

doi: 10.18720/MCE.76.22

## Creep behavior of geosynthetics by temperature accelerated testing

## Ползучесть геосинтетических материалов при ускоренных температурных испытаниях

**S.G. Srungeri,  
N.N. Alekseev,  
I.A. Kovalenko,  
O.N. Stolyarov,**  
*Peter the Great St. Petersburg Polytechnic  
University, St. Petersburg, Russia*

**Студент С. Срунгерри,  
студент Н.Н. Алексеев,  
студент И.А. Коваленко,  
канд. техн. наук, доцент О.Н. Столяров,**  
*Санкт-Петербургский политехнический  
университет Петра Великого,  
г. Санкт-Петербург, Россия*

**Key words:** geosynthetics; viscoelastic properties; creep; step isothermal method; prediction

**Ключевые слова:** геосинтетические материалы; вязкоупругие свойства; ползучесть; метод ступенчатых изотерм; прогнозирование

**Abstract.** Predicting the creep behaviour of geosynthetics is very important for determining the design life of geosynthetic based structures. In this paper, geogrids and geotextiles made of two major types of synthetic polymer namely, polyester and polypropylene were investigated for accelerated creep test. In short-term measurements, creep was accelerated by temperature in equal steps. As a result of the analysis, predicted creep curves for up to 30 years of design life were obtained by the stepped isothermal method. The predicted creep deformation for a period of 30 years has been analyzed. The geogrid samples made of polyester showed better creep resistance compared to polypropylene geogrids. Geosynthetic materials made of polyester are more suitable for various loaded applications as a reinforcement function.

**Аннотация.** Прогнозирование ползучести геосинтетических материалов является необходимым для определения расчетного срока службы конструкций с их применением. В данной работе были проведены испытания на ползучесть георешеток и геополотен, изготовленных из двух основных типов синтетических полимеров - полиэфира и полипропилена, используемых при производстве геосинтетических материалов. Прогнозируемые кривые были получены с помощью метода ступенчатых изотерм. При кратковременных измерениях деформация ползучести ускорялась при помощи увеличения температуры равными шагами. Проведено сравнение прогнозируемой деформации ползучести исследуемых образцов геосинтетических материалов на период до 30 лет. Образцы геосинтетических материалов из полиэфира показали лучшую устойчивость к деформации ползучести по сравнению с образцами, изготовленными из полипропилена. При практическом применении геосинтетические материалы из полиэфира являются предпочтительными при использовании в функции армирования.

### Introduction

In world of innovation and rapid development, the changes occurring in the area of construction with respect to material properties of engineering structures is an important aspect of economical and efficient construction. Geosynthetics are polymeric products used to improve or resolve the problems in various civil engineering and geotechnical applications [1, 2]. They find there usage in almost all the applications of civil engineering [4, 14], such as geotechnical, hydraulic, transportation, environmental, and developmental applications such as roads [3, 6, 8, 10–12], airfields, embankments [9, 13, 16], retaining structures [5, 7, 15], reservoirs, canals, dams, erosion control, sediment control, landfill liners, mining, aquaculture and agriculture. In addition to the conventional structural materials like steel, concrete and other building material, geosynthetics find application in all fields of civil engineering due to their unprecedented high performance properties. With the recent development of geosynthetic reinforcement, the scope of usage has increased fourfold as it has both economical and eco-friendly benefits. Therefore, different forms of geosynthetic reinforcement such as geotextile, geogrid and geosynthetic strip reinforcement are developed.

Срунгерри С., Алексеев Н.Н., Коваленко И.А., Столяров О.Н. Ползучесть геосинтетических материалов при ускоренных температурных испытаниях // Инженерно-строительный журнал. 2017. № 8(76). С. 255–265.

The viscoelastic properties of geosynthetics have been widely investigated by many researchers in the last three decades. Over the years, the accelerated test methods have gained popularity for predicting the long-term properties of geosynthetics materials along with conventional creep tests [18–24]. These methods include SIM – Stepped Isothermal Method [17, 25–27] and TTS - Time Temperature Superposition Method [28]. The viscoelastic properties mainly indicate the long-term strength of geosynthetic materials due to uneven forces resulting the deformation of the material over time. It is of utmost importance in evaluating the long-term structural durability of geosynthetic materials depicting the process of creep, as it is subjected to constant load in real working conditions. In some of the implementations, geosynthetics undergoes the process of reduction of internal forces due to fixation of their structure and dimensions.

