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INVESTIGATIONS OF FATIGUE OF ASPHALT LAYERS WITH GEOSYNTHETICS

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This paper presents the results of an extensive investigation of asphalt concrete beams with geosynthetics interlayer. The subject of the research is an evaluation of influence of geosynthetics interlayer applied to bituminous samples on their fatigue life. The results of the tests evidences that when geosynthetics are used, the fatigue life depends mainly on the type of bituminous mixture, the type of geosynthetics, and the type and the amount of bitumen used for saturation and sticking. The amount of bitumen used to saturate and fix the geosynthetic significantly changes the samples fatigue properties. Essential positive correlation between fatigue and parameters of interlayer bonding (shear strength, shear stiffness) occurs in both testing temperatures.

Key words: fatigue life, shear strength, asphalt concrete, geosynthetics interlayer.

1. Introduction

Conception of geosynthetics interlayer in bituminous pavement has been developing for many years as a solution of the reflecting cracking problem [1], [2], [3], [4], [5], [6], [7], [8], as well as in pavement strengthening [9], [10], [11], [12], 13], [14]. The most popular solution to these ~~this~~ problems are provided by geosynthetics such as nonwoven, geogrids or geocomposites.

It was found out [15] that the shear strength of the geosynthetics interlayer contact area with asphalt layers, even in optimal bonding conditions, is lower than inside the layer, so applying geosynthetics in asphalt pavement worsens interlayer bonding in comparison to the pavement without geosynthetics.

In the paper the results of an extensive investigation of asphalt concrete samples with geosynthetics interlayer [16], [17], [18], [19] are presented. The main aim of the investigation is to define factors determining asphalt samples fatigue. To attain the above aim, the following variables were taken into account:

– type of geosynthetics (polyester nonwoven – PN, polyester geocomposite – PG, two geocomposites including glass grid and polyester nonwoven – GG and samples without geosynthetics -WG),

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– kind of upper asphalt layer in specimens (comparatively: two asphalt concretes – AC with grading 0/12,8 mm and 0/16 mm plus SMA (Stone Mastics Asphalt) 0/12,8 mm),
– amount of bitumen used in layers' bonding (investigated for AC 0/12,8 mm).

2. Test methods

Static and repetitive bending tests of samples were done in INSTRON apparatus according to the 3-point bending beam test (pattern illustrated in Fig. 1). The choice of testing method was caused by actual equipment availability, currently the 4-point bending beam test is used, where a region of the specimen with more potential for defects and flaws is extended.

In the static mode, samples were tested in temperature T = 22°C, and the static bending strength was established according to Eq.(2.1).

$$\sigma_a = \frac{\frac{3}{2} * P * l}{b * h^2} \tag{2.1}$$

Where:
P – maximum loading force [N]
l – upport length [mm]
b – beam width [mm]
h – beam thickness [mm]

Additionally, energy absorbed by samples during the test was determined as an area under curve load versus displacement.

Repetitive bending tests were done according to the program of constant load amplitude under sinusoidal load in frequency 10 Hz (in accordance to recommendations [22]), what represents traffic load with speed 72 km/h. the tests were performed at two chosen temperatures: -2°C, +18°C. For all types of interlayer system 5-6 specimens were prepared in the laboratory. The specimens were compacted in moulds in two layers with geosynthetic interlayer, applied on the bitumen tack coat. Dimensions of beam samples for bending tests were: 75 x 75 x 300 mm.

The fatigue life of beam was defined as a number of load cycles in order to decrease stiffness by half. Load conditions were determined on the basis of preliminary static bending tests, according to proper temperature. Lower level of force amplitude was determined as equal to 0.5 kN for both temperatures. Upper level was calculated as a sum of lower limit plus 50% of maximum force. Accepted characteristics of load is given in table 1.

The following parameters of samples were recordered:

– Dimensions of samples [mm]
– Volume of voids in compacted specimens [%]
– Number of load cycles to fatigue [-]
– Initial tensile strain under bending [micro-strain]

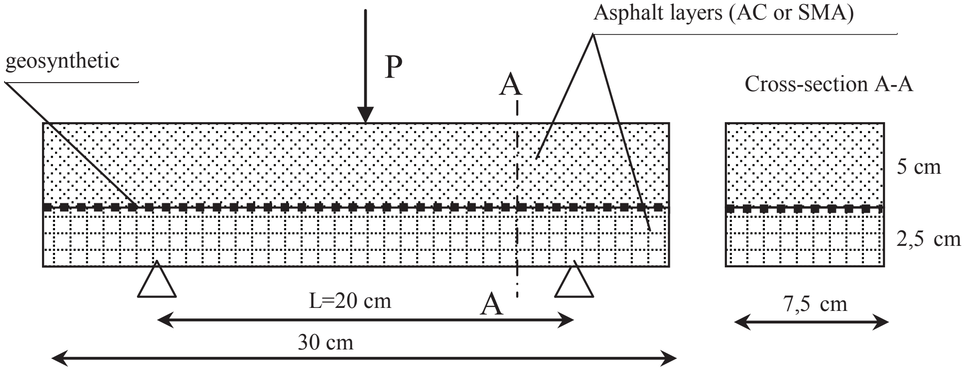

Fig. 1. Pattern of repetitive bending test asphalt concrete specimens with geosynthetics interlayer

Table 1

Load characteristics applied in fatigue tests

Load characteristics	Test temperature	
	-2°C	+18°C
Max load – P_{max}	5,5 kN	2,5 kN
Min load – P_{min}	0,5 kN	0,5 kN
Load amplitude – P_a	2,5 kN	1,0 kN
Mean value of load – P_m	3,0 kN	1,5 kN
Frequency – f	10 Hz	10 Hz
Coefficient of amplitude $R = P_{min} / P_{max}$	0,091	0,200

3. CHARACTERISTICS OF INVESTIGATED MATERIALS

Asphalt mixes designed according to PN-S- 96025:2000 and prepared in a mixing plant were used for preparations of specimens. Geosynthetics and bitumen used to saturate and bond geosynthetics were received from distributors. Detailed data concerning material characteristics were presented in reports [16] and [17], whereas parameters of geosynthetics applied in the tested specimens are given in table 2.

