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Relationship Between Structure and Viscoelastic Properties of Geosynthetics

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Abstract. In this work, a study on viscoelastic properties of geosynthetic materials used in civil engineering is presented. Six samples of geofabrics and geogrids with different structures including woven geotextile fabric, nonwoven geotextile fabrics, warp-knitted geogrids and extruded geogrid were investigated. The tensile properties of geosynthetics including tensile strength, strain at maximum load and tensile load at specified strain have been determined. The creep and relaxation tests were carried out. The structure type was found to significantly affect the viscoelastic properties of the geosynthetics materials. In the article some results of numerous conducted tests are presented, analyzed and may be used to preselection of geosynthetics materials.

1 Introduction

Geosynthetic materials are widely used in civil engineering applications presenting a special class of modern building structural materials [1-2]. They have found a number of applications and have a great potential in various fields of civil engineering, including the construction of engineering structures, road construction, railway construction, hydraulic engineering, building of sports facilities, etc. Historically this type of materials used in the largest quantities in road construction. Most geosynthetics are man-made materials made from various types of polymers both natural and synthetics used in environmental, transportation and civil engineering projects. Geosynthetics are used in one or more of the following functions: separation; reinforcement; protection; filtration; drainage; erosion control; barrier. Along with the traditional structural materials such as steel, concrete and other building materials, they have high strength properties. However, apart from this positive structural characteristic, geosynthetics have exceptional viscoelastic properties. These ones become a problem when assessing the long-term strength of the structure due to variability force and deformation of material over time. The viscoelastic properties are developed in the area of non-destructive mechanical effects and affect the mechanical performance of geosynthetic materials.

Geosynthetics are a class of materials that have exceptional time-dependent mechanical properties. In many practical cases, geosynthetics and articles made of them are subjected to loading or elongation and such a stressed-strained state may remain for a long time. As experience has shown, the deformation stiffness and consequently their response to subsequent mechanical effects are essentially a function of time and therefore these properties must be taken into account in various tasks. The time-dependent mechanical properties of geosynthetics can be determined in various modes

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of loading and elongation: creep and recovery tests, stress relaxation and inverse stress relaxation tests as shown in Fig. 1 [4].

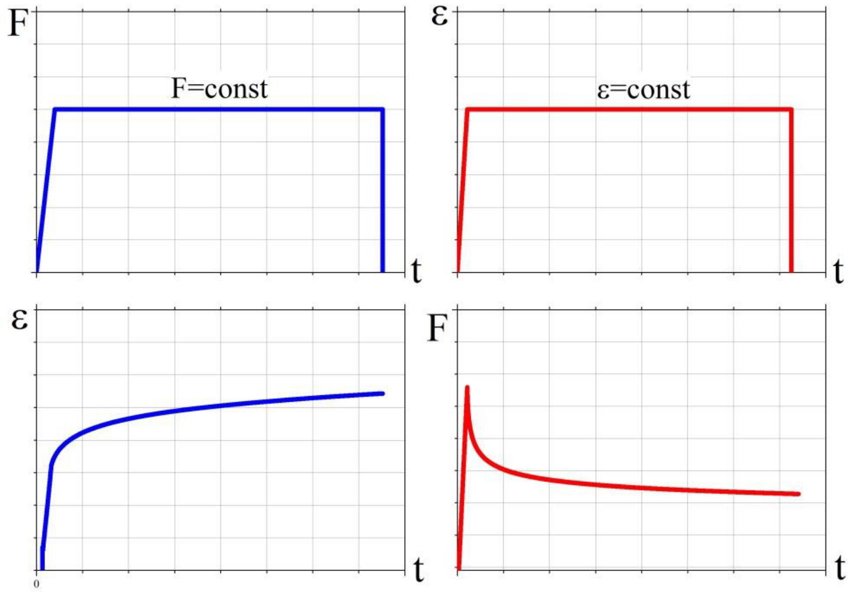


Figure 1. Test mode: (a) creep; (b) stress relaxation.