Creep accelerated temperature test generally includes TTS and SIM tests. TTS is the concept; by increasing the temperature accelerates the creep rate. This acceleration reduces the time needed for a given amount of creep to occur. Thus, elevated temperature creep experiments can achieve the result in a short time, which can take many days, weeks or even years, to accomplish at laboratory-ambient temperature. On the other hand, SIM is a single specimen method in which the temperature is varied gradually for a given time at constant load, where the changes in deformation are measured as a function of time. Both the tests are used for characterization of viscoelastic properties of polymeric materials [28]. Lee et al [32] stated that the creep reduction of geosynthetics can be determined through conventional creep test and accelerated creep tests. They tested geotextiles made of coated PET yarns in TTS and SIM modes and the test results vary under different use of data from various methods. Zornberg et al [33] conducted a temperature-accelerated tensile testing program to characterize a woven polypropylene geotextile. Their test program was divided into three major steps and included: loading tensile tests at room and elevated temperatures; conventional and accelerated creep tests; and rapid loading tensile tests conducted after sustained creep loading. 8-hours long temperature accelerated test was used to predict the geotextile behavior for periods beyond 100 years at various load levels using SIM test. As a result, a new approach was developed to quantify the residual tensile strength of geosynthetics. Hsiesh et al [17] studied five different types (woven and warp-knitted) of polyester geogrids with tensile strengths ranging from 100 to 400 kN/m by conventional and SIM tests. They concluded that the results of SIM tests require a minimum of 6 to 8 steps to predict the creep behavior beyond 75-years. In addition, they showed that knitted geogrids showed higher creep strains than woven geogrids. Mok et al [34] presents the results of compressive creep deformations beyond 100,000 h of two types of geonets. S.R. Allen [35] used SIM of accelerated compression creep to measure the time dependent loss of thickness and porosity (and thus flow) of planar geosynthetic drains. He proposed some changes in testing approach of the existing product specification, design procedures and economy of cost. As a result, he concluded that there is opportunity to reach for real-time flow tests at pre-established time-dependent thicknesses and presents the test results with special emphasis on thickness. Zou et al [26] presents the creep behavior and stress relaxation of high-density polyethylene (HDPE) geogrid at four different load levels of 20%, 40%, 50% and 60% of ultimate tensile strength. Numerical modeling using finite element method has also been used to assess the impact of geogrids on the long-term performance of reinforced soil retaining wall on the deep soft soil foundation. The results shows the constitutive model to ensure the stability of the retaining wall and indicates that the working stress of geogrids should be less than 40% of ultimate tensile strength, and the high strength geogrids should be adopted in the middle of the wall or the spacing of geogrid reinforced layers should be reduced. The deep soft soil foundation, which is treated by piles, can ignore the creep behavior of soft soil. Hsuan et al [28] has studies and analyzed the creep behavior of HDPE geogrids using both TTS and SIM accelerated creep tests. They concluded stating that the application of the SIM test is well suited for PET geogrid whereas for HDPE geogrids, the application of SIM has not been well established. The study confirmed that values for temperature steps of 7°C and a dwell time of 10,000 seconds are suitable for HDPE geogrids and the results of primary and secondary creep at 10%, 20%, 30% and 40% of ultimate tensile strength. Jin et al [29] presented the creep property of geogrids measured using three methods; conventional tests were carried out in comparison to TTS and SIM. All three methods showed similar behavior, but it turned out that there is more voltage to the SIM method at a higher temperature. Reducing coefficients for long-term strength and limited deformation were similar in each method. Tong et al [30] evaluated the creep tests were carried out for polymeric geogrids at various load levels and at an ambient temperature of 40 and 60 °C. Experimental results showed that the ambient temperature has a significant effect on the geogrid creep behavior, while the geogrid also shows a significant dependence of the load level. A certain creep strain during the first hour was greater than the total creep strain by about 80%. In the end, the specified parameters are proposed for predicting long-term creep behavior. Along with thermoplastic yarns and fabrics, in [31] the SIM test was applied to aramid fibers. However, the behavior of aramid fibers under the high temperature is differing to thermoplastic fibers. With increase of temperature, the shrink of fibers occur. Therefore, the correction in the form of vertical shift should be applied.

Creep accelerated test methods (SIM and TTS) are often used as it significantly reduces the test time by several order of magnitude and obtain satisfactory results and predicted curves. The use of this method is has many advantages in experimental analysis but it requires specialized equipment like computed controlled universal testing machines with thermo-chamber.

The aim of this work is to predict the creep deformation of the major types of geogrids and geotextiles using an accelerated test method. The objective of this work included:

- 1) study the creep of geosynthetic samples by the method of temperature acceleration using the stepped isothermal method;
- 2) comparative analysis of geosynthetic samples having different structure;
- 3) determination of characteristics in the temperature acceleration of creep deformation of geosynthetic samples made of PET and PP;
- 4) prediction of creep deformation and determination of the effectiveness of their practical application up to 30 years of the estimated service life, depending on the type of geosynthetics and the type of raw material.

## *Experimental materials and methods*

### *Materials*

This paper presents the work on two major types of geosynthetics, geotextile and geogrids. The geotextile fabrics include woven fabric made of PP slit yarn (indicated as 1-GTX), used majorly as reinforcement fabric and nonwoven thermobonded fabrics made of PP fibers (denoted as 2-GTX) used majorly as filter and separation of material layers. The geogrids studied in this work find application in various civil engineering structures, and are manufactured by textile and plastic processing technologies. The main purpose of the geogrid is the reinforcement of structures. The test sample 1-GGR is a geogrid with a cell size of 35 by 35 mm, made of high-strength polyester yarns. This sample further includes an additional nonwoven fabric. Test samples 2-GGR and 3-GGR are manufactured using plastic processing technology. The orientation of the samples reinforcing ribs is in bi-axial and uni-axial direction respectively. In case of biaxial stretched geogrid, the nodal joints of the geogrids form peculiar stress concentrators that can affect the properties of the geogrid. In unidirectional geogrid, longitudinal ribs are connected by additional non-load bearing ribs. The sample 4-GGR is a woven geogrid with 22 x 22 mm mesh cells, which is additionally coated with PVC to increase dimensional stability. The characteristic of the investigated samples are listed in Table 1. These two types of polymer are dominant in the market of geosynthetics.