Table 2

Parameters of geosynthetics applied in testing specimens

Geosynthetics type	Surface mass [g/ m^2]	Tensile strength [kN/m]		Elongation at break [%]		Temperature [°C]	
		along	crosswise	along	crosswise	softening	melting
Polyester nonwoven	189	8.23	8.41	79	92	230-240°C	257-264° C
Polyester geocomposite	360	grid: 50	grid: 50	grid: 12	grid: 12	230-240°C	257-264° C
geocomposite glass grid + polyester nonwoven	360	grid: >35	grid: >56	grid: 3	grid: 3	glass: 500-750°C polyester: 230-240° C	glass: various temp. polyester: 257-264° C

4. Results of tests

4.1. Results of static bending beam test

According to the tests schedule, the results were determined and presented in figures below, where:

- (Fig. 2) – load versus deflection curves
- (Fig. 3) – energy adsorbed by specimens during the test.

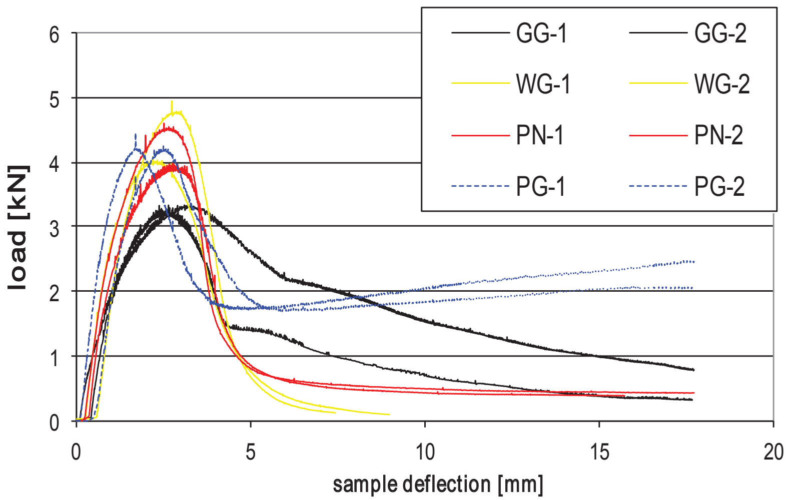

Fig. 2. Load – deflection curves in static bending beam tests for specimens with various interlayers

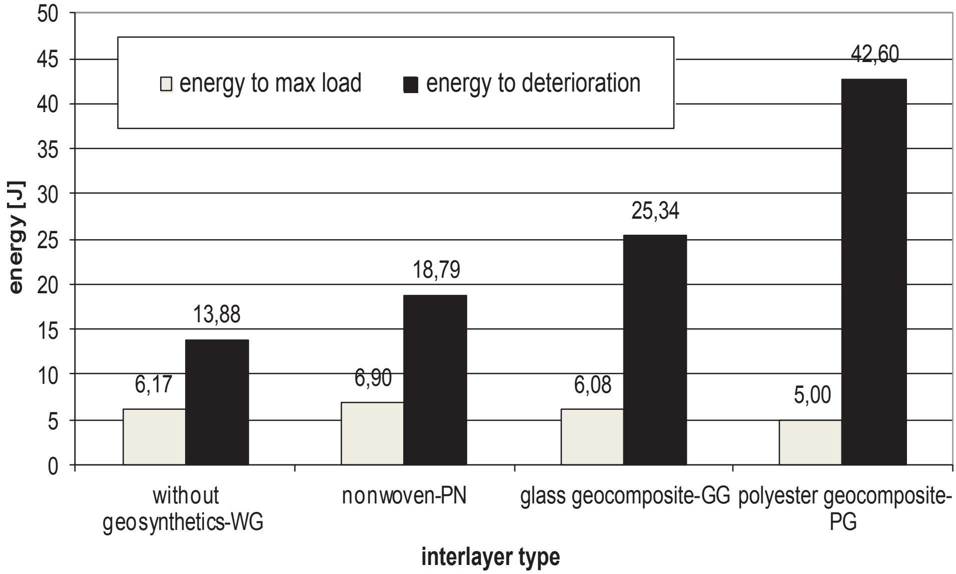

Fig. 3. Static bending beam tests energy for specimens with various interlayers

On the basis of static bending, the test results and their analysis, the following conclusions are formulated:

- Static bending strength of samples with geosynthetics interlayer depended on interlayer bonding, but application of geosynthetics did not increase this strength, in case of interlayer bonding decrease, static strength could also be decreased.
- Value of deformation energy to maximum bending load was similar for all tested samples (5-6,9 [J]).
- Essential differences were established in deformation energy to destroy the specimens, where positive effect of geosynthetics application occurred, especially in the case of polyester geocomposites with good adhesion to asphalt layers. Glass composites gave smaller increase of this energy, which was related to poor adhesion and then delamination of samples.
- In the case of specimens without geosynthetics, after reaching maximum load, the specimens were immediately destroyed, but in the case of geosynthetics application the effect of reinforcement by geosynthetic was confirmed.