The viscoelastic properties of geosynthetics have been investigated in detail by many authors. Geosynthetics are characterized by the elastic and viscoelastic properties that bring some difficulties to the design of structures using geosynthetic materials [11]. The study of the properties of geosynthetic materials, which appear over time, is not less important than short-term tests. Viscoelastic properties are also one of the most important assessment criteria of evaluating long-term strength of geosynthetic materials used as reinforcement [12, 13]. The greatest interest in estimation long-term structural durability of geosynthetic materials represents the process of creep, because in real operating conditions a geosynthetic material is subjected to a constant load [14, 15]. Although in some applications the functions of geosynthetics can experience the processes of reducing the internal forces due to the fixation of their size, for example, by anchoring. To determine the stress relaxation throughout the experiment, a constant deformation must be set [16]. In articles [17-20] an investigation of creep based on the measurement of the sample elongation as a function of external tensile force was done. Tests were carried out at different levels of an applied load. Generally, the load steps are chosen as a percent value by maximum tensile strength of geosynthetic material in a particular range, for example, in 5, 10, 20, 30, 40, 50 and 60 % of maximum tensile strength [21].

There are a wide variety of methods in practice for the determination of creep of geosynthetic materials. The simplest method to determine creep of geosynthetic materials is the direct measurement of specimen deformation over a long period of time. The duration of measurements, as a rule, is thousands and tens of thousands of hours [1, 2]. In [14], the creep experiment was conducted during 6 years. Data obtained from such experiments can be used to assess the long-term deformation of geosynthetic material that haven't exceed the maximum allowable deformation [13,14]. The main disadvantage of such measurements is the period of time that requires special equipment, allowing conducting such tests with a big number of samples. The use of such systems significantly increases the cost of testing and doesn't always guarantee the achievement of the reliable result.

Along with direct measurements of the creep accelerated test methods become popular. They allow to activate deformation processes in time by load or elevated temperature [22-25]. Creep measurements carried out with the use of such techniques can significantly reduce the test time by several orders of magnitude and obtain satisfactorily predicted curves. The use of such methods provides a significant advantage in experimental studies, however, requires using of expensive specialized equipment – thermochamber. Besides, these methods depend on the testing conditions and the type of investigated geosynthetic material. So, for example, varying temperature in the step of 1-2 ^{o}C leads to substantial differences in the shape of the resulting creep curves.

Methods of creep determination are rather contradictory. On the one hand the direct measurement of creep has an advantage in determining the long-term strength, because it eliminates the influence of various factors, e.g. temperature. On the other hand such tests are time-consumption. In addition, sometimes a large part of materials, which is intended for use in the project, may be rejected on the basis of experimental data. At the same time, application of accelerated tests doesn't always guarantee an adequate outcome. In our opinion, one of the major disadvantages in determining the viscoelastic properties of geosynthetic materials is the lack of express method that would allow identify the viscoelastic properties of geosynthetics for a short period of time. Such information may be used for preliminary selection of geosynthetic material and for more optimal planning of experimental work on the determination of viscoelastic properties. This also may allow reducing cost of tests significantly.

2 Experimental

2.1 Materials

The objective of this work was studying the viscoelastic properties of geosynthetic materials of various structures at short-term measurements in creep and relaxation stress. The main factors that affect the viscoelastic properties of geosynthetics depend on the structure of the material, type of weave in the fabric, raw materials used, etc. For the experiment, six different types of geosynthetics including geotextile fabrics and geogrids have been investigated. Table 1 summarizes the designation and characteristic of samples investigated.

Table 1. Experimental data.

№	Sample Designation	Structure	Raw materials	Surface density, g/m^2
1	1-GTX-PET	Woven geotextile fabric	Polyester	400
2	2-GTX-PP	Nonwoven needle-punched geotextile fabric	Polypropylene	160
3	3-GTX-PP	Nonwoven thermobonded geotextile fabric	Polypropylene	160
4	1-GGR-PET	Warp-knitted geogrid with layer of nonwoven fabric, mesh size: 35*35	Polyester	285
5	2-GGR-GL	Warp-knitted geogrid, mesh size: 40*40	Glass, Treatment: Bitumen polymer	300
6	3-GGR-PP	Extruded geogrid, mesh size: 40*40	Polypropylene	530

They include three geotextile samples and three geogrid samples. Geotextile samples consist of woven fabric (denoted as 1-GTX-PET), which have a mass per area of 480 g/m^2 functioning as separation and reinforcement fabric and made of polyester and two types of nonwovens including needle-punched fabric (denoted as 2-GTX-PP) and thermobonded fabrics (denoted as 3-GTX-PP) which have a mass per area of 160 g/m^2 and made of polypropylene functioning as filter and protection layer. Geogrid samples consist of warp-knitted geogrid (denoted as 1-GGR-PET) with layer of nonwoven fabric, the components are sewn together, which have a mass per area of 285 g/m^2 functioning as reinforcement and made of polyester; warp-knitted geogrid (denoted as 2-GGR-GL) made of glass fibers treated with bitumen polymer and extruded plastic geogrid (denoted as 2-GGR-PP) made of polypropylene functioning as reinforcement.

