GEOGRID REINFORCEMENT OF ASPHALT PAVEMENTS

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Abstract. Geogrid materials applied within asphalt layers defer or prevent the occurrence of reflective cracking. The contribution of this work significantly adds to extending pavement serviceability and improving benefit/cost analysis. Since 1970s many studies have demonstrated the benefits of geogrid reinforcement in asphalt pavements, but this knowledge did not translate to their extensive usage in the actual construction practice. Among potential reasons are higher initial costs, lack of in-depth understanding of working mechanism within adjacent asphalt layers and lack of commonly standard design procedures. This paper presents a recent study, which investigated the effect of geogrid reinforcement on asphalt mixture specimens. Two types of laboratory experiments were conducted, namely monotonic (strength and fracture) testing and cyclic (fatigue and modulus) testing. The results demonstrated a significant strengthening contribution of geogrid, which was observed regarding fracture energy results and terminal deflections in the fatigue testing. This paper also presents a short example connecting pavement deflections with the allowable axle loading (also known as fatigue life) to demonstrate the practical implications of geogrid reinforcement. The undertaken analysis shows the reduction of pavement deflections due to the geogrid application, which potentially leads to a significant extension of pavement fatigue life. Paper concludes with several recommendations for further work in the area of geogrid reinforcement.

Keywords: geogrid, reinforcement, fatigue, asphalt pavement.

1. Introduction and objectives

Geosynthetics application in asphalt pavements has been in practice since the 1970s. However, despite numerous laboratory, analytical and demonstration studies, no general methodology has been developped for selection, assessment, and implementation of geosynthetics into pavement design. Available approaches differ on their input parameters and basic conspects. On the other hand, this situation unstopped the growing demand for geosynthetics products worldwide. It is quite apparent that the driving force behind such a market success ought to be a superior performance of existing field sections with documented distress history. These sections were designed using predominantly empirical approaches. It is very likely the application of geosynthetics increases with more scientific and proven evidence from the demonstration projects and associated Life Cycle Analysis (LCA). Additionally, geosynthetics application is envisaged to be even more extensive as many national highway networks are in the deteriorating condition, and significant investments are required for their rehabilitation.

There have been several comprehensive studies in the recent years that tried to systemize application of geosynthetics in asphalt pavements (Andrews 2013; Button, Lytton 2007; Rathmayer 2007; Vaitkus *et al.* 2007, 2010; Virgili *et al.* 2009).

Some experiments have been performed on the IFSTTAR accelerated pavement testing facility (APT) in Nantes, which is is an outdoor circular carousel dedicated to full-scale pavement experiments. The experiments were carried out in order to compare the behaviour of a section reinforced with a traditional grid with a tack coat and of an unreinforced pavement section. Results showed that the glass fiber grid properly installed near the bottom of the asphalt layer improves significantly the fatigue life of the reinforced pavement (Nguyen *et al.* 2013).

Since asphalt reinforcement techniques are currently not thoroughly covered in any standard or method statement in most parts of the world, Brusa *et al.* (2016) proposed a design methodology for asphalt pavement reinforcement. It is an empirical mechanistic process and is based on the research commissioned by the Highway England,

which resulted in a design software for reinforced overlays. The proposed method and software called OLCRACK is suitable for use in overlay design and which uses a linear elastic crack fatigue model.

In summary, with appropriate design and correct installation, many improvements can result from reinforcing asphalt overlays: increased tensile strength; increased resistance to reflective cracking and bottom-up fatigue cracking; increased shearing resistance and hence may reduce shoving and flow rutting; increased coherence in the overlay; and potential material savings and enhanced pavement performance so significant whole design life benefits (Brusa *et al.* 2016; Čygas *et al.* 2004; Zofka *et al.* 2015). In addition, it seems the geosynthetics have growing potential particularly in alternative maintenance techniques.

According to Al-Qadi *et al.* (2008) and Górszczyk and Gaca (2012)as well as macros specially designed in APDL programming script and VBA were used to model the considered problem. The analysis included computation of stress, fatigue life, damage matrix and rainflow matrix. The method applied was the one of fatigue calculation: stress – number of cycles in short S-N. On the basis of the performed high cycle fatigue analysis, the influence of the location of the used geogrid and of its bond with asphalt layers on the fatigue life and the work of the asphalt pavement structure were determined. The study was carried out for three temperature seasons, i.e. spring and fall (assumed as one season geosynthetics may provide one (or more) of the following functions when applied to a pavement structure:

  – separation;
  – filtering;
  – moisture barrier;
  – reinforcement (geogrids);
  – stress relief/strain absorption.