4.2. Results of repetitive bending beam test

Selected results of repetitive bending beam tests are presented in figures below, where:

- (Fig. 4) – samples with AC16+SMA12 and AC16+AC16, T = +18º C
- (Fig. 5) – samples with AC12+AC12, T = +18º C
- (Fig. 6) – samples with AC16+SMA12 and AC16+AC16, T = -2º C

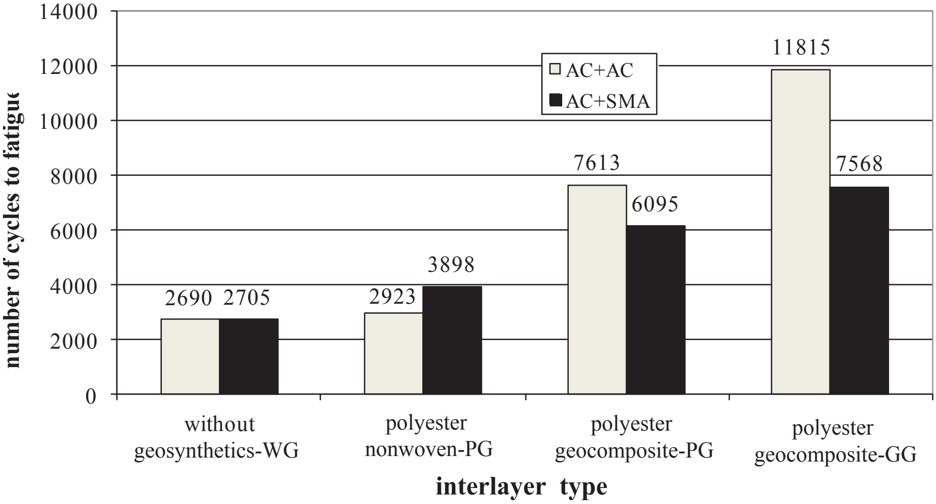

Fig. 4. Relation between type of interlayer and number of fatigue cycles, T = +18º C

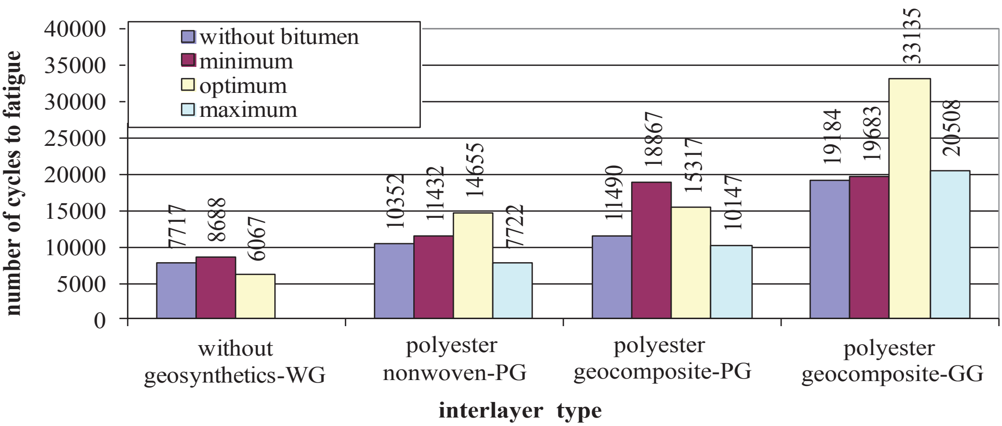

Fig. 5. Relation between fatigue life and type of interlayer for samples AC 12 with various amounts of bitumen spreading in interlayer, T = +18º C

Statistical analysis of the achieved results were carried on with the use of the computer program Statgraphics Plus v. 5.1. [23] according to the procedure given in [24]. After having examined normality of the results, the tests were performed in order to find out if there was any statistically significant difference between the averages of the variable. In all tested cases, the differences between tested structures were significant at a given confidence level equal 0.95. ANOVA table was used for this purpose. To determine which interlayer systems differed significantly from one another, the analysis

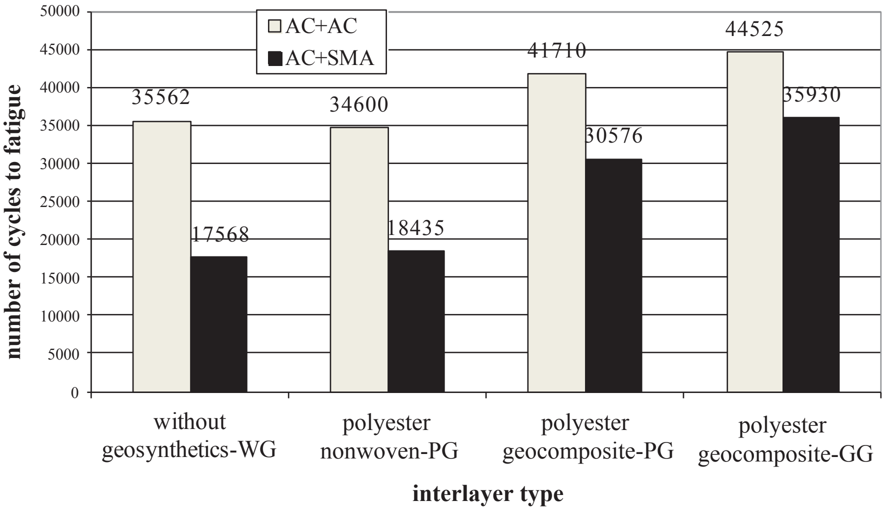

Fig. 6. Relation between number of fatigue cycles and type of interlayer, T = -2ºC

of multiply range tests with application of LSD (least square differences) option was used. Detailed tables of significant differences are reported in the work [19], whereas examples of graphical presentation of the results are given in Figures 7-11 (on the vertical axe there is an amount of bitumen spreading for samples: without bitumen, optimum amount, over optimum amount, and for comparative purposes single layer samples).

