Determination of geosynthetic materials resistance to cyclic loading

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ABSTRACT: The questions of remaining life evaluation and resistance to damages of geosynthetic materials (grids and thermally bonded textiles) at repeated loading are observed in the article. Endurance test method was developed in order to choose various geosynthetic materials for given service conditions. Method's backbone lies in evaluation of geosynthetic materials' endurance at cyclic loading of stretching and bending. Statistical treatment methods of fatigue test results to determine fatigue strength with desired reliability was improved. Strength remaining life is evaluated on the base of the results of energy of absorption determination according to diagrams "loading-deformation" after specified number of cycles (usually 5 000, 10 000 and 15 000) of repeated loading. Relationship between energy of absorption with fatigue characteristics of geosynthetic materials was determined. Developed theoretical dependences and experimental results are used for development of testing express-method on fatigue in order to choose reinforcing material for given service conditions.

1 INTRODUCTION

In Ukraine as well as abroad the normative document, regulating methods of geosynthetic materials testing on repeated loading is absent. (Koerner R.M. 2005). Lack of such document causes difficulties in design, construction, operating and quality control of materials. Pavement of highways operate at transport loading, applied repeatedly (from 50 till 70 000 traffic passes per hour) during long-term service life (9-15 years) till capital repair. In view of significant traffic intensity on highways, the most important characteristic for geosynthetic materials which are used in road pavement constructions should be endurance ratio at repeated loading cycles.

2 CHARACTERISTICS OF EQUIPMENT AND MATERIALS

During research and investigation the characteristics of geosynthetic materials were compared in terms of:

(1) fatigue is accumulation of damages at cyclic loading, caused to material or its structural element damage;

(2) endurance is material elements property to keep property characteristics after specified number of repeated loading applications. Endurance ratio is relation of breaking load, elongation or energy absorption of geosynthetic materials structure elements before and after endurance testing.

Three types of grids, which are widely used in reinforcement of asphalt concrete pavements in Ukraine (Tabl. 1) and two types of thermally bonded geotextiles, which are widely used for drainage and separation of ballast layers (Tabl.2) were taken for testing.

Table 1. Technical characteristics of different types of grids

Characteristics	Value	GR-1 PET	GR-2 PVA	GR 3 GL
Tensile strength, kN/m	avg, MD	55	55	45
	Tolerance	-5	-5	-
	avg, CMD	55	55	45
Elongation at break, %	Tolerance	-5	-5	-
	avg, MD	11	6	3
	Tolerance	+1,5	+/-1,5	-
	avg, CMD	11	6	3
	Tolerance	+/-1,5	+/-1,5	-
Note: Amount in direction (lengthwise - MD/ cross-wise CMD)				

Raw material for production of grids GR -1 ia polyester (PET), GR-2 ia polyvinyl alcohol (PVA) and for GR-3 – fibreglass (GL)

Geotextiles are made on the basis of polypropylene fibres GT – 1 and GT – 2.

Table 2. Physical and mechanical characteristics of geotextiles

Characteristics	GT – 1	GT – 2
1. Mass per unit area, g/m^2	136	190
2. Variation coefficient of surface density, %	4.0	4.3
3. Thickness, mm: under loading: 2 kPa	0.43	0.53
20 kPa	0.41	0.53
200 kPa	0.38	0.48
4. Resistance to ball punching, N	430	353
5. Tensile strength, kN/m		
lengthwise	7.6	10.0
widthwise	4.7	4.8
6. Elongation at maximum strength %		
lengthwise	35.0	49.4
widthwise	26.8	40.0
7. Secant stiffness (at 5 % elongation), kN/m		
lengthwise	80	133
widthwise	110	130

Characteristics of geosynthetic materials are defined according to the standards of Ukraine SOU 45.2-00018112-025: *Geosynthetic materials. Methods of tests*.
As main equipment, testing machine, used at fatigue investigation of cord filaments in tires, was chosen (produced by "Metrimplex", Hungary).
During tear resistant testing the press-machine up to 1 kN was used (Kao Tieh Testing Mashine, Japan). Loading speed was 100 mm per min.