2.2 Tensile test

The tensile test was performed on an Instron 5965 tensile machine. The determination of tensile behavior of geotextiles under uniaxial loading is performed by standard method named strip test. The stress-strain diagrams were obtained with a 100-mm sample base and clamp movement of 100 mm/min. Testing of geogrids was conducted on single ribs. No fever than five specimens in the machine direction (MD) were tested. It should be noted that tensile strains were calculated from crosshead displacement. The tensile diagrams of samples investigated in MD and CMD are presented in figures 1 and 2 respectively. Using the test results, the relative values of the tensile strength normalized to the sample width; strain at maximum load and tensile load at specified strain (2%) were determined from stress-strain curves.

The tensile strength of a geosynthetic is expressed in kilonewtons per meter (kN/m) directly from the data obtained from the tensile testing machine as follows:

$$T_{max} = F_{max} \cdot c \tag{1}$$

Where F_{max} is the recorded maximum load, in kilonewtons; c is the specimen width.
For woven and nonwoven c is determined as follow:

$$c = \frac{1}{B} \tag{2}$$

where B is the specimen nominal width, in meters.
For geogrids c is determined as follow:

$$c = \frac{N_m}{N_s} \tag{3}$$

where N_m is the minimum number of tensile ribs within a 1 m width of the geogrid; N_s is the number of tensile elements within the test specimen.

2.3 Creep and stress relaxation tests

Creep tests and stress relaxation tests are usually carried out at several levels of a given load in percentage of the maximum tensile strength of the sample [26]. In this work the samples were tested for creep and stress relaxation at the load level of 30% of T_{max}, that provides a comparable test for materials of different structures. The test time was 3600 s.

3 Results and discussion

3.1 Tensile properties

Test results of tensile strength, strain at maximum load and tensile load at specified strain (2%) are shown in Figure 2a, Figures 2b, and 2c respectively. The obtained data show that almost all of the investigated structure geosynthetics are isotropic in strength, except for sample 1-GTX-PET. This sample has the greatest strength in the machine direction. Samples of nonwoven fabrics exhibit highest elongation. This sample is thermally bonded fabric (3-GTX-PP) has a similar tensile strength to the needle-punched fabric (3-GTX-PP) at a lower surface density. It should also be noted that glass-fiber geogrid (2-GGR-GL) has the lowest elongation. As it can be seen from the results geosynthetics have a wide range of mechanical properties.