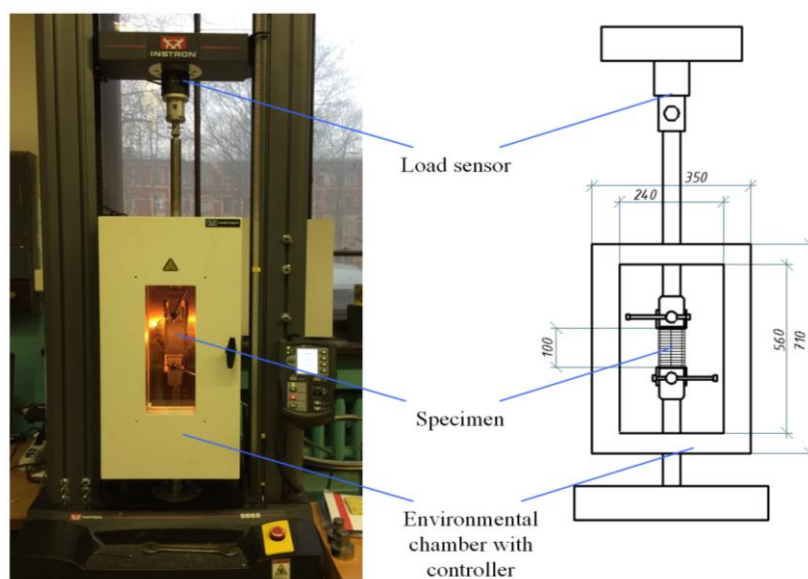
**Table 1. Characteristics of the geogrids**

	Sample designation	Structure	Raw materials	Mass per unit area, g/m <sup>2</sup>
1	1-GTX	Woven slit yarn geotextile fabric.	PP	400
2	2-GTX	Nonwoven thermobonded geotextile fabric.	PP	90
3	1-GGR	Warp-knitted geogrid with layer of nonwoven fabric, mesh size: 35x35	PET	285
4	2-GGR	Biaxial extruded geogrid, mesh size: 35x35	PP	530
5	3-GGR	Uniaxial extruded geogrid, mesh size: 42x42	PP	294
6	4-GGR	Woven PVC coated geogrid, mesh size: 22x22	PET	250

### *Methods*

The testing machine used for conducting the SIM analysis for the materials mentioned in the above table is computer controlled high temperature electronic universal testing machine Instron 5965 with thermo-chamber, which enables us the mechanical testing of materials across a range of temperatures, humidity and caustic conditions which are ideal for conducting tension, compression testing of various materials. It also features a temperature-controlled chamber that is mounted to the back panel for convenient access in which hot and cold air is forced to circulate and re-circulate around the specimen to

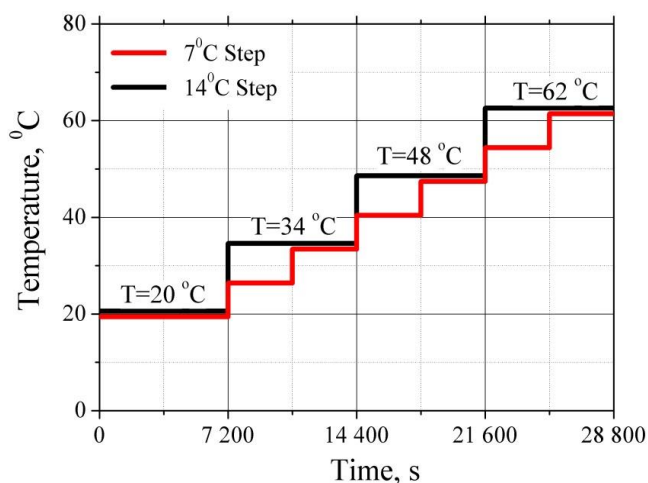
offer thermal stability (Figure 1). The front panel clearly displays the set time and loading points. Additionally, air circulates around the outer skin of the chamber to keep it neat and cool.



**Figure 1. Experimental set-up**

Considering the equipment is calibrated and ready for testing. The environment for testing is dry as the effect of elevated temperature is to reduce the humidity of ambient air without special control. The standard reference temperature is taken as  $20 \pm 1$  °C. Utmost importance has to be taken to ensure uniform thickness of the test specimen. The gauge length of the specimen was taken as 100 mm. Time, temperature, displacements and tensile load data were collected at a minimum rate and recorded using an automatic data acquisition system on the computer and were analyzed. Data were collected every second to adequately capture the strain response. The temperature steps for SIM are taken at 7°C for PP samples and 14°C for PET samples as it is recommended in [36]. In this case, the readings are taken for the temperature steps as per the specimen and creep curves were obtained at the level of 30% of ultimate tensile strength.

Figure 2 indicates the model of temperature steps taken in this analysis. In order to provide uniform testing results and comparison of sample results, the above temperature steps was adapted as mentioned in [36]. Here the black and red line in the graph indicates time vs. temperature steps for PET and PP samples respectively. At room temperature, i.e. 20°, all the samples are under constant load for a span of 7200 seconds (two hours) and the next six hours the samples were exposed to higher temperatures. The creep strain behavior of the sample was noted during constant load portions of the test within the time.



**Figure 2. Experimental temperature steps**



The computation procedure for SIM is indicated in Figure 3. This procedure includes four basic steps.

1) Stress and creep strain vs. linear time: This graph shows the raw data of the specimen tested under constant applied load. The creep strains are shown in the figure as a function of time at each temperature steps. The different color indicates the raw data at each temperature exposure scaled to its reference temperature of the specimen starting from room temperature 20 °C to 62° C.

2) Creep modulus vs. log time: The creep strains are shown in the figure as a function of time at each temperature steps. A shift time is selected and tabulated so that the final slope of strain time curve at a specific temperature step matches the initial slope of the strain time curve at the subsequent temperature step. The creep data at each temperature exposure is scaled so that strain rate corresponds to that of the reference temperature. The scaled data is plotted on a semi-logarithmic scale as presented.

