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Laboratory Testing of Fatigue Crack Growth in Geosynthetically Reinforced Large Scale Asphalt Pavement Samples

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Abstract

While using the geosynthetics for pavement reinforcement the proper role and designed application is often misunderstood by engineers and constructors of such technology in asphalt road structures. The efficiency of reinforcement is erroneously identified with increasing the AC stiffness rather than fatigue life of reinforced pavement system. The original laboratory method is developed here in order to check the influence of selected reinforcing geosynthetic type on a fatigue life of asphalt pavement samples. To simulate real pavement conditions the research laboratory set-up scale was fit to large size samples cut from asphalt pavement layers. Two types of commonly used in Poland geosynthetic materials were tested in order to evaluate the reinforcement efficiency on inhibition of crack propagation. Test results also gave some indications on numerical model simulation parameters.

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Keywords: large asphalt concrete samples fatigue; crack growth in asphalt pavement samples.

1. Introduction

Although the geosynthetics employed for asphalt pavements reinforcement are in use for many years, still some problems require extensive research. Considering the discussion on correct installation [1], laboratory and numerical studies which proves the benefits of using geosynthetics to improve the pavement structure performance. Still, however, some problems remain unsolved, among them is the selection and modeling criteria for geosynthetics to be used in reinforced pavements [2-7]. But there are also some observations [8] that geosynthetics between asphalt layers may not be effective, if: (1) bearing capacity of the base course/subgrade is unstable or insufficient, (2) the overlay thickness is too thin, (3) preconstruction repair of distressed old pavement is inappropriate (no leveling course both with or without milling, unrepaired cracks, potholes). The primary basis for the development of these technologies is a scientific experiment. In most cases, the choice from a wide range of available geosynthetics without any scientific grounding will be inexpedient [9]. In terms of reinforcement, by using geogrids or geocomposites between asphalt layers, is possible to increase fatigue resistance, reduce rutting and/or limit reflective cracking. Anyway, the final result will depend on size and shape of the mesh, stiffness and position in pavement structure or type of material composition [7], [10].

However due to the cost of in situ experiments the laboratory scale tests or experiment enhanced with computer modeling of pavement reinforcement systems are the most desirable analysis paths.

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The work [11-12] presents, that durability, reinforced pavement lifetime prediction analysis and grading of geosynthetic asphalt interlayer systems can be obtained by fatigue crack growth testing with the wedge splitting test instead of the most commonly used beams and bending tests [13]. Based on such experiment they reported that SAMI and SAMI + asphalt reinforcement asphalt interlayer systems outperform standard asphalt reinforcement systems (asphalt emulsion spraying) and non-interlayer systems by far, especially at low temperatures and high loads.

Experimental data clearly evidences the beneficial, though rather qualitative, character of engaged geosynthetics. Among many available in the literature method of modeling the crack propagation in composite materials, the embedded discontinuity, constitutive smeared cracking [14], or X-FEM [15] seem to be frequently used by various researchers to capture the crack growth effect. In the discrete crack propagation formulation a linear elastic fracture mechanics is usually employed, on the other hand for the constitutive modeling of crack the damage mechanics is used. The discreet and smeared approaches are different in nature but both require a particular set of parameter in order to properly simulate fracturing and degradation of material stiffness during fatigue test. Unfortunately not all of the needed parameters are easily accessible. Therefore the careful choice of proper crack modeling technique has to be made based on available experimental data and desired modeling expectations. During the fatigue test often more than millions of loading cycles are generated therefore the crack closing and opening (due to cycling loading) and self-healing of visco-elasto-plastic materials seem to be an important phenomenon. In order to capture such behavior the proper material model which is capable to describe compressive and tensile stiffness degradation separately (e.g. [14], [16]) should be employed. By having independent material behavior in tension and compression one can observe a recovery of progressive damage especially when material switches from tension to compression and vice versa.

However the task of pavement modeling is an example that confirms the thesis, that relatively simple engineering approach of analysis of a layered system is a better approximation to the reality than the mathematically exact solution [17].