3 EVALUATION METHOD OF FATIGUE AND ENDURANCE CHARACTERISTICS

Method's backbone is in estimation of grids and thermally bonded geotextiles endurance at cyclic loading of stretching and bending.

3.1. Test procedure

Testing breaking load (P_o), elongation at a break (ε_{p0}) and energy of absorption (W_0) of samples, are determined according to the normative document on material testing methods SOU 45.2-00018112-025.
Prepared samples in width 370 mm are put into the machine. The width of the sample is accepted from 25 to 50 mm depending on durability of a geosynthetic material. The maximum thickness of the sample 2 mm.

One end of the simple sample is inserted into the clamp 5, to do it upper part of a clamp should be taken off, material sample should be inserted, and then upper part of a clamp should be returned in the initial position and fixed with bolts 6.
With the help of a hook, which is a part of equipment, the sample should be inserted between rollers in such a way that the sample is inserted between the rollers (Fig. 1)

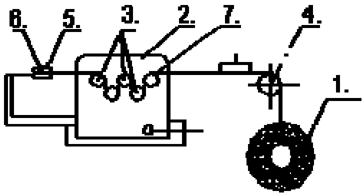

Figure 1. Scheme of a simple sample insertion
1) batch, 2) slide, 3) rollers, 4) bearing disc, 5) clamp, 6) clamping bolt, 7) simple sample of grid or geosynthetic materials.

The sample is loaded with balance weights. Value of sample loading is taken as equal to 5.0%, 10%, 15% or 20% from breaking load of the sample.
Prepared batch is hinged on the simple sample and the device is turned on. During fatigue testing the samples are brought to failure. During endurance testing loading values are predetermined in percentage of the destructive one and after passing of specified number of loading cycles on the sample, the device is turned off. The samples are taken out of the device and simple samples are cut out of them for testing. Breaking load (P_1), elongation at break (ε_{p0}) and energy of absorption (W_1) are determined after specified number of repeated loading.

3.2. Estimation of testing results

3.2.1. Fatigue testing data processing

For approximation of fatigue testing to sample destruction the function is used:

$$N_c = \left(\frac{R_p}{\sigma}\right)^b \qquad (1)$$

Where, R_p = imaginary tensile strength of the sample at one loading cycle,
σ = permanent operating tension,
b = value.
By least-square method coefficients *a'* i *b'* are determined, which approximate the curve in two logarithmic scale and endurance curve is constructed, which corresponds to probability of non-damaging 50%.
Standard deviation stdev and quantile probability *qt(P)* are determined, which correspond to specified

probability P. With small number of tests Student distribution is used instead of normal distribution.
According to Student's standard deviation stdev and quantile

$$s_N = stdev(N) \cdot \sqrt{1 - corr(N,\sigma)^2} \qquad (2)$$

for reliability 99% - t_{99}=2,764, 95% - t_{95}=1,812, here corr(N,σ)- coefficient of correlation.
Top and bottom of tolerance interval for specified reliability (θ=99, 95 or 90%) are determined

$$\lg(\sigma_\theta) = a' + b' \cdot (\lg(N) \pm t_\theta \cdot s_N) \qquad (3)$$

3.2.2. Endurance testing data processing

Endurance ratio of the material at strength K_M, elongation K_B and energy of absorption K_W is calculated with the formula:

$$K_M = \frac{P_1}{P_o}, \quad K_B = \frac{\varepsilon_{p1}}{\varepsilon_{po}}, \quad K_W = \frac{W_1}{W_o} \qquad (4)$$

Where, P_o, P_1, ε_{p0}, ε_{p1}, W_0, W_1 – accordingly, breaking load, elongation at break and energy of absorption of the samples before and after endurance testing.
Energy of absorption is determined as area under the curve "loading P – displacement l" or "tension σ - elongation ε" by integration with the formula:

$$W = W_P + W_S = \int_0^{\varepsilon_p} \sigma d\varepsilon + \int_{\varepsilon_p}^{\varepsilon_{\max}} \sigma d\varepsilon \qquad (5)$$