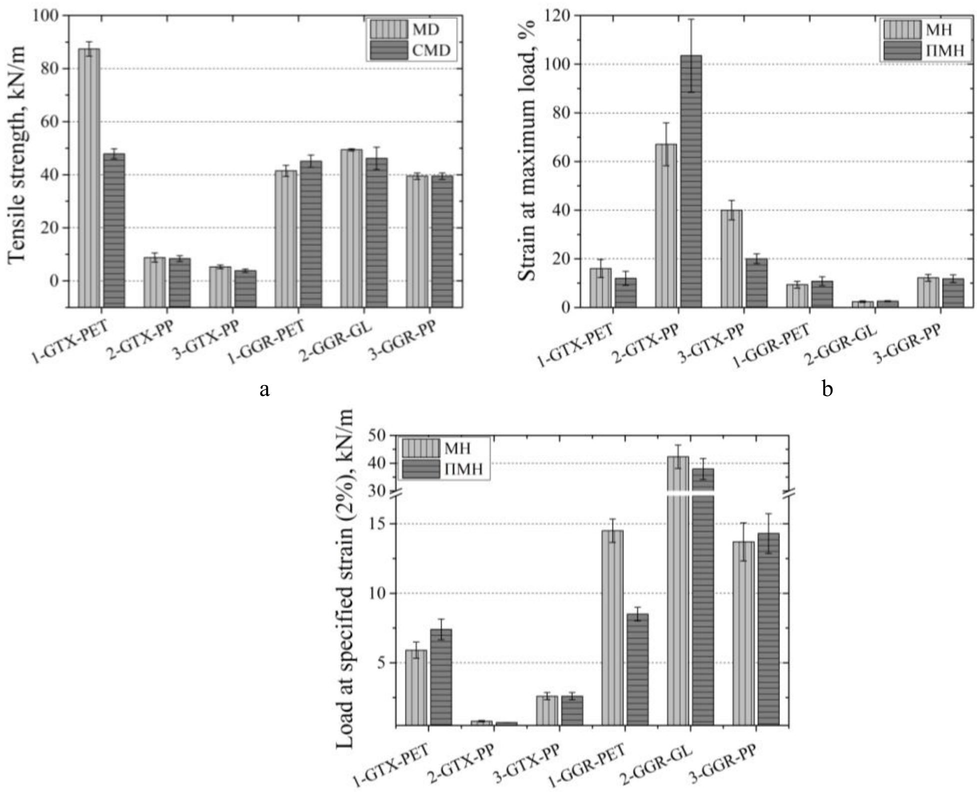


Figure 2. Results of tensile test: tensile strength (a), strain at maximum load (b) and tensile load at specified strain of 2% (b).

3.2 Viscoelastic properties

Creep and stress relaxation curves under load level of 30% of the T_{max} for all of the samples are shown in Figure 3a and 3b, respectively. From these curves it is clear that all of the materials exhibit viscoelastic properties. Samples of nonwoven fabrics show the greatest creep due to their relatively high compliance. At the same time the stiffest sample of glass-fiber geogrid (2-GGR-GL) showed no change in strain with time. Its slight increase in strain may be caused by creep of a bituminous coating adhesion to glass fiber. The behavior of the samples during stress relaxation test was found similar.

In order to evaluate the effect of the structure on the viscoelastic properties of geosynthetic materials. Two characteristics of creep and stress relaxation were analyzed. The creep behaviour was characterized by creep rate (s^{-1}), increment of deformation over time and determined by the following equation:

$$\dot{\varepsilon} = \frac{\varepsilon(t_2) - \varepsilon(t_1)}{t_2 - t_1} \quad (4)$$

where $\varepsilon(t_i)$ is the creep strain at i - measured point, %; t_i is the time, h.