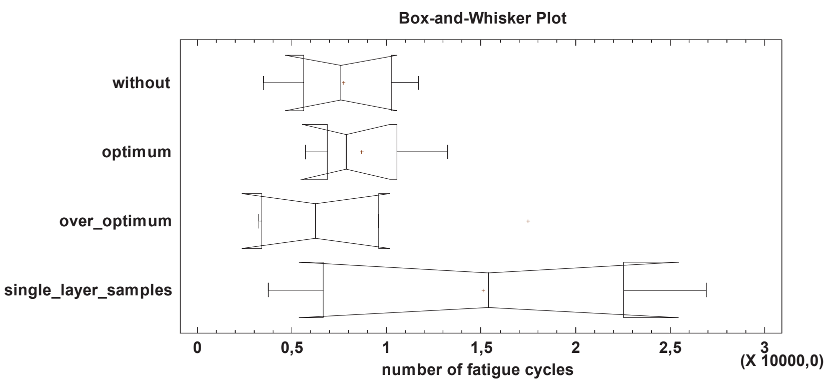

Fig. 7. Relations between number of fatigue cycles and amount of bitumen to glue the layers for specimens without geosynthetics, T = 18º C

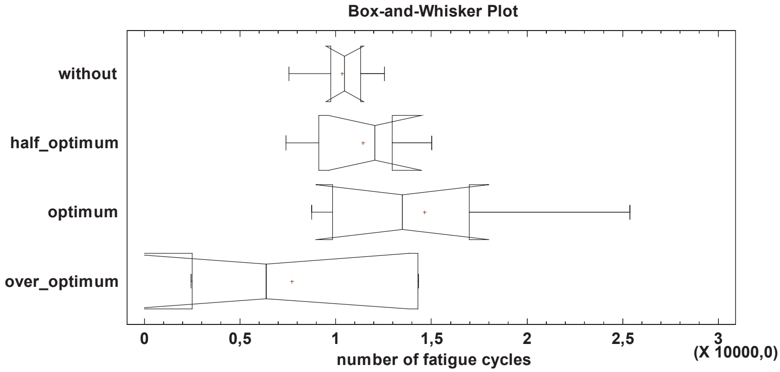

Fig. 8. Relations between number of fatigue cycles and amount of bitumen to glue the layers for specimens with polyester nonwoven, T = 18º C

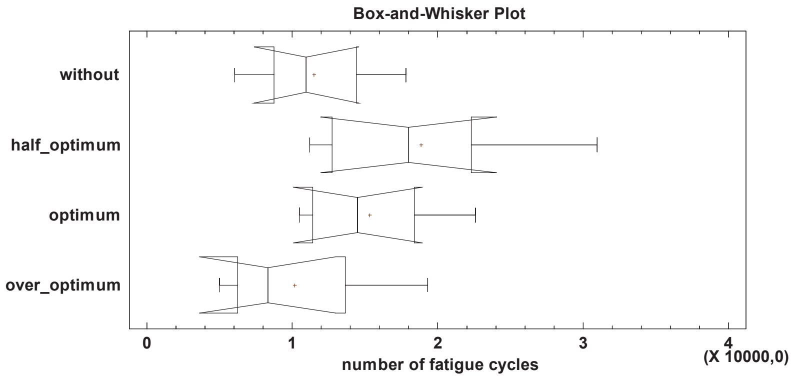

Fig. 9. Relations between number of fatigue cycles and amount of bitumen to glue the layers for specimens with polyester geocomposite, T = 18º C

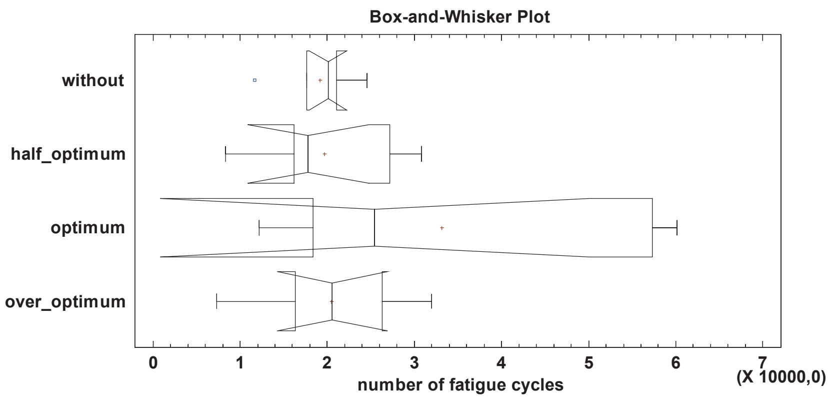

Fig. 10. Relations between number of fatigue cycles and amount of bitumen to glue the layers for specimens with glass geocomposite, T = 18º C

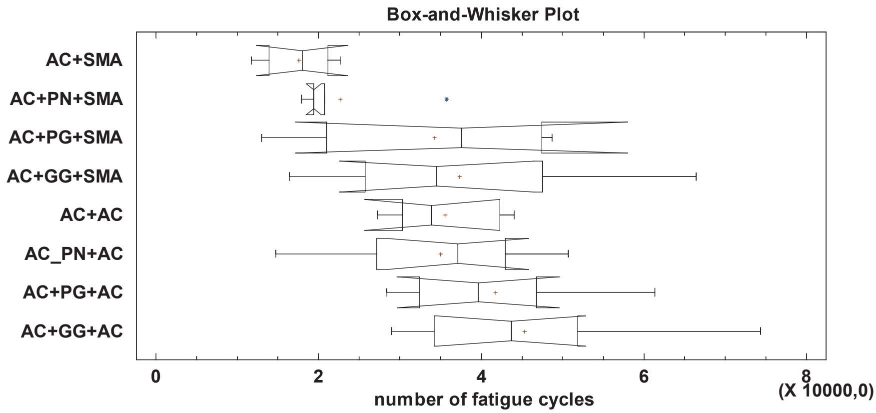

Fig. 11. Relations between number of fatigue cycles and interlayer type, T= -2º C

Results of the analysis of significance of differences for asphalt mixes specimens with different interlayers are presented in Tables 3-4.