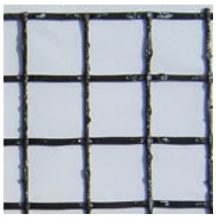
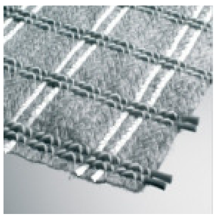
2. Models of composites with isotropic matrix reinforced with regular grid

Here the attention is given to the group of theoretical solutions, which may include alternative models of reinforced concrete pavement construction [18]. The composite material consisting of a discrete grid embedded in the mineral-asphalt matrix can be further simplified through e.g. homogenization. Alternatively, if the composite is modeled as layered structure in the frame of isotropic linear theory of elasticity, the reinforcement can be treated as an equivalent layer with finite thickness.

2.1 Employment the elementary homogenization

Selected for analysis examples are based on geosynthetics made of glass fibers. The first is the geogrid and the other is a geocomposites, see Table 1.

Table 1 Parameters of geosynthetics chosen for analysis

a) GEOGRID ::GlassGrid 8550::		
Tensile strength:	50 × 50 kN/m	
Grid elongation at break:	< 5%,	
Grid size:	25 × 25 mm,	
Young`s modulus of the glass filaments:	73 000 MPa,	
Mass per unit area:	185 g/m2,	
Adhesive backing:	pressure sensitive.	
b) GEOCOMPOSITES ::PGM-G 100/100::		
Tensile strength:	100 × 100 kN/m,	
Grid elongation at break:	< 3%,	
Mesh width of the glass filaments:	40 × 40 mm,	
Young`s modulus of the glass filaments:	73 000 MPa,	
Mass per unit area:	430 g/m^2,	
Asphalt retention:	1.1 kg/m^2,	
Strength at 2% strain:	68 × 68 kN/m.	

To determine the elastic parameters of the section, the homogenization method described in [18, 20] is used here. Due to the negligible stiffness of geocomposites, the calculation was carried out only for the geogrid (Table 1a). The geometry of the sample was prepared similar to the size of A4 format.

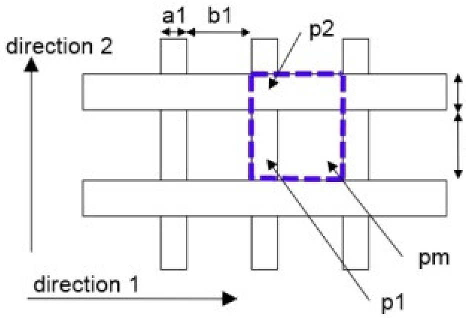


Table 2 Results of macroscopic geometry measurements GG8550

Width of rib, mm	
a1	a2
1.5	1.5
Grid size, mm	
b1	b2
25	25
Thickness of rib	
g1	g2
1.5	1.5
Distance between ribs, mm	
a1 + b1	a1 + b1
26.5	26.5

The remaining parameters needed to determine the characteristics of the equivalent layer are calculated from the formulas:

$$u_1 = u_2 = \frac{a_1}{(a_1 + b_1)}, \quad p_1 = p_2 = \frac{a_1 \cdot g_1 \cdot (a_1 + b_1)}{(a_1 + b_1) \cdot (a_1 + b_1) \cdot 2g_1}, \quad p_1 + p_2 + p_m + p_p = 1 \tag{1}$$

where: $u_1 = u_2$, $p_1 = p_2$ - respectively percentage of the ribs area in the width and length of the grid and their volume fraction in the grid structure,

p_p content of space unfilled by the matrix,

p_m part of matrix in total volume of grid,

Considering the model of geogrid, which uses the values of geometrical measurements and the parameters declared by the manufacturer (gathered in Table 1) a secant modulus was calculated by Equation (2):

$$E = \frac{F_m}{u_i} \cdot \frac{1}{g_i \cdot \varepsilon_m} = 11\ 778 \text{ MPa} \tag{2}$$

where:

F_m maximum tensile force kN/m,

u_i part of the material in the strip of the grid mm/mm

g_i thickness of the rib in the „i^{th}" direction mm,

ϵ_m grid elongation at break mm/mm.