A detailed discussion of each of the function is beyond the scope of this paper, but it needs to be noted that every function is based on different mechanism and thus different properties and physical parameters of geosynthetics are desirable. This article is focused on geogrids and their reinforcement effect.

Results and discussion presented in this paper are a first stage of the long-term study initiated in Poland to characterize and quantify the benefits of using geogrids within asphalt layers. The details are presented elsewhere (Zofka *et al.* 2017). In this paper, the following objectives were considered:

1. Demonstrate the effect of geogrid reinforcement on asphalt mixture specimens in two types of laboratory experiments: monotonic (strength and fracture) and cyclic (fatigue and modulus).

2. Present a short example connecting pavement deflections with the allowable axle loading (also known as fatigue life).

2. Methodology

The following paragraphs present materials and specimen preparation used in this study together with an experimental methodology for both monotonic and cyclic testing.

2.1. Materials

This study utilized double layered hot mix asphalt beam specimens, reinforced with different geogrids installed within the lower part of the beam. Hot mix asphalt specimens were prepared from dense-graded asphalt concrete AC 16 comprising basaltic and limestone aggregate and penetration 50/70 neat bitumen. Both layers of composite beam specimens were prepared with the same mix.

Regarding geogrid materials, there were two different geogrids utilized in this research study: glass grid, abbreviated as *GF* and carbon grid, abbreviated as *CF*. The average grid opening for the two materials is 18 mm. The glass grid is formed with the use of glass fibers in both directions, while for the carbon grid geogrid the longitudinal direction is made of glass fibers, and the transverse direction is formed with carbon fibers. The unique feature of these geogrid materials is that all fibers are covered with a thin asphalt layer to promote adhesion among pavement layers.

Composite beam specimens were prepared and compacted in the laboratory slab compactor to examine the effect of geogrid reinforcement. Nominal beam dimensions were 100×200×400 mm. In all beams, the interlayer interface was located approx. 30 mm from the bottom of the beam. In total 18 beams were prepared: 6 without any reinforcement (*NR*), 6 with *GF* interface, and 6 with *CF* interface.

2.2. Methodology

Composite beams were examined in two different laboratory experiments: three-point bending (3PB) and four-point bending (4PB). During the testing several specimen responses were simultaneously recorded such as beam midspan deflections at the neutral axis, beam mid-span deflections at the top of the beam, applied force and horizontal gauge displacement at the bottom of the beam (for 4PB testing only). All testing was conducted at 13±1 °C. This temperature was recently calculated as an equivalent temperature suitable for temperature conditions in Poland (Rys *et al.* 2015). Monotonic testing in 3PB was conducted with 1 mm/min in actuator displacement control mode. Cyclic testing in 4PB comprised two groups. The first group was devoted to modulus testing performed in a controlled force mode with five different amplitudes at 1 Hz. The second test was fatigue assessment with 4 kN amplitude at 1 Hz. The test termination was set to 36 000 load cycles.

3. Results

The loading mode organizes results obtained in this study, i.e. first, the summary of monotonic testing is presented followed by the results from the cyclic testing.

3.1. Monotonic testing

Figure 1 shows the middle section of the beam specimen after monotonic (strength) testing. Crack paths in Fig. 1 indicates the crack initiation at the bottom of the beam due to tension and then upward movement till the geogrid interface. At the interface, the crack propagated along the geogrid until the deflection caused the excessive tensile condition in the layer above the interface. At such condition, the crack crossed the interface and propagated vertically upwards until complete failure, which translated to virtually no bearing capacity and test termination.

The summary of monotonic testing is presented in Fig 2. Several parameters were calculated:

1. Maximum (i.e. peak) force recorded during the test.
2. Time of maximum force measured from the test start.
3. Beam deflection recorded at the time of maximum force.
4. Total fracture energy calculated as the area under the force-displacement curve.

Based on Fig. 2 one deducts that the maximum force for all beams is similar, which suggests no effect of reinforcement on the crack initiation. More information and distinction among different interfaces are provided by the time and deflection measurements at the maximum force. It is noted in both cases that the values corresponding to *CF* interface are significantly higher and therefore the reinforcement effect is clearly defined. Similarly, this effect is also shown in the Fig. 2 (total fracture energy) where total energy for the *CF* is significantly higher than for the other two interfaces. The practical interpretation of this observation is that 2.5 times more energy is necessary for the crack to propagate through the *CF* reinforced beam than for the unreinforced beam.