On the basis of the repetitive bending beam, the test results and their analyses, the following conclusions are formulated:

- Application of nonwoven in asphalt layers has no influence on fatigue characteristics, it was caused by low stiffness modulus of nonwoven.
- Effect of application of geocomposites increases at higher temperatures (e.g. +18°C), when geocomposites stiffness modules achieve similar or higher values than modules of asphalt layers. At temperature +18°C, all tested geocomposites give essential increase of asphalt layers fatigue, the highest increase was noted for geocomposites including glass grid.
- It was demonstrated that bitumen spreading in interlayer has a basic influence on fatigue properties of layers.
- At temperature -2°C effect of geosynthetics application is not very meaningful for fatigue.

5. Regressive analyses

The aim of the present analyses is to find regressive dependency between interlayer bond characteristics, geosynthetics stiffness, chosen characteristics of investigated specimens, and their fatigue, which is represented by a number of repetitive bending cycles to decrease stiffness modulus by half. The specimens are characterized by the following parameters:

- amount of air voids [%]
- bulk density [kg/m^3]
- initial tensile strain [μm/m]

Table 3

Significance of statistical differences for specimens with various interlayer glued with 70Pen bitumen, T=18°C

Layers	AC+SMA	AC+AC	AC+PN+SMA	AC+PN+AC	AC+PG+SMA	AC+PG+AC	AC+GG+SMA	AC+GG+AC
AC+SMA	-	N	N	N	**Y**	**Y**	**Y**	**Y**
AC+AC	N	-	N	N	**Y**	**Y**	**Y**	**Y**
AC+PN+SMA	N	N	-	N	**Y**	**Y**	**Y**	**Y**
AC+PN+AC	N	N	N	-	**Y**	**Y**	**Y**	**Y**
AC+PG+SMA	**Y**	**Y**	**Y**	**Y**	-	N	N	**Y**
AC+PG+AC	**Y**	**Y**	**Y**	**Y**	N	-	N	**Y**
AC+GG+SMA	**Y**	**Y**	**Y**	**Y**	N	N	-	**Y**
AC+GG+AC	Y	Y	Y	Y	Y	Y	Y	-

where: **Y – differences are significant**
N – differences are not significant

Table 4

Significance of statistical differences for specimens with various interlayer glued with 70Pen bitumen, T= -2°C

Layers	AC+SMA	AC+AC	AC+PN+SMA	AC+PN+AC	AC+PG+SMA	AC+PG+AC	AC+GG+SMA	AC+GG+AC
AC+SMA	-	**Y**	N	**Y**	N	**Y**	**Y**	**Y**
AC+AC	**Y**	-	**Y**	N	N	N	N	N
AC+PN+SMA	N	**Y**	-	**Y**	(N/**Y**)*	Y	Y	Y
AC+PN+AC	**Y**	N	**Y**	-	N	N	N	**Y**
AC+PG+SMA	N	N	(N/**Y**)*	N	-	N	N	**Y**
AC+PG+AC	**Y**	N	Y	N	N	-	N	N
AC+GG+SMA	Y	N	**Y**	N	N	N	-	N
AC+GG+AC	**Y**	N	**Y**	**Y**	**Y**	N	N	-

(N/**Y**) * there is no statistical differences at confidence level equal to 95%, but exist at confidence level equal to 90%

Geosynthetics stiffness is represented by stiffness modulus [MPa], whereas interlayer bond is represented by shear strength [MPa] and shear stiffness [$N/mm/mm^2$].

Stiffness modulus for chosen geosynthetics was investigated in laboratory tests and their values are given in work [17]. Detailed structural characteristics of asphalt mixes are presented in the report [18] and in the paper [19].

Regressive dependency between fatigue durability and materials characteristics of the tested specimens was carried out using computer program Statgraphics Plus v. 5.1. [23]. In the first step the basic statistical characteristics were described, e.g. mean value, standard deviation, skewness coefficient, kurtosis and normality of data. Then the correlation coefficients for tested characteristics were determined, describing their statistic significance and correlation power. Regressive equations were fixed on the basis of multiple regression analysis.

For proposed equations, the coefficient of determination (R^2) and corrected coefficient of determination (R^2_{kor}) were calculated. Then, the errors analysis was performed, concerning normality and independency of errors. For testing errors normality, unusual residuals and influential points were used. Independency of errors was tested using Durbin-Watson statistics, which tests the residuals to determine if there is any significant correlation based on the order.

For the analysed parameter, the following symbols were used:

L – number of cycles to specimen fatigue [-]
P – volume of air voids in a sample [%]
M – geosynthetics modulus [MPa]
S – shear stiffness [$N/mm/mm^2$]
W – shear strength [MPa]
e – initial tensile strain [µm/m]

Fitting the established models to the obtain results are presented in Fig. 12, 13, 14 and 15.

5.1. RESULTS AT TEMPERATURE +18°C

For specimens without geosynthetics, significant positive correlations were determined between the number of fatigue cycles and shear stiffness (correlation coefficient r=0,46), and the shear strength (r=0,52). Negative correlations were estimated between the number of fatigue cycles and the volume of air voids (r=-0,46) and initial tensile strain (r=-0,79). Initial strain in repetitive bending was positively correlated with volume of air voids (r=0,67), while shear strength showed negative correlation with initial strain (r=-0,41).

