (Auburn, Alabama)

[16] Jaskula P 2014 Badania i analizy sczepności międzywarstwowej w nawierzchniach asfaltowych *Bud. i Archit.* **13**(4) pp 117–125

[17] Jaskula P 2014 Influence of compaction effectiveness on interlayer bonding of asphalt layers *The 9th International Conference Environmental Engineering* p 7

[18] Vaitkus A, Čygas D, Laurinavičius A, Vorobjovas V and Kleizienė R 2012 Research of asphalt layer bonding in Lithuanian pavement structures *Građevinar* **64**(11) pp 915–20

[19] White G 2016 State of the art: interface shear resistance of asphalt surface layers *Int. J. Pavement Eng.* **8436** pp 1–15

[20] Szydło A and Malicki K 2016 Analysis of the Correlation between the Static and Fatigue Test Results of the Interlayer Bondings of Asphalt Layers *Achives Civ. Eng.* **62**(1) pp 83–98

[21] Raab C and Partl M N 2009 Long term performance of asphalt pavement interlayer bonding *EMPA Act.* **08/09**(3) p 1

[22] Raab C, Grenfell J, Abd El Halim A O and Partl M N 2015 The influence of age on interlayer shear properties *Int. J. Pavement Eng.* **16**(6) pp 559–69

[23] Partl M N, Bahia H U, Canestrari F, de la Roche C, Di Benedetto H, Piber H and Sybilski D 2013 Advances in Interlaboratory Testing and Evaluation of Bituminous Materials, State-of-the-Art *Report of the RILEM Technical Committetee 206-ATB* (Springer)

[24] Shell Bitumen Business Group 1998 *BISAR 3.0 User Manual*

[25] Judycki J, Jaskuła P, Pszczoła M, Ryś D, Jaczewski M, Alenowicz J, Dołżycki B and Stienss M 2014 *Analizy i projektowanie konstrukcji nawierzchni podatnych i półsztywnych* (Wydawnictwa Komunikacji i Łączności: Warsaw, Poland)

[26] Judycki J, Jaskula P, Fronc T and Sierosławski T 2006 *Badania i ocena wpływu sczepności międzywarstwowej na trwałość konstrukcji nawierzchni asfaltowej, etap II* (Politechnika Gdańska, Poland)

[27] Stöckert U 2002 *Ein Beitrag zur Festlegung von Grenzwerten für den Schichtenverbund im Asphaltstraßenbau* (Technische Universitat Darmstadt)

[28] NCHRP Project 1-37A 2004 *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, Final Report, Part 3 – Design and Analysis* Champaign

[29] Research and Development of the Asphalt Institute's 1982 *Thickness Design Manual (MS -1): Ninth edition* RR-82-2

[30] Iwanski M, Buczynski P, Mazurek G 2016 Optimization of the road binder used in the base layer in the road construction *Construction and Building Materials* **125** pp 1044–54