3.2. Cyclic testing

Figure 3 presents results from the cyclic testing regarding deflection histories. Similar to other studies mentioned supra, the reinforcement effect of geogrids is present. Geogrids located at approximately 31% height of the beam (measured from the bottom) contributed effectively in the
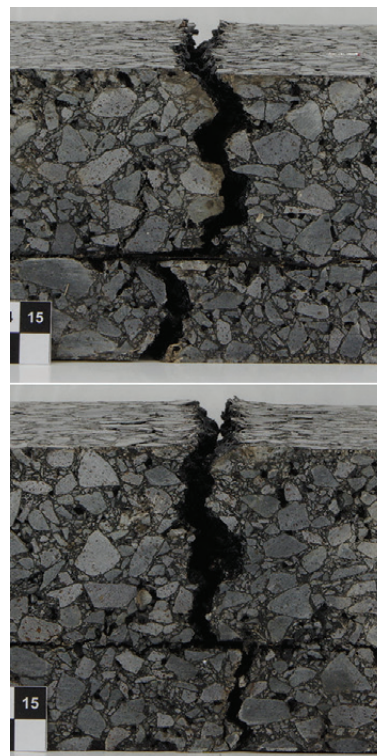

Fig. 1. Middle sections of beams after monotonic (strength) testing (beams reinforced with carbon grid)
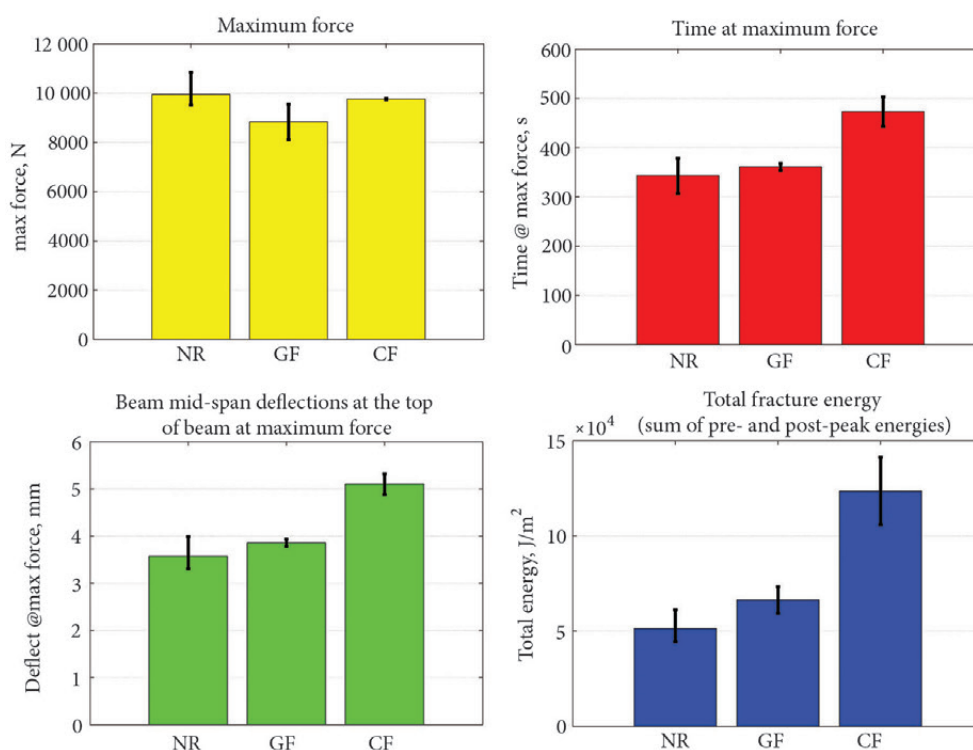

Fig. 2. Different parameters from monotonic testing

tension zone, which resulted in smaller vertical deformations at the test termination (36,000 cycles). Keeping in mind that deflections are of particular importance in the evaluation of pavement bearing capacity, results presented in Fig. 3 indicate a significant extension of fatigue life for the pavements reinforced with geogrids. A representative example is presented in the following section.