The obtained function dependency, representing a number of L fatigue cycles, is presented in equation (6.1) whereas fitting of model is shown in Fig. 12.

$$L = 1{,}05\ E\text{-}23 * e^{-8{,}19} \tag{6.1}$$

Corrected coefficient of determination – R^2_{kor} = 81,7%
Standard error of estimation – SSE = 0,25
Mean absolute error – MAE = 0,20
Durbin-Watson statistics = 1,73 > 1,4 – autocorrelation of non-existing residuals

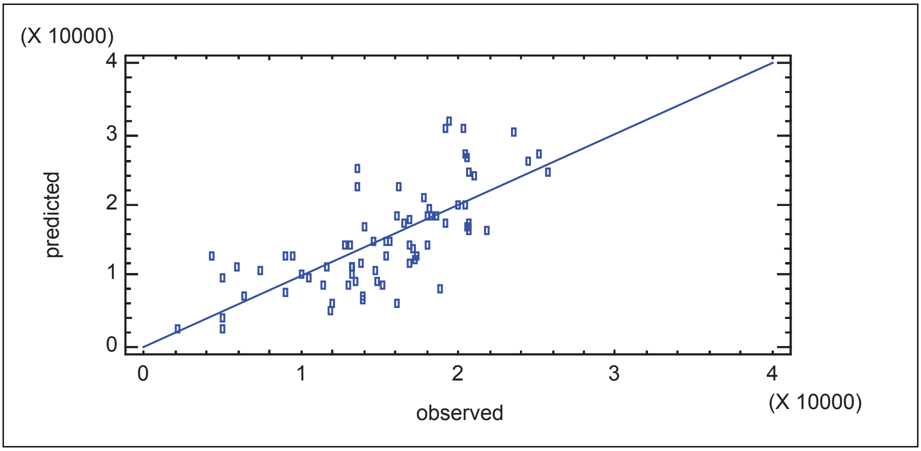

Fig. 12. Relations between observed and predicted number of fatigue cycles for specimens without geosynthetics

For the specimens with geosynthetics, significant positive correlations were determined between the number of fatigue cycles and stiffness of geosynthetics (correlation coefficient r=0,48). Negative correlations were observed between the number of fatigue cycles and the volume of air voids (r=-0,44) and the initial tensile strain (r=-0,65). Initial strain in repetitive bending was positively correlated with volume of air voids (r=0,47), while shear strength (r=-0,24) and stiffness of geosynthetics (r=-0,14) showed negative correlation with initial strain.

The obtained function dependency, representing the number of L fatigue cycles, are presented in equation (6.2), while fitting of the model is shown in Fig. 13. Additionally, Fig. 14 shows dependency between the number of fatigue cycles, initial tensile strain, and stiffness modulus of geosynthetics.

(6.2) $$L = 74505 - 1{,}14\ E8 * e + 7{,}35 * M$$

Corrected coefficient of determination – R^2_{kor} = 50,6 %
Standard error of estimation – SSE = 5055
Mean absolute error – MAE = 3840
Durbin-Watson statistics = 1,67 > 1,4 – autocorrelation of non-existing residuals

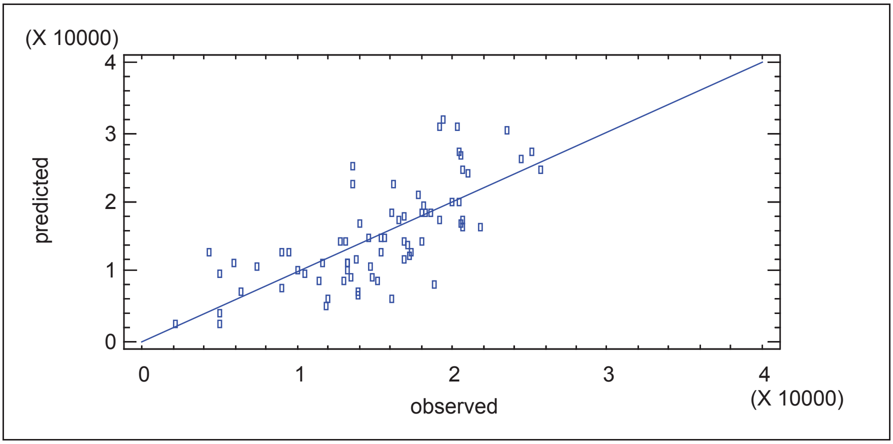

Fig. 13. Relations between observed and predicted number of fatigue cycles for specimens with geosynthetics

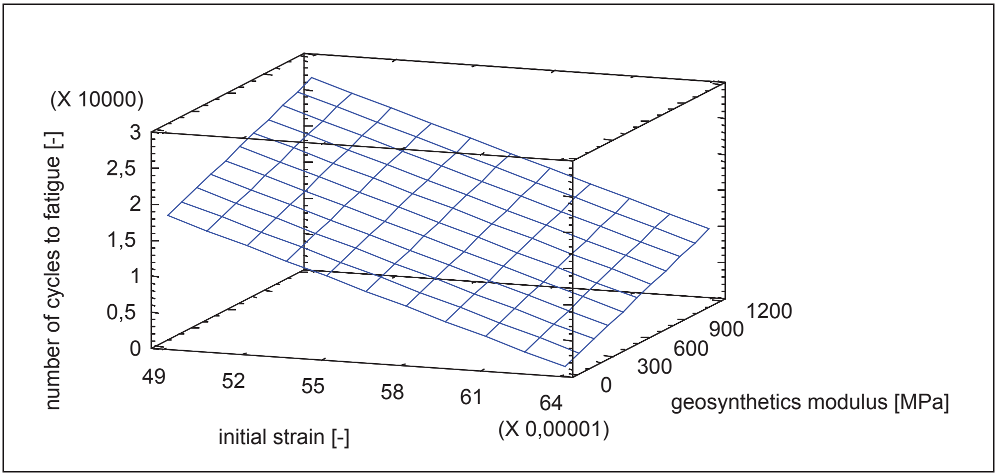

Fig. 14. Relations between the number of fatigue cycles, initial tensile strain and stiffness modulus of geosynthetics

5.2. RESULTS AT TEMPERATURE -2°C

For the specimens with geosynthetics, significant positive correlations were determined between the number of fatigue cycles and shear stiffness (correlation coefficient r=0,57), and stiffness modulus of geosynthetics (r=0,36).