Here, W is sum of energy of reversible deformation (W_p) and dissipated energy on plastic deformation) (W_s).
Dependence "σ - ε" is approximated by parabolic function of the 6th order $\sigma = \sum_{i=1}^{6} a_i \cdot \varepsilon^i$, then energy of absorption is determined with formula:

$$W = \sum_{i=1}^{6} \frac{a_i}{i+1} \cdot \varepsilon_p^{\,i+1} \qquad (6)$$

Given dependencies allows setting up relation between fatigue and remaining life of geosynthetic materials.

4 TEST REUSLTS AND ANALYSES

4.1. Evaluation of testing results of grids

Fatigue testing results for the materials, made of polyester, polyvinyl alcohol and glass fibre is given at Fig. 2.
The best resistance to multiple loading showed GR-1 PET materials with the basis of polyester fibres. More intensive strength decrease at repeated loading occurs for grid GR-2 PVA. The lowest resistances at fatigue have grids made on the basis of glass fibre.
It is not possible to determine endurance ratio for glass grids, so as they are failed fast just after a few hundred cycles.

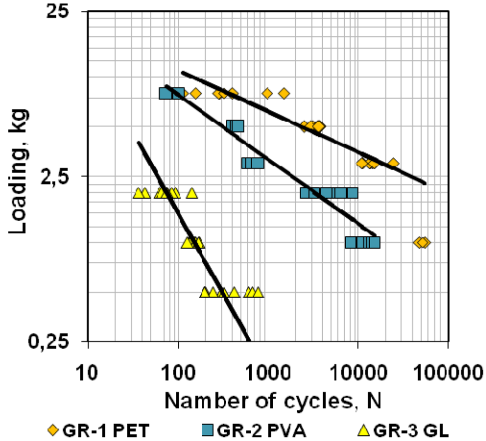

Figure 2. Resistance to influence of many cycled loading of 3 types of grids: ◊- GR-1 PET , ○ - GR-2 PVA, Δ - GR- 3 GL.

Diagrams "loading-elongation" after specified number of loading cycles is given at Fig. 3, and results of determination of endurance characteristics in Table 3.

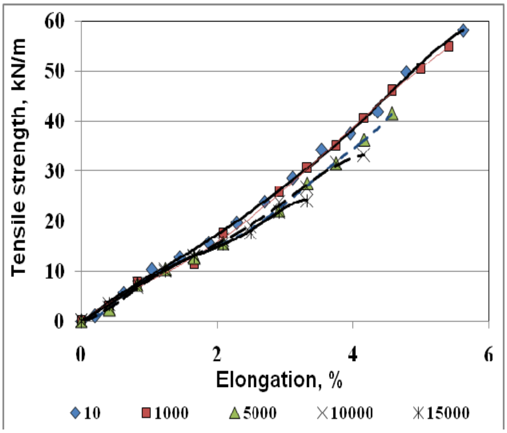

Figure 3. Diagrams "tensile strength-elongation" after given number of cycles of repeated loading (10, 1000, 5000, 10000, 15000) for GR-2 PVA grid.

Fibre structure changes in the process of fatigue testing can be seen at Fig. 4. In case of ideal smooth surface of fibres, absence and insignificant number of cycles of loading application to breaks occurrence and numerous defects in the form of fluffiness at the surface are observed after 15 000 cycles.