4. Discussion

As mentioned earlier, reduction of pavement deflections is one of the measures to extend pavement fatigue life. A simplified example is presented to demonstrate a link between pavement deflections and pavement fatigue life. This example is using a standard fatigue life criterion from the Asphalt Institute (Shook *et al.* 1982). A simple formula proposed by (Molenaar 2007) is used to estimate tensile strain at the bottom of asphalt layers. The two steps are as follows:

1. Determine tensile horizontal strains at the bottom of asphalt layers using the following formula:

$$\log(\varepsilon_t) = 0.481 + 0.991 \log(SCI_{300}), \qquad (1)$$

where ε_t – strains at the bottom of asphalt layers; SCI_{300} – *Surface Curvature Index* (*SCI*) calculated as:

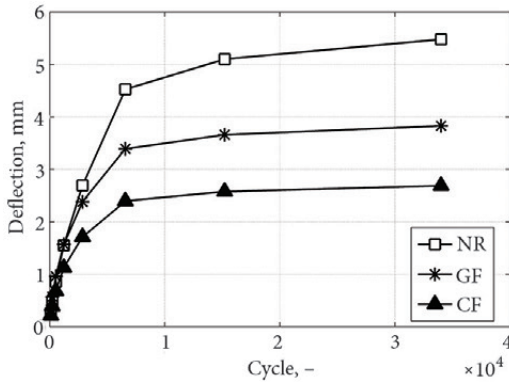$$SCI_{300} = GF \cdot d_0 - d_{300}, \qquad (2)$$

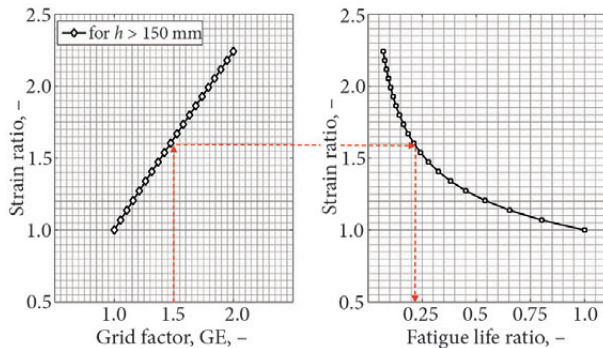**Fig. 3.** History of beam deflections in cyclic testing

Fig. 4. An example of the effect of grid reinforcement (geogrid factor) on pavement fatigue life: a) relationship between geogrid factor and strain ratio; b) normalized fatigue life as a function of strain ratio

where *GF* – strengthening geogrid factor, assumed to vary between 1 and 2; d_0 and d_{300} deflections at 0 mm and 300 mm assumed as 150 µɛ and 50 µɛ, respectively.

2. Determine pavement fatigue life from the following formulas:

$$N_f = 18.4C(6.167 \cdot 10^{-5} \, \varepsilon_t^{-3.291} \, E^{-0.854}), \qquad (3)$$

$$C = 10^{\left(4.84\left(\frac{V_b}{V_a + V_b} - 0.69\right)\right)}, \qquad (4)$$

where *E* – modulus of asphalt layer, assumed as 9000 MPa; V_a and V_b – air voids and binder volume in the asphalt mix, assumed as 5 vol% and 11 vol%, respectively.

It is noted that Equation (1) is valid only for relatively thick pavements with a total thickness of asphalt layers more than 150 mm. *GF* is be determined from the Fig. 3 and is be defined as:

$$GF = \frac{\delta_{NR}}{\delta_{CF}}. \qquad (5)$$

If *glass grid* equals to 1, there is no strengthening effect of geogrid whereas when *GF* equals to 2, then terminal deflections of *NR* specimens are twice the deflections of *CF* specimens. In Figure 3, *GF* parameters equal to approximately 5.5/2.8 = 1.96. It should also be mentioned as it was assumed that *GF* is only affecting d_0 in *SCI* calculations. Figure 4a presents a relation between *GF* and normalized strain at the bottom of asphalt layers. It is easily observed the stronger the geogrid effect then the strains are increasing for a given un-reinforced structure. Figure 4b is next connecting these strains with the fatigue life calculated from Eq (3)−(4). Fatigue life ratio is defined similar to Equation (5), i.e. fatigue life for un-reinforced pavement is normalized with the fatigue life of the geogrid reinforced pavement. For example, when *GF* equals to 1.5 it results in 60% higher strains for the *NR* case (Fig. 4a). Then from Fig. 4b it can be concluded that *NR* pavement would have only 20% of fatigue life as compared to *CF* reinforced pavement. While this example may overestimate the effect of geogrid reinforcement on pavement fatigue life, nonetheless it demonstrates the potential benefit of using the geogrid in asphalt pavements. Further, this example considers only one phenomenon (bottom-up cracking) while there are other factors either affecting this phenomenon or contributing to other phenomena such as resistance to low temperature (Zofka, Braham 2009), pavement dynamic response (Li *et al.* 2012) or aging resistance (Li *et al.* 2006). In the recent years, there is also a growing awareness that there is a close link between chemical and mechanical properties of asphaltic materials, which also needs to be taken into consideration (Paliukaitė *et al.* 2015; Yut, Zofka 2014).