The obtained function dependency, representing the number of L fatigue cycles, are presented in equation (6.3), whereas fitting of model is shown in Fig. 15.

(6.3) $$L = -35681 + 23.01 * M + 15679 * S$$

Corrected coefficient of determination – $R^2_{kor} = 52{,}6$ %
Standard error of estimation – SSE = 10500
Mean absolute error – MAE = 8191
Durbin-Watson statistic = 1,68 > 1,4 – autocorrelation of non-existing residuals

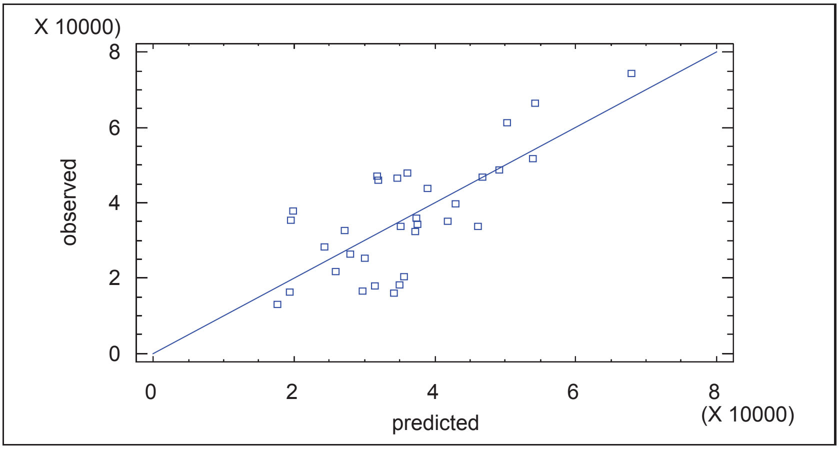

Fig. 15. Relations between observed and predicted number of fatigue cycles for specimens with geosynthetics

5.3. Discussion on the regresive analysis

The obtained regressive dependency between fatigue and material parameters allow to formulate the following remarks:

- Material parameters, with an essential influence on fatigue of asphalt pavement with geosynthetic interlayer dependeds on temperature and kind of geosynthetics interlayer.
- For the specimens tested at temperature +18°C, positive correlation between fatigue and characteristics of interlayer bonding (e.g. shear strength and shear stiffness) was concluded, independently of the interlayer type, while initial tensile strain and volume of air voids in the specimens were negatively correlated with fatigue.
- The obtained function of fatigue dependency on characteristics of interlayer bonding for the specimens with geosynthetics were weak (coefficient of determinations $R^2_{kor} =_r 13{,}2 - 16$ %), whereas for specimens without geosynthetics there was a clear correlation between fatigue and shear strength (coefficient of determination – $R^2_{korr} =_r 36$ %).
- It was concluded that shear strength is a better estimator of fatigue in specimens with small amount of bitumen used in interlayer system (e.g. specimens without

geosynthetics, specimens with polyester geocomposite), while in the case of greater amount of bitumen (samples with nonwowen or glass geocomposite) fatigue is better represented by shear stiffness.

- For all specimens with geosynthetics interlayer, function dependency of fatigue increased with the increase of geosynthetics stiffness modulus, and decrease of amount of air voids, and initial tensile strain decrease in repetitive bending. Characteristics of interlayer bonding represented by shear strength or shear stiffness were inessential parameters in probabilistic model, although for the separate analysis, these features were positively correlated with fatigue. It can be connected with the results of specimens with glass geocomposites, where the highest fatigue and low shear strength are reported. However, shear strength and shear stiffness essentially influenced the initial strain of samples contributing to fatigue changes.
- It was also concluded that the mean fatigue durability for specimens with geocomposites was essentially higher than the fatigue durability for specimens without geosynthetics or with nonwoven.
- The use of geosynthetics influenced to a greater degree the fatigue durability of asphalt concrete specimens at temperature +18°C; the influence of geosynthetics modulus on fatigue was a few times greater than at temperature -2°C. It comes from variability of asfalt concrete stiffness modulus at different temperatures, whereas stiffness modulus of geosynthetics is practically constant in wide temperature spectrum.
- In the case of specimens with geosynthetics tested at temperature -2°C, the fatigue depends on geosynthetics modulus and shear stiffness in geosynthetics interlayer, moreover, both parameters are positively correlated with fatigue.

6. Final conlusions

On the basis of the results of fatigue tests and their statistical analysis, the following conclusions were formulated:

1. The amount of bitumen used to saturate and fix geosynthetics through influence on interlayer bonding, significantly changed the fatigue properties of specimens. Application of too small or too great amount of bitumen decreased fatigue 1,5-2 times. For both testing temperature, there existed essentially positive correlation between fatigue and parameters of the interlayer bonding (shear strength, shear stiffness).
2. Nonwoven used in asphalt layers structure, independently of the testing temperature, did not increase fatigue significantly, thus it could be used only as stress relieving layer.
3. Geocomposites could–also be used as a reinforcement of asphalt pavements. According to the theory of composites, the effectiveness of reinforcements depends on the following factors: transfer of load from asphalt layers to reinforcement elements (stiffness of bonding), volume ratio of reinforcement, stiffness modulus

of reinforcement to stiffness modulus of asphalt layers ratio, and durability of geosynthetics parameters during usage. Because stiffness modulus of asphalt mixes is strongly dependent on temperature and frequency of load, a given system of interlayer in one condition could be treated as a reinforcement, and in another condition it could not. It concerns various seasons (e.g. temperature of summer or winter), stage of crack initiation or propagation, damages during application of too hot mixes.