Table 3. Dependence of endurance ratio after given number of loading cycles

Number of cycles		5000	10000	15700
Endurance ratio for GR-1 PET	K_M_*PET*	0.80	0.73	0.48
	K_B_*PET*	0.75	0.74	0.47
	K_W_*PET*	0.60	0.54	0.23
Number of cycles		5000	10000	15000
Endurance ratio for GR-2 PVA	K_M_*PVA*	0.72	0.57	0.42
	K_B_*PVA*	0.79	0.72	0.57
	K_W_*PVA*	0.51	0.44	0.26

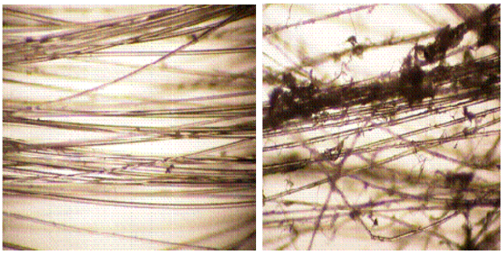
a) b)

Figure 4. Fibre appearance with enlargement in 400 times a) after 1 000 loading cycles, b) after 15 000 loading cycles. Fibre diameter is 0.0188 mm.

4.2 Determination of geotextiles resistance to influence of cyclic loading.

Endurance testing of nonwoven thermally bonded geotextiles – GT – 1 and GT – 2 was hold after impact of 10 000 loading cycles in the amount from 5 to 20% from breaking load (Fig. 5). Sample parameters: sample length GM is 370 mm, width is 50 mm.

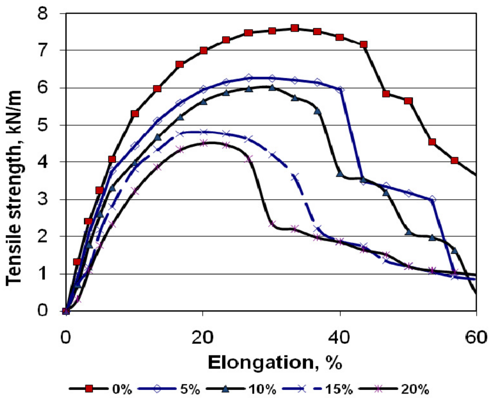

Figure 5. Change of tensile strength from elongation of the samples at different loading for a) GT – 1 - 1) without fatigue, 2) 5 %; 3) 10%; 4) 15%; 5) 20% from breaking load after 10 000 cycles.

Comes under notice exhaustion of strength resource and decrease of material deformation (the area is limited by the curve "pressure- relative deformation") under influence of different levels of cyclic loading that can be characteristic of material resistance at influence of technical transport and in service.

Change of energy of absorption of geotextiles after 10 000 loading cycles practically decreases linearly depending on loading in percents from breaking load (Tabl. 4).

Table 4. Change of geotextile properties after 10 000 loading cycles

Loading from breaking	Strength, kN/m		Elongation %		Energy of absorption, кN/м
	max	break.	мax	break.	
GT – 1					
0%	8.4	8.1	33.4	43.4	3.01
5%	6.3	5.9	30.1	40.1	2.04
10%	6.0	5.4	30.1	36.7	1.70
15%	4.8	3.6	16.7	33.4	1.25
20%	4.6	4.1	23.4	26.7	0.87
GT – 2					
0%	12.1	12.1	56.8	56.8	4.27
5%	7.5	7.1	23.4	33.4	2.63
10%	5.2	4.6	16.7	26.7	0.93
15%	3.2	1.8	16.7	20.0	0.29

5 CONCLUSIONS

Fatigue testing results are opposite in full to the results of the tear resistance testing. At multiple loading glass grids are destruction catastrophically. Materials made of polyvinyl alcohol have lower fatigue resistance than materials on the basis of polyester fibres.

Thus, developed method allows:

- to determine limit multiple cyclic loading, when geosynthetic materials preserve strength more than 50%;
- to compare geosynthetic materials in relation to fatigue and endurance to multiple cyclic loading;
- to choose geosynthetic materials for purposive application in service subject to their resistance to multiple cyclic loadings.

In order to reduce spread of testing results it is necessary to sort out separate samples before testing on endurance according to characteristics of surface density or structure.

REFERENCES

Koerner R.M. 2005. *Designing with Geosyntheics.* 5th Edition, New Jersey, USA.

SOU 45.2-00018112-025: *Geosynthetic materials. Methods of tests*. 2007. Kiev, Ukravtodor.