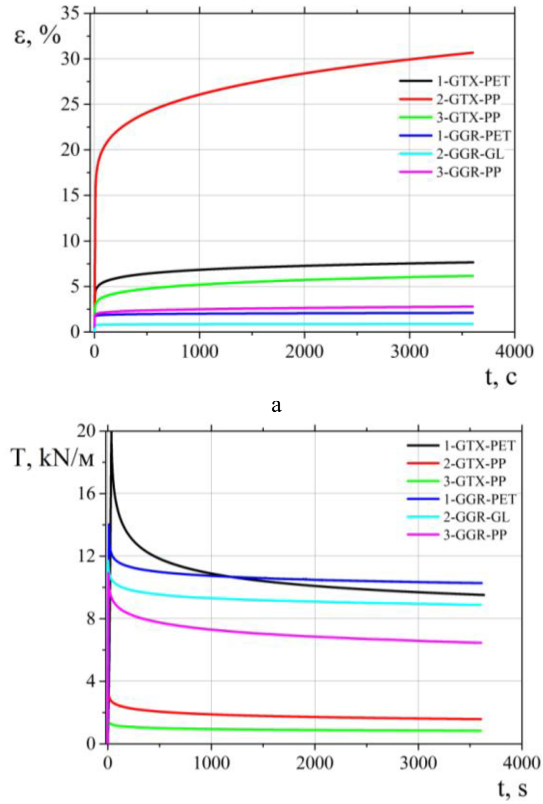


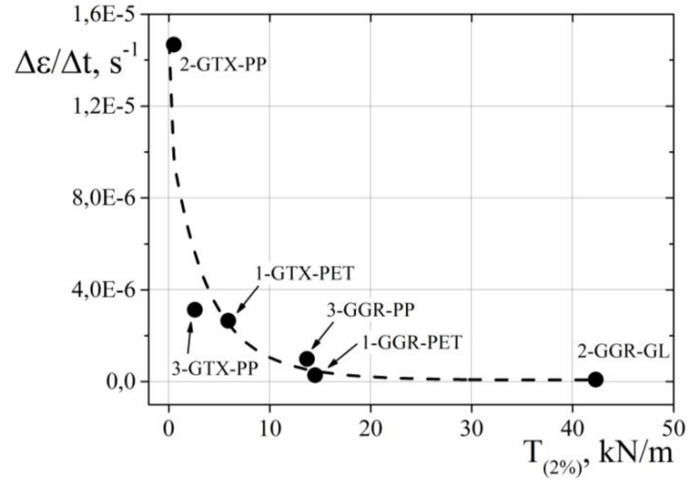
Figure 3. (a) test creep; (b) stress relaxation.

To characterize the behavior of the samples in the relaxation, the residual stress was determined by the following equation:

$$T_r = \frac{T_к}{T_0} \tag{5}$$

where$T_к$ –force in the sample at t = 3600 s (kN / m), T_0 - initial sample load (kN/m).

The obtained results have been plotted compare to the load at an elongation of 2%. Figure 4a shows the variation in creep rate as a function of $T_{2\%}$. The obtained data show that with increasing the stiffness of the material, creep rate decreases dramatically. The more compliance material, for example, samples of the nonwoven fabrics (3-GTX-PP and 3-GTX-PP), have less resistance to creep. The minimum creep rate, and as a result, the maximum stiffness has glass-fiber geogrid (2-GGR-GL). Also samples of other geogrids have a good creep resistance, which determines their reinforcement function. An exponential curve can be fit to resulting plot. The plateau was found at an infinitely large stiffness of the material. Figure 4b shows the results of calculations of residual relaxation stresses of the experiment, depending on the $T_{2\%}$. The decreasing loss of stress in time was found with the increase of the stiffness of material. Samples of geotextile show greatest loss of stress. Further, with an increase in stiffness of the sample, a decrease in the relaxation time was observed. The test results on the relaxation are well-correlated with the creep test. Samples with high compliance have a high creep rate and a significant reduction in stress at a given constant strain, and vice versa, the most severe examples of geogrids well withstand mechanical stress. It should also be noted that the samples of nonwoven fabrics used as a function of separation and/or filtration, and not reinforcement. However, an excessively high strain can lead to fracture in their structure.



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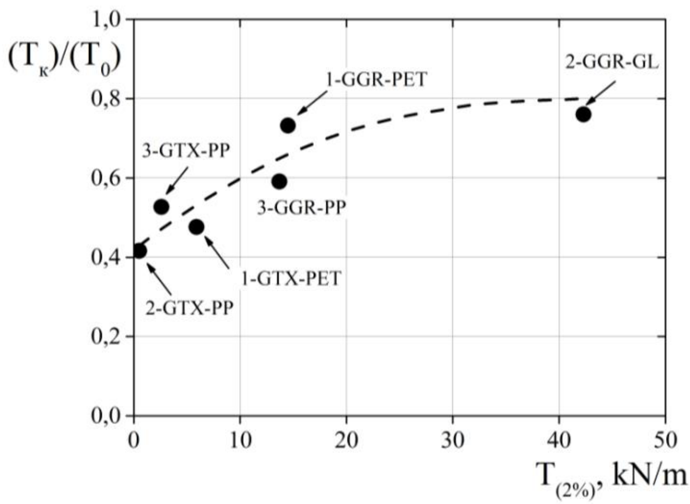

b

Figure 4. Dependences of: (a) the creep rate; (b) residential stresses relaxation of the experiment depending on the $T_{2\%}$

4 Conclusions

The tensile and viscoelastic properties of various geosynthetic materials including woven geotextile fabrics, nonwoven geotextile fabrics, warp-knitted geogrids and extruded geogrids were determined.

The viscoelastic properties were investigated with laboratory measurements in creep and stress relaxation processes at the load level of 30% of maximal tensile strength. The tensile properties of geosynthetics including tensile strength, strain at maximum load and tensile load at specified strain have been determined. It was found that the viscoelastic properties of various geosynthetic materials significantly vary.

Dependences of the creep rate and residential stresses relaxation of the experiment depending on the $T_{2\%}$ was determined. Results shows that the structure and polymer type significantly affect the viscoelastic properties of the geosynthetics materials. It can be used for goal-oriented solution of problems of the manufacturing technology of geosynthetic materials and the study of their properties in use.

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