Finally, using the method which converts the basic features of the geogrids, from the real model to its surrogate, an equivalent E_K modulus and Poisson's ratio of HMA composite with reinforcement can be calculated [18].

$$E_K(E, \nu, p_m, \kappa) = \frac{E[2(1-\nu-2\nu^2)\kappa^2 + 3p_m(7-8\nu)\kappa + 45p_m^2]}{12(1-\nu-2\nu^2)\kappa + 45p_m} \quad \text{[MPa]}$$

$$\nu_k(\nu, p_m, \kappa) = \frac{(1-\nu-2\nu^2)\kappa + 15\nu \cdot p_m}{4(1-\nu-2\nu^2)\kappa + 15p_m}, \quad \kappa = p_1 \frac{E_{z1}}{E} + p_2 \frac{E_{z2}}{E}, \tag{3}$$

where:

E AC stiffness, MPa;

E_k Composite stiffness (AC + Geogrid), MPa;

E_{zi} Geogrid stiffness along "i" direction;

ν Poisson ratio of AC;s

ν_k Poisson ratio of composite (AC+Geogrid) MPa.

Tab. 3 Theoretical reinforcement efficiency of composite structure (AC+geogrid)

	AC features		Composite of AC and geogrid			Theoretical Reinforcement Efficiency
	Poisson coefficient [---]	Stiffness modulus, [MPa]	Coefficient, κ [---]	Poisson coefficient ν_K [---]	Stiffness modulus E_K, [MPa]	[%]
Summer	0.4	3 000	0.222	0.39	2949	**-1.7**
Spring	0.3	10 000	0.067	0.30	9545	**-4.5**
Winter	0.25	18 000	0.037	0.25	17092	**-5.0**

3. The laboratory experiment

By limiting the analysis to the basic scope of the calculation of the stress / strain only, a beneficial effect of reinforcement is likely to "reveal" only in situations in which used geosynthetics will have a significant stiffness (e.g. glass fiber mesh in the matrix epoxy resin). The experiment is expected to provide the results of the analyzes leading to answer the question concerning the effectiveness and meaning of reinforcement of asphalt layers by geosynthetics with low stiffness.

3.1. The general depiction of experiment

Samples for laboratory tests have been cut from the test section pavement described in detail [19]. At the laboratory, there was built a set-up for fatigue tests of large-scale cores, using a Schenck strength device. Laboratory set-up was constructed based on own concept, by using HBM measurement system. During the tests the following values were measured: (1) force, (2) displacements on the surface of plate sample and (3) contractual length of crack in the area of potential influence of artificial notch with a height around 8 cm (Fig. 1a). The observation area was covered with a smooth, very thin layer of gypsum in white, thus facilitating to observe the process of crack propagation in successive moments of time during fatigue tests. Crack growth propagation was determined visually by using image analysis techniques. This study compares three groups of asphalt interlayer systems. In the Fig. 1b, the first row shows the condition of the sample prior to fatigue testing, and in the second row are aligned sample images, shortly before the end of fatigue tests.

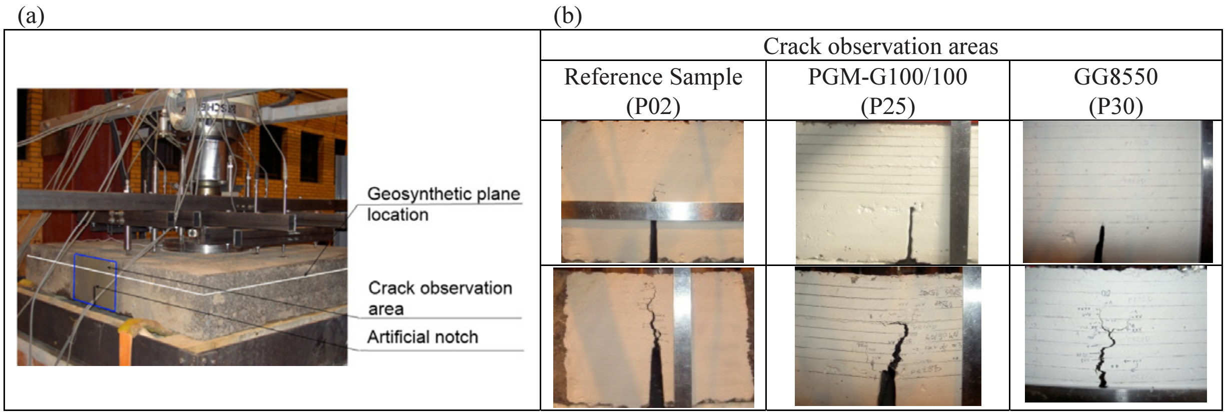


Fig. 1. (a) Original laboratory fatigue crack growth investigation set-up (the plate dimensions: 1.0 × 1.0 × 0.15 [m]); (b) laboratory fatigue crack growth study cases (horizontal lines on particular images are called here contractual levels of crack growth observation)

The following list shows the chosen for comparison the most commonly used geosynthetic materials for flexible pavement reinforcement in Poland:

- Reference samples (P02);
- PGM-G 100/100 (P25);

- Glass Grid 8550 (P30).