3) Master creep modulus vs. log time after rescaling and applying horizontal shift factor. The scaled creep curve segments correspond to the reference temperature as shown in the figure. Appropriate horizontal shift factor was applied. The curve at 20° C was selected as a basis point and then the following curves were shifted along the x- (time) axis to obtain smooth master curve.

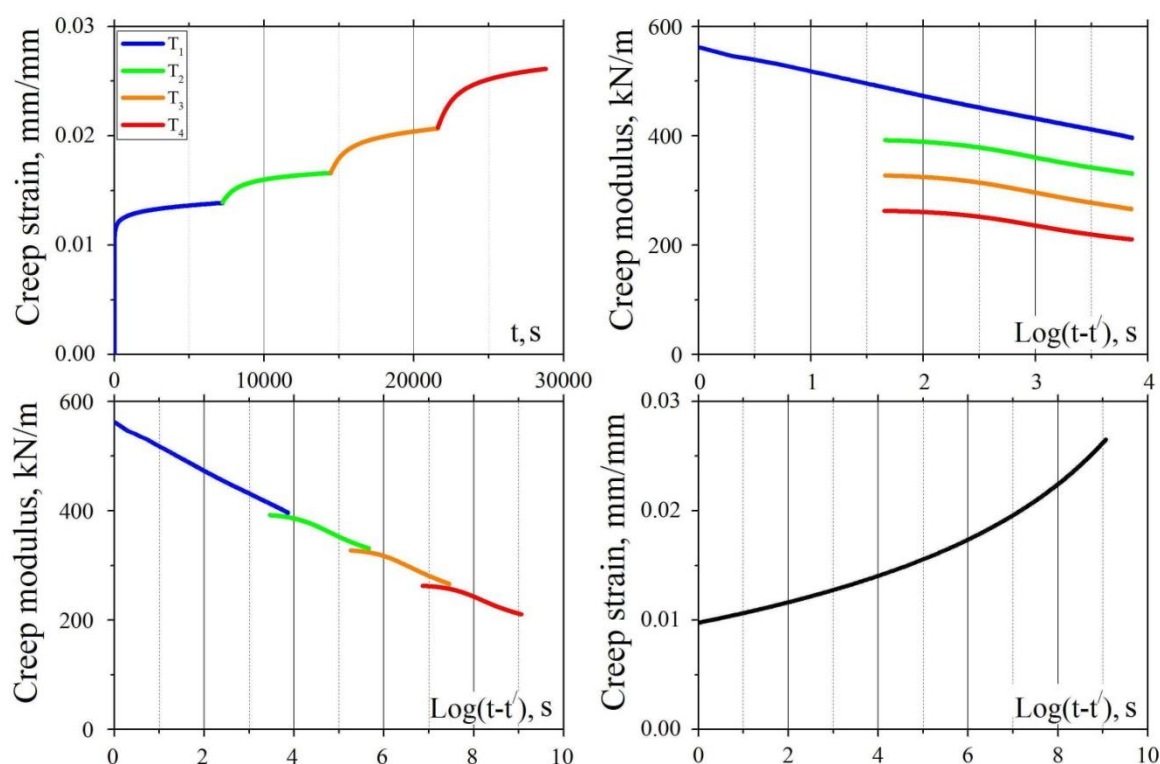


Figure 3. Stepped Isothermal method

Master creep strain vs. log time after rescaling and applying horizontal shift factor: Master curve can be defined by composing into a single curve of creep responses measured at different isothermal exposures during SIM testing. Master curve was obtained superimposing the creep strain responses measured at different temperatures by horizontal shifting. The rescaling for the shifting steps was done accordingly to achieve a smooth master curve.

In order to evaluate the long-term creep properties of various types of geosynthetics, the load level of 30% of  $T_{max}$  was chosen and temperature accelerated time was set at eight hours. As it was recommended in [33], these experiments parameters gave reliable results for comparative analysis.

## Results and Discussions

### Tensile properties

As noted above, geosynthetic materials have mechanical properties in a fairly wide range. In this work, the selected test samples also cover a wide range of mechanical behavior of geosynthetic materials. The tensile properties of the samples were determined using the Instron 5965 universal testing

Срунгері С., Алексеев Н.Н., Коваленко І.А., Столяров О.Н. Ползучість геосинтетических матеріалів при ускорених температурних іспитаннях // Інженерно-строительный журнал. 2017. № 8(76). С. 255–265.

machine. Samples of geotextile fabrics were prepared in the form of strips with a width of 50 mm and a length of 200 mm. The gauge length was 100 mm. The samples of the geogrid were tested along the single rib. The crosshead speed was 50 mm/min.

Figure 4 shows the tensile curves of the samples investigated in the longitudinal (machine) direction. The curves obtained show the samples various tensile behavior. All samples tested, except 2-GTX, are intended for use in the reinforcement function. As a result, their tensile behavior is characterized by a high maximum breaking load and low elongation at maximum load. Sample 2-GTX demonstrates the cardinally opposite tensile behavior. The elongation of the specimen at maximum load is several times greater than that of the reinforcing samples. The tensile strength thus leaves the minimal values.