5. Conclusions

The results presented in this paper shows there is a significant strengthening contribution of geogrid onto

composite beam response in the tree-point bending and four-point bending testing in the laboratory. This effect is observed for the fracture energy results (tree-point bending testing) as well as in terminal deflections in the fatigue testing (four-point bending). Geogrid reinforced beams produced 2.5 times higher fracture energy then non-reinforced beams. In terms of terminal deflections, the observed difference was similar with non-reinforced beams producing approximately 5.5 mm whereas reinforced beams only 1.9 mm. To further demonstrate the practical implications of geogrid reinforcement, a short representative example was prepared. This case showed that reduction of pavement deflections due to the geogrid application might lead to a significant extension of pavement fatigue life. However, this the described case is based on certain assumptions and simplifications, and more rigorous research study is required to prepare a comprehensive implementation plan for the mechanistic-empirical design procedure for geogrids within asphalt layers. Such a plan should start with definition of work mechanism(s) of geogrids within asphalt layers. Then one should prepare proper computational algorithm including important factors influencing the behaviour of geogrids within asphalt layers. Such algorithm requires also development of performance-related laboratory experiments for geogrid characterization and should model geogrid bonding and anchoring as well as incorporate realistic material, loading and temperature conditions. Any mechanistic-empirical design requires verification and validation so calibration field sections should be established in parallel and their condition should be evaluaed in systematic and unbiased manner. Based on the assessment results, each model in the algorithm should be calibrates and further refined if necessary. In the final step, one should assess cost-effective for the application of geogrids. Only a few studies have been considering this aspect, and they seem to agree the geogrids are beneficial, under certain conditions, when included in the Pavement Life Cycle Cost Analysis.

References

Al-Qadi, I. L.; Morian, D. A.; Stoffels, S. M.; Elseifi, M.; Chehab, G.; Stark, T. 2008. *Synthesis on Use of Geosynthetics in Pavements and Development of a Roadmap to Geosynthetically-Modified Pavements*, Federal Highway Administration, McLean, VA, Report No. FHWAHRT, 1–195.

Andrews, C. M. 2013. The Contribution of Asphalt Reinforcement Geo-Composites in a Pavement Structure; a Long Term Performance Review, in *Proc. of the XXVIII International Baltic Road Conference*, 26–28 August, 2013, Vilnius, Lithuania.

Brusa, N.; Crowther, D.; Pezzano, P. 2016. Asphalt reinforcement through geosynthetics: design method and UK experience, in *Proc. of the LJMU 15th Annual International Conference on Asphalt Pavement Engineering and Infrastructure*, 24–25 February 2016, Liverpool, UK. Vol. 15. ISBN 978-0-9571804-8-2.

Button, J. W.; Lytton, R. L. 2007. Guidelines for Using Geosynthetics with Hot Mix Asphalt Overlays to Reduce Reflective Cracking, *Transportation Research Record* 2004: 111–119. https://doi.org/10.3141/2004-12

Čygas, D.; Laurinavičius, A.; Juknevičiūtė, L.; Vaitkus, A. 2004. Investigations of Pavement Structure of Public Transport Stops on Vilnius City Streets, in *Proc. of the 8th International Conference on Modern Building Materials, Structures and Techniques*, 19-21 May 2004, Vilnius, Lithuania. ISBN:9986-05-757-4: 186–192.