3.2. Detailed assumptions of performed experiment

Many previous attempts to a target research programme, helped to develop a solution, which guarantee their completion. It was considered that the most beneficial effect of “simplification-results quality” relationship was obtained with large-sized samples placed on steel beams along the opposite edges of the sample in parallel to the longitudinal axle line of artificial crack. Crack growth propagation tests carried out on the assumption that the vertical displacement rate, measured at the surface of the sample in the load axis is constant and is equal to 1 mm/hour (Fig. 2).

During the measurements the average value of the load, to satisfy the above condition was F = 14 kN. The frequency of sinusoidal change of load cycles was f = 10 Hz. Average temperature of the samples during fatigue tests was T = 13 ± 1 °C.

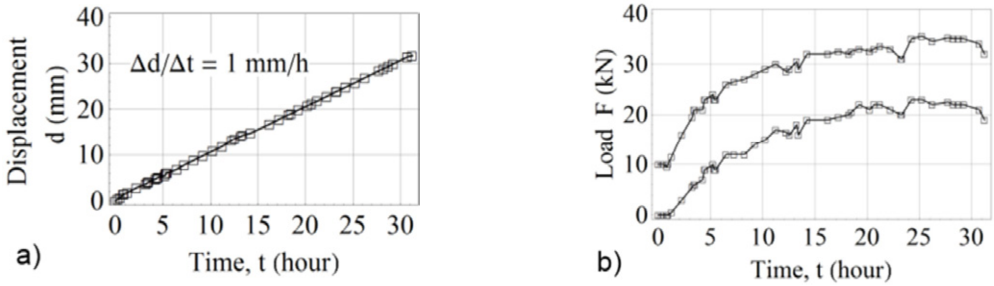


Fig. 2. An example of (a) constant vertical displacement rate; (b) minimal and maximal envelope values of sinusoidal load

4. The experimental results

This section summarizes the results of laboratory tests. Contractual level of crack tip in relation to maximal value of sinusoidal force amplitude is shown in the Fig. 3. This analysis compares the values of the forces needed to damage large size samples, reinforced with considered types of geosynthetic materials.

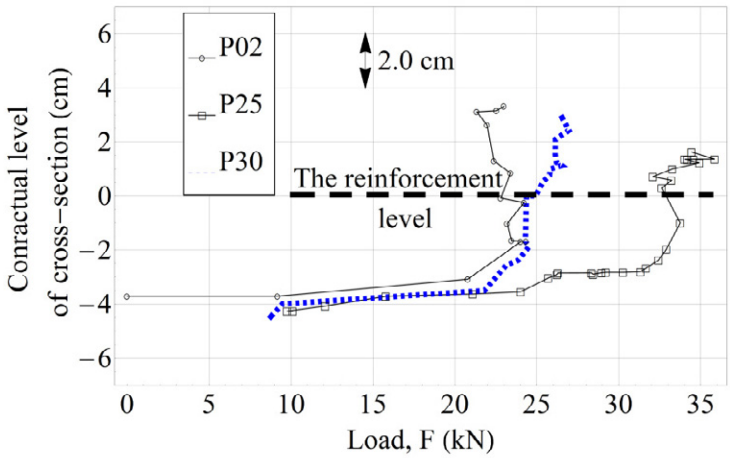
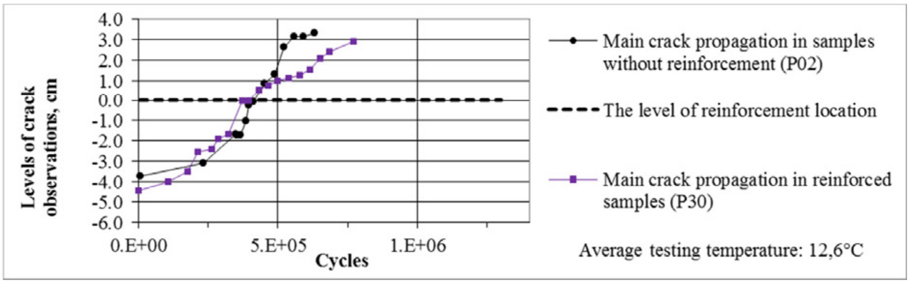
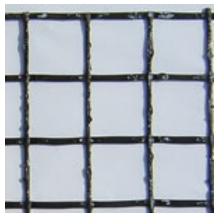