4. In current investigations, formulation of universal equation describing strict dependency between fatigue of asphalt pavement with geosynthetics interlayer and their material characteristics is a difficult task. It is related to difficulties of description of geosynthetics interlayer parameters, but this problem can be solved with application of FEM in accordance with laboratory investigations, as was showed in the paper [25].

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References

1. RILEM REPORT 18: Prevention of Reflective Cracking in Pavements, State-of Art. Report of RILEM Technical Committee 157 PRC, Systems to Prevent Reflective Cracking in Pavements, Edited by A.Vanelstraete and L. Francken , E& FN SPON, 1997.
2. P. Dumas, J. Vecoven, Processes reducing reflective cracking: synthesis of laboratory tests, Proceedings of the Second RILEM Conference „Reflective cracking in Pavements", Liege, 1993, pp. 246-253.
3. A.H. De Bondt, Anti-Reflective Cracking Design of Reinforced Asphaltic Overlays, Ph. D. Thesis, Delft University of Technology, 1999.
4. A. Gibney, G. Lohan, V. Moore, Laboratory study of the resistance of bituminous overlays to reflective cracking, Proceedings of the 2002 TRB Annual Meeting of the Transportation Research Board, Washington, DC, 2002.
5. R.G. Lugmayr, E.K. Tschegg, J. Weissenböck, The use of geosynthetics in paving applications – Factors influencing the reflective cracking, Nicea 2002, pp. 938.
6. J.W. Button, R.L. Lytton, Guidelines for using geosynthetics with hot mix asphalt overlays to reduce reflective cracking, Proceedings of the 2007 TRB Annual Meeting of the Transportation Research Board, Washington, DC, 2007.
7. F. Vervaecke, J. Maeck, A. Vanelstraete, On site validation and long term performance of anti-cracking interfaces, Proceedings of the 6th RILEM International conference on cracking in pavements, Chicago, 2008, pp. 761-768.
8. I.L. Al-Quadi, J. Baek, W.G. Buttlar, Development of reflective cracking index do determine the effectiveness and service life of strip interlayer systems, Proceedings of the 6th RILEM International conference on cracking in pavements, Chicago, 2008, pp. 801-810.
9. Button J., Lytton R.L.: Evaluation of fabrics, fibers and grids in overlays, Proceedings of the Sixth International Conference Structural Design of Asphalt Pavements, Volume I, Delft, 1987.

10. Doligez D., Coppens M.H.M.: Fatigue improvement of asphalt reinforced by glass fibre grid.: Laboratory simulation and modeling of overlay systems, Proceedings of the Third International RILEM Conference, Reflective Cracking in Pavements, Maastricht, 1996.
11. Sprague C.J., Alen S., Tribbett W.: Tensile Properties of Asphalt Overlay Geosynthetic Reinforcement, Proceedings of the the 1998 TRB Annual Meeting of the Transportation Research Board, Washington, DC, 1998.
12. De Bondt A.H.: Effect of reinforcement properties, Proceedings of the Fourth International RILEM Conference, Reflective Cracking in Pavements, Ottawa, 2000.
13. Jaecklin F.P., Scherer J.: Asphalt reinforcing using glass fibre grid „Glasphalt", Nicea 2002.
14. M. Tazl, M. Meyer, Lifetime extension of reconstructed asphalt pavements by using geosynthetic interlayers: effectiveness of an innovative combined system, Proceedings of the 9th International Conference on Geosynthetics, Brazil, 2010, pp. 1496-1498
15. P. Zieliński, Investigations of geosynthetic interlayer bonding in asphalt layers, Archives of Civil Engineering, 4/2011.
16. P. Zieliński *at al.*, *Research project Nr 5.TO7 E.070.25, Geosynthetic bonding of interlayer on fatigue life of bitumen pavement construction.*[in Polish]. 2003-2004.
17. W. Grzybowska, Zieliński P, *Influence of material parameters on asphalt-mineral mixtures durability in road pavement in different load conditions*. [in Polish]. Wydawnictwo Poligraficzne MarGraf, Kraków 2003.
18. P. Zieliński, *Influence of material parameters on durability of bitumen layers with geosynthetic interlayer*. [in Polish]. Politechnika Krakowska, L-2/362/BW/2004, 2004.
19. P. Zieliński, *The selected problems of durability of asphalt-concrete pavement with geosynthetic interlayer*. [in Polish]. Ph. D. Thesis, Politechnika Krakowska 2004.
20. J. Judycki, Fatigue of asphalt mixes, University of Oulu, Finland 1991.
21. J. Zawadzki, P. Skierczyński, T. Mechowski, *The influence of asphalt layers bonding od pavemenet durability* [in Polish]. IX Międzynarodowa Konferencja „Trwałe i bezpieczne nawierzchnie drogowe", Kielce, 2003, s. 415-423.
22. *The catalogue of reinforcements and renovation of flexible and semi-rigid pavements* [in Polish]. IBDiM, D. Sybilski, ed., Warszawa, 2001.
23. *Computer software Statgraphics Plus v.5.1* [in Polish]. A Manugistics Inc. Product, Rockville, MD USA, 2000, Nr 537672031051732.
24. M. Dobosz, *Computer aided statistical analysis of research results* [in Polish]. Problemy współczesnej nauki, Teoria i zastosowania, STATYSTYKA, AOW EXIT, Warszawa, 2001.
25. J. Górszczyk, *Influence of the geosynthetic interlayer reinforcement on fatigue life of asphalt road pavement* [in Polish]. Ph. D. Thesis, Politechnika Krakowska 2010.

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