Górszczyk, J.; Gaca, S. 2012. The Influence of the Carbo-Glass Geogrid-Reinforcement on the Fatigue Life of the Asphalt Pavement Structure / Wpływ Zbrojenia Siatka Weglowo–Szklana Na Trwałosc Zmeczeniowa Asfaltowej Nawierzchni Drogowej, *Archives of Civil Engineering* 58(1): 97–113. https://doi.org/10.2478/v.10169-012-0006-z

Li, J.; Zofka, A.; Yut, I. 2012. Evaluation of Dynamic Modulus of Typical Asphalt Mixtures in Northeast US Region, *Road Materials and Pavement Design* 13(2): 249–265. https://doi.org/10.1080/14680629.2012.666641

Li, X.; Zofka, A.; Marasteanu, M.; Clyne, T. R. 2006. Evaluation of Field Aging Effects on Asphalt Binder Properties, *Road Materials and Pavement Design* 7 (sup1): 57–73. https://doi.org/10.1080/14680629.2006.9690058

Molenaar, A. 2007. Prediction of Fatigue Cracking in Asphalt Pavements: Do We Follow the Right Approach?, *Transportation Research Record* 2001: 155–162. https://doi.org/10.3141/2001-17

Nguyen, m. L.; Blanc J.; Kerzrého, J. P.; Hornych, P. 2013. Review of Glass Fiber Grid Use for Pavement Reinforcement and APT Experiments at IFSTTAR, *Road Materials and Pavements Design*, 14(1): 287–308. https://doi.org/10.1080/14680629.2013.774763

Paliukaitė, M.; Vaitkus, A.; Zofka, A. 2015. Influence of Bitumen Chemical Composition and Ageing on Pavement Performance, *The Baltic Journal of Road and Bridge Engineering* 10(1): 97–104. https://doi.org/10.3846/bjrbe.2015.12

Rathmayer, H. G. 2007. Reinforcement of Pavements with Steel Meshes and Geosynthetics, in *Proc. of Design and Construction of Pavements and Rail Tracks-Geotechnical Aspects and Processed Materials*. 1–14. https://doi.org/10.1201/9780203937549.pt1

Rys, D.; Judycki, J.; Jaskula, P. 2015. Analysis of Effect of Overloaded Vehicles on Fatigue Life of Flexible Pavements Based on Weigh in Motion (WIM) Data, *International Journal of Pavement Engineering* 17(8): 719–726. https://doi.org/10.1080/10298436.2015.1019493

Vaitkus, A.; Čygas, D.; Laurinavičius, A.; Juzėnas, A. A. 2007. Evaluation of Geotextiles Separation Performance on the Impact of Transport Loads: Experimental Research – Stage I, *The Baltic Journal of Road and Bridge Engineering* 2(1): 45–50.

Vaitkus, A. 2010. Geotextile Selection Methods for the Lithuanian Road and Street Structures, *The Baltic Journal of Road and Bridge Engineering* 5(4): 246–253.
https://doi.org/10.3846/bjrbe.2010.33

Virgili, A.; Canestrari, F.; Grilli, A.; Santagata, F. A. 2009. Repeated Load Test on Bituminous Systems Reinforced by Geosynthetics, *Geotextiles and Geomembranes* 27(3): 187–195.
https://doi.org/10.1016/j.geotexmem.2008.11.004

Shook, J. F.; Finn, F. N.; Witczak, M. W.; Monismith, C. L. 1982. *Development of the Asphalt Institute Thickness Design Manual* (MS-1) No. 81–2. Research Report. 16 p.

Yut, I.; Zofka, A. 2014. Correlation between Rheology and Chemical Composition of Aged Polymer-Modified Asphalts, *Construction and Building Materials* 62: 109–117.
https://doi.org/10.1016/j.conbuildmat.2014.03.043

Zofka, A.; Braham, A. 2009. Comparison of Low-Temperature Field Performance and Laboratory Testing of 10 Test Sections in the Midwestern United States, *Transportation Research Record* 2127: 107–114. https://doi.org/10.3141/2127-13

Zofka, A.; Maliszewski, M.; Bernier, A.; Josen, R.; Vaitkus, A.; Kleizienė, R. 2015. Advanced Shear Tester for Evaluation of Asphalt Concrete under Constant Normal Stiffness Condition, *Road Materials and Pavement Design* 16(1): 187–210.
https://doi.org/10.1080/14680629.2015.1029690

Zofka, A.; Maliszewski, M.; Maliszewska, D. 2017. Glass and Carbon Geogrid Reinforcement of Asphalt Mixtures, *Road Materials and Pavement Design* 18(sup1): 471–490.
https://doi.org/10.1080/14680629.2016.1266775