Fig. 3. Contractual level of crack tip in relation to maximal value of sinusoidal force value

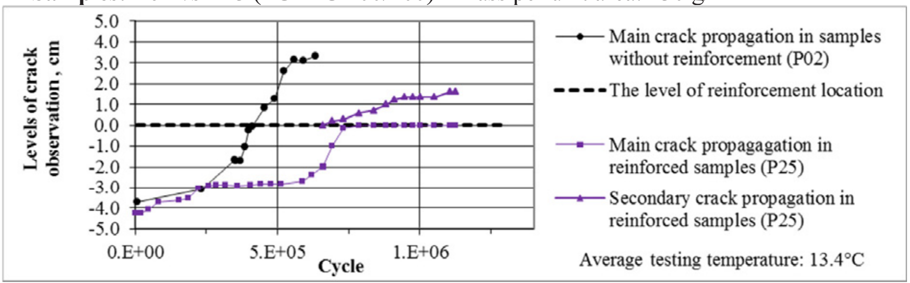
On the individual graphs (Fig. 4) one can observe the propagation of fatigue cracks in the reinforced samples always compared to the sample results under the same testing conditions but without reinforcement (called here the reference model P02).

Samples: P02 vs P30 (GlassGrid 8550) - Mass per unit area: 185 g/m^2,





Samples: P02 vs P25 (PGM-G 100/100) **-** Mass per unit area: 430 g/m^2



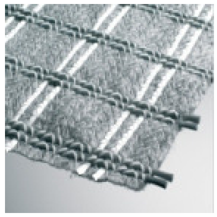


Fig. 4 The average paths of crack propagation in samples reinforced with chosen geosynthetics and the reference samples

5. Laboratory and theoretical results discussion

The role of the reinforcement by geosynthetic materials with low flexural stiffness is checked here. First, using one of the methods of homogenization of composite with reinforced layer, where equivalent stiffness of reinforced course is computed (i.e. stiffness of the composite AC with geogrid). Based on the obtained results, as expected, the lack of efficiencies of reinforcement was observed (negative values in Tab. 3, last column). The example of calculation concerned only geogrid, however, due to the similar properties of the second material, one can expect the same results. In other words, if one thinks of reinforcements as a stiffness improvement of the composite, formed from a mixture of asphalt and reinforcing layer, than the meaning of the application of the grid GG8550 or geocomposites PGM 100/100 for such solutions is questionable.

The overall picture of reinforcement in these materials dramatically changes when subjected to the fatigue analysis. In order to check the fatigue resistance a large-scale laboratory testing of the sample plate cut from the experimental section of asphalt layers is examined here. Assessing the effectiveness of the reinforcement in the form of relative measure which takes into account only the number of cycles until the crack tip reaches the reference of + 2 cm (see Fig. 4) the following observations was taken:

- The increase of the fatigue life by 16% for samples reinforced with geogrid;
- The increase by 37% in the case of geocomposites` reinforcement.

6. Conclusions

The results showed that the testing protocol presented in the paper is suitable for laboratory studying the performance of reinforced large scale samples, making possible to find out the difference between fatigue life of samples reinforced with different materials. The results of the analysis revealed that:

- Theoretical analysis of the reinforcement's influence, reduced to assess the impact on the stiffness of the surrogate models of composite shows no improvement if reinforcement material has no bending stiffness.
- The same types of materials (with no bending stiffness) assessed for fatigue life in laboratory conditions, on the large-scale specimens cut from the asphalt pavement layers, revealed the beneficial properties of such solutions. Geogrids increased fatigue life by 16% in the case of geocomposites was an increase over 35%.
- The impact of geosynthetics should be judged only on the basis of the analysis which takes into account the phenomenon of fatigue due to cyclic loads. There is a need to develop the theoretical methods to optimize the pavement design with the use of reinforcement technologies.

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