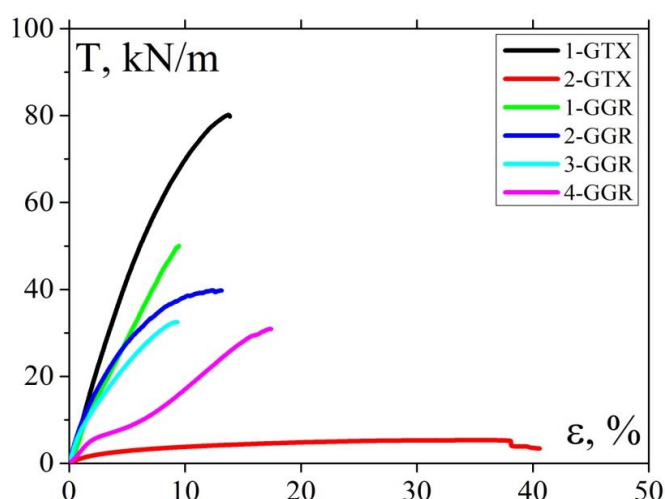


Figure 4. Tensile diagrams of investigated samples

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:

$$T_{\max} = F_{\max} \cdot c, \quad (1)$$

where  $F_{\max}$  is the recorded maximum load, in kilonewtons;  $c$  is the specimen width.

For geotextile fabrics  $c$  is determined as follow:

$$c = \frac{1}{B}, \quad (2)$$

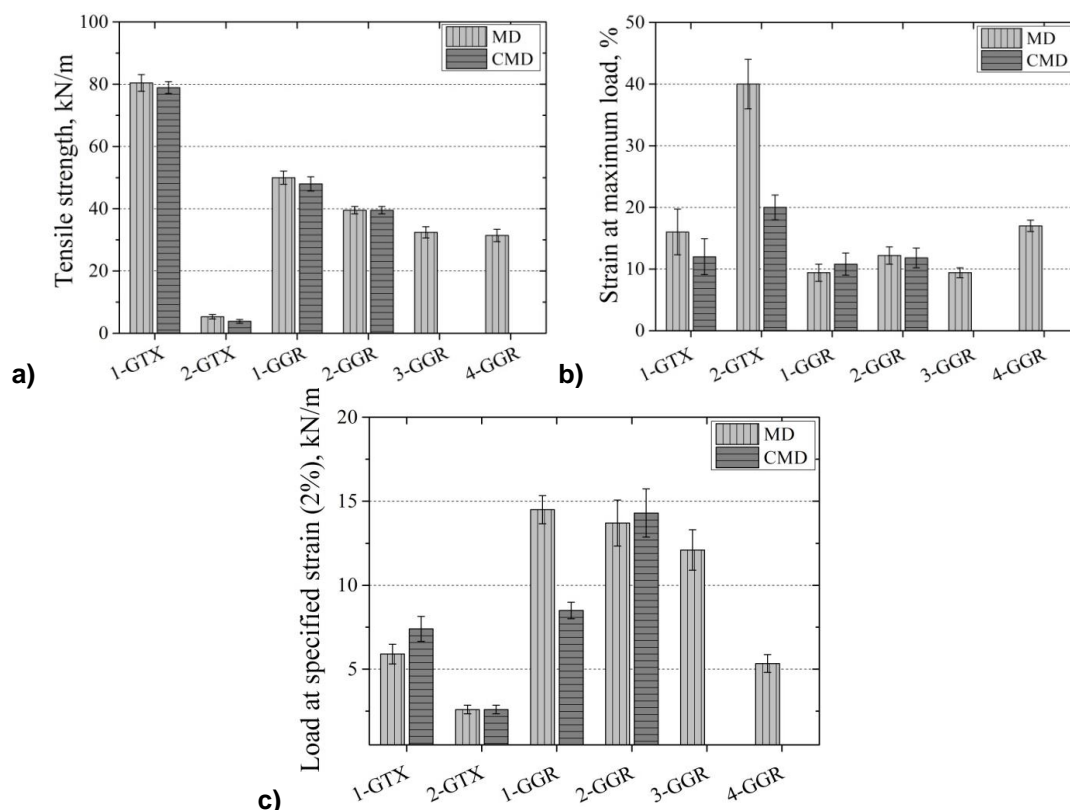
where  $B$  is the specimen nominal width, in meters.

For geogrids  $c$  is determined as follow:

$$c = \frac{N_m}{N_s}, \quad (3)$$

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.

In addition to the tensile strength, the following characteristics were determined: strain (in percent) at maximum load and load at specified strain (at 2%). The latter characteristic is widely used for geosynthetic materials and expresses the tensile stiffness of the specimen. The application of this characteristic is due to the complexity of applying the tangent line to the initial part of the tensile curve due to its nonlinearity. The results for tensile strength, strain at maximum load and tensile load at specified strain of 2% are given in Figure 5a-5c respectively.



**Figure 5. Results of tensile test: tensile strength (a), strain at maximum load (b) and tensile load at specified strain of 2% (c)**

Analyzing the obtained data, it should be noted that the tensile strength of the investigated samples varies significantly. The maximum tensile strength is provided by the 1-GTX sample of the order of 80 kN/m, the minimum strength is the sample of 2-GTX of the order of 5 kN/m. The tensile strength of the investigated geogrid samples lies in the range of 30–40 kN/m that is typical for reinforcement function. The strain at the maximum load in the samples also varies significantly. The strain of reinforcing geogrids is in the range of 10–15 %, for the geotextile sample of 2-GGR it is dozens of percents. The tensile load at specified strain of 2 % also varies significantly for different samples. The difference between the minimum value for a 2-GTX sample and the maximum for a 1-GTX sample is one order of magnitude.

### *SIM analysis*

SIM curves were obtained for all the samples in machine direction. The curves are shown in Figure 6. As can be seen from the data obtained, all curves have significantly different deformation behavior. Especially noticeable is the difference in the increase in elongation between the samples made of PP and PET. The first group is characterized by a noticeable increase in deformation when heated from the first temperature step (from 7200 s). The 2-GTX sample, made of PP fibers, experiences the greatest deformation. Unlike PP samples, the samples of the second group (1-GR and 4-GR) made of PET, although they show an increase in the creep rate, but not so significant. The obtained curves were analyzed by the stepped isothermal method described above. Each curve was divided into equal parts according to temperature steps, recalculated into a creep modulus. Then, a shift along the horizontal time axis was carried out, and the generalized master curve of the creep modulus obtained in this way was rearranged into a creep curve as shown in Figure 3.

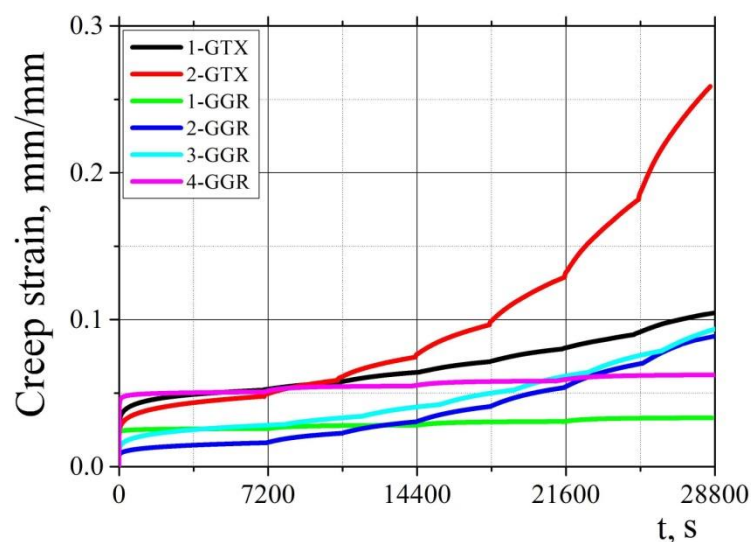


Figure 6. Results of SIM test

The results of analyzing the curves are shown in Figure 7. Along with the logarithmic time scale, an additional time grid is added, which allows estimating the predicted creep deformation of the geosynthetic material depending on the design life. Considering the dependence of the creep strain on time, it can be seen that the geosynthetic samples made of PET have a gradual linear slight increase in strain over the time. The predicted deformation of samples made of PP significantly increases already at relatively short times (for example, 1 day or 1 month). For longer times, the deformation increases even more, and, for example, for a 2-GTX sample, it becomes practically commensurable with a failure deformation. In order to assess the deformation achieved at a certain point in time, two time interval were taken, equal to 1 year and 30 years. The values of the predicted deformation for these time intervals are plotted in Figure 8. It can be seen from the histograms shown that samples made of PET fibers (1-GGR and 4-GGR) have the least increase in strain, as predicted earlier. In addition, they also have a minimal creep deformation among all the samples studied. Samples made of PP show a huge increase in deformation. Moreover, for a 2-GTX sample it is not possible to estimate the deformation after reaching 30 years, because during the test period, it practically reached a pre-failure deformation. On average, the predicted deformation of PP samples after 30 years is 8–12 %, which is quite a lot. The predicted deformation of PET samples is 2.6 % and 6.3 % for 1-GGR and 4-GGR samples, respectively, which is more acceptable for the reinforcement function.

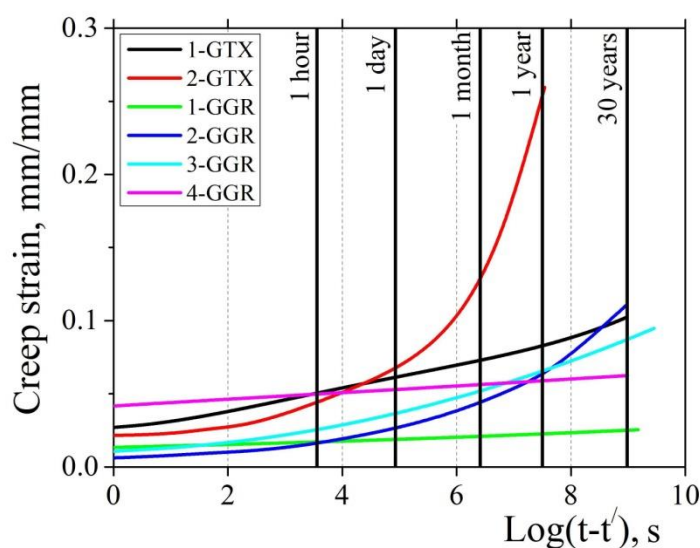
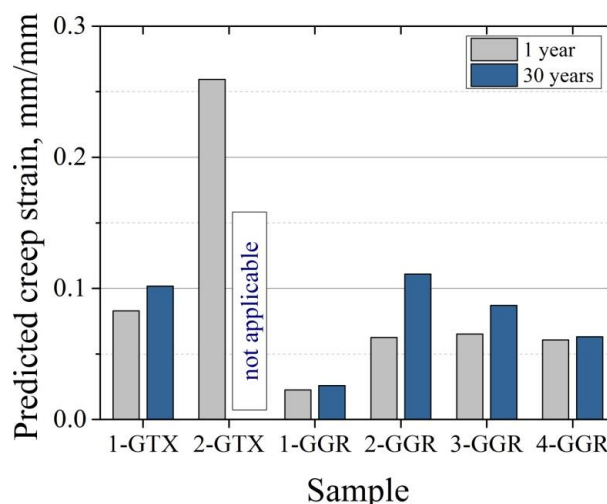


Figure 7. Predicted curves by SIM test





**Figure 8. Predicted creep strain after 1 and 30 years**

The results of this research provide useful information with regard to structural design applications of geotextiles and geogrids mainly concerning reinforcement function. The graphs presented show tensile, creep strain and creep deformation properties analyzed by SIM test at elevated temperature of the materials. Observing the graphs we can clearly conclude that woven split yarn and non-woven thermobonded geotextiles show maximum and minimum tensile behavior compared to all the other materials mentioned, whereas creep behavior of non-woven thermobonded geotextile shows highest deformation and wrap-knitted geogrid with a nonwoven fabric layer shows the least deformation comparatively. Therefore, this research can give a better understanding of the results of temperature accelerated method of six different PP and PET samples of geosynthetics used primarily for reinforcement function.

## Conclusions

In this work, the deformation behavior of various samples of geosynthetic materials was analyzed. Six samples, including two samples made of PET and four samples made of PP, were investigated for creep by SIM test. As a result of the analysis, predicted creep curves for up to 30 years of design life were obtained. The best resistance to creep is possessed by samples made of PET, which is mainly explained by their work below the glass transition temperature. Samples of PP have a much worse creep resistance, because the temperature range of operation lies above their glass transition temperature. As a result, it can be concluded that PET samples have better creep resistance and can be used in various loaded applications as a reinforcement function. The SIM test showed its applicability for predicting creep deformation for long periods based on short-term measurements.

## Reference

1. Sarsby R.W. *Geosynthetics in Civil Engineering*. Woodhead Publishing Ltd. 2007. 295 p.
2. Koerner R.M. *Designing With Geosynthetics*, 6th Ed. Xlibris Publ. Co. 2012. 914 p.
3. Mounes S.M., Karim M.R., Khodaii A., Almasi M.H. Evaluation of permanent deformation of geogrid reinforced asphalt concrete using dynamic creep test. *Geotextiles and Geomembranes*. 2016. No. 44(1). Pp. 109–116.
4. Yang B.H., Lai J., Lin J.H., Tsai P.H. Simulating the loading behavior of reinforced strip footings with a double-yield soil model. *International Journal of Geomechanics*. 2016. No. 16(1).
5. Wang, H., Yang G.B., Liu H.C., Liu W.B., Wu L.D. Research on dynamic behavior of geogrid reinforced soil retaining wall with wrapped face. *Tiedao Xuebao/Journal of the China Railway Society*. 2016. No. 38(2). Pp. 131–140.
6. Ooi T.A., Tee C.H. Advance in geogrid reinforced slopes in Malaysia. *Geotechnical Engineering*. 2011. No. 42(1). Pp. 9–34.
7. Peng F.L., Li F.L., Hirakawa D., Tatsuoka F. Deformation and strength characteristics of geogrid-reinforced soil

## Литература

1. Sarsby R.W. *Geosynthetics in Civil Engineering*. Woodhead Publishing Ltd. 2007. 295 p.
2. Koerner R.M. *Designing With Geosynthetics*, 6th Ed. Xlibris Publ. Co. 2012. 914 p.
3. Mounes S.M., Karim M.R., Khodaii A., Almasi M.H. Evaluation of permanent deformation of geogrid reinforced asphalt concrete using dynamic creep test // *Geotextiles and Geomembranes*. 2016. № 44(1). Pp. 109–116.
4. Yang B.H., Lai J., Lin J.H., Tsai P.H. Simulating the loading behavior of reinforced strip footings with a double-yield soil model // *International Journal of Geomechanics*. 2016. № 16(1).
5. Wang H., Yang G.B., Liu H.C., Liu W.B., Wu L.D. Research on dynamic behavior of geogrid reinforced soil retaining wall with wrapped face // *Tiedao Xuebao/Journal of the China Railway Society*. 2016. № 38(2). Pp. 131–140.
6. Ooi T.A., Tee C.H. Advance in geogrid reinforced slopes in Malaysia // *Geotechnical Engineering*. 2011. № 42(1). Pp. 9–34.
7. Peng F.L., Li F.L., Hirakawa D., Tatsuoka F. Deformation and strength characteristics of geogrid-reinforced soil

- retaining wall under change of loading rate and its FEM simulation. *Yantu Gongcheng Xuebao/Chinese Journal of Geotechnical Engineering*. 2011. No. 33(2). Pp. 174–180.
8. Sannikov S., Kuyukov S., Kubasov D. Increase of a roadway covering durability by using the cement-concrete base fragmented with the geogrid. *MATEC Web of Conferences*. 2016. No. 73.
  9. Christopher B.R., Holtz R.D., Berg R.R. Geosynthetic reinforced embankments on soft foundations. *Geotechnical Special Publication*. 2001. No. 122. Pp. 206–236.
  10. Sannikov S., Kuyukov S., Kubasov D. Increase of a roadway covering durability by using the cement-concrete base fragmented with the geogrid. *MATEC Web of Conferences*. 2016. No. 73.
  11. Tian Q.B. The application research of geogrids in road broadening engineering. *Resources, Environment and Engineering – 2nd Technical Congress on Resources, Environment and Engineering, CREE.2015*. 2016. Pp. 163–168.
  12. Canestrari F., Ferrotti G., Abuaddous M., Pasquini E. Geocomposite-reinforcement of polymer-modified asphalt systems. *RILEM Bookseries*. No. 11. Pp. 383–395.
  13. Leshchinsky B., Evans T.M., Vesper J. Microgrid inclusions to increase the strength and stiffness of sand. *Geotextiles and Geomembranes*. 2016. No. 44(2). Pp. 170–177.
  14. Yang B.-H., Lai J., Lin J.-H., Tsai P.H. Simulating the loading behavior of reinforced strip footings with a double-yield soil model. *International Journal of Geomechanics*. 2016. No. 16(1).
  15. Navarrete F., Reddy D.V., Lai P. Creep of geogrid reinforcement for retaining wall backfills. *Geosynthetics Conference*. 2001.
  16. Singh A., Phanikumar B.R., Prasad R. Effect of geogrid reinforcement on load carrying capacity of a coarse sand bed. *International Journal of Civil Engineering and Technology*. 2016. No. 7(3). Pp. 1–6.
  17. Hsieh C.W., Lee K., Yoo H.K., Jeo, H. Tensile creep behavior of polyester geogrids by conventional and accelerated test methods. *Fibers and Polymers*. 2008. No. 9(4). Pp. 476–480.
  18. Den Hoedt G. Creep and relaxation of geotextile fabrics. *Geotextiles and Geomembranes*. 1986. No. 4(2). Pp. 83–92.
  19. Cho S.D., Lee K.W., Cazzuffi D.A., Jeon H.Y. Evaluation of combination effects of installation damage and creep behavior on long-term design strength of geogrids. *Polymer Testing*. 2006. No. 25(6). Pp. 819–828.
  20. Alekseev N.N., Kovalenko I.A., Stolyarov O.N., Melnikov B.E. Viscoelastic properties of geosynthetic materials. *Construction of Unique Buildings and Structures*. 2017. No. 5(56). Pp. 17–32. (rus)
  21. Suvorova Yu.V., Alekseyeva S.I., Kupriyanov D.Y. Modelirovaniye dlitelnoy polzuchesti georeshetok tipa Fortrac na osnove polietilentereftalata. [Modeling of the long creep of geogrids of the Fortrac type based on polyethylene terephthalate]. *High-molecular compounds*. 2005. No. 6. Pp. 1058–1061. (rus)
  22. Suvorova Yu.V., Alekseyeva S.I. Eksperimentalnyye i analiticheskiye metody otsenki dolgovechnosti geosinteticheskikh materialov. Problemy mashinostroyeniya i nadezhnosti mashin. [Experimental and analytical methods for assessing the durability of geosynthetic materials]. *Problems of machine building and machine reliability*. 2010. No. 4. Pp. 105–110. (rus)
  23. Loginova I.I., Artamonova D.A., Stolyarov O.N., Melnikov B.E. Vliyaniye struktury na vyzkouprugiye svoystva geosinteticheskikh materialov [Effects of structure type on viscoelastic properties of geosynthetics]. *Magazine of Civil Engineering*. 2015. No. 4(56). Pp. 11–18. (rus)
  24. Koo H.-J., Kim Y.-K. Lifetime prediction of geogrids for retaining wall under change of loading rate and its FEM simulation // *Yantu Gongcheng Xuebao/Chinese Journal of Geotechnical Engineering*. 2011. No. 33(2). Pp. 174–180.
  8. Sannikov S., Kuyukov S., Kubasov D. Increase of a Roadway Covering Durability by Using the Cement-Concrete Base Fragmented with the Geogrid // *MATEC Web of Conferences*. 2016. № 73.
  9. Christopher B.R., Holtz R.D., Berg R.R. Geosynthetic reinforced embankments on soft foundations // *Geotechnical Special Publication*. 2001. № 122. Pp. 206–236.
  10. Sannikov S., Kuyukov S., Kubasov D. Increase of a roadway covering durability by using the cement-concrete base fragmented with the geogrid // *MATEC Web of Conferences*. 2016. № 73.
  11. Tian Q.B. The application research of geogrids in road broadening engineering // *Resources, Environment and Engineering – 2nd Technical Congress on Resources, Environment and Engineering, CREE.2015*. 2016. Pp. 163–168
  12. Canestrari F., Ferrotti G., Abuaddous M., Pasquini E. Geocomposite-reinforcement of polymer-modified asphalt systems // *RILEM Bookseries*. No. 11. Pp. 383–395.
  13. Leshchinsky B., Evans T.M., Vesper J. Microgrid inclusions to increase the strength and stiffness of sand // *Geotextiles and Geomembranes*. 2016. № 44(2). Pp. 170–177.
  14. Yang B.-H., Lai J., Lin J.-H., Tsai P.H. Simulating the loading behavior of reinforced strip footings with a double-yield soil model // *International Journal of Geomechanics*. 2016. № 16(1).
  15. Navarrete F., Reddy D.V., Lai P. Creep of geogrid reinforcement for retaining wall backfills // *Geosynthetics Conference*. 2001.
  16. Singh A., Phanikumar B.R., Prasad R. Effect of geogrid reinforcement on load carrying capacity of a coarse sand bed // *International Journal of Civil Engineering and Technology*. 2016. № 7(3). Pp. 1–6.
  17. Hsieh C.W., Lee K., Yoo H.K., Jeo, H. Tensile creep behavior of polyester geogrids by conventional and accelerated test methods // *Fibers and Polymers*. 2008. № 9(4). Pp. 476–480.
  18. Den Hoedt G. Creep and relaxation of geotextile fabrics // *Geotextiles and Geomembranes*. 1986. № 4(2). Pp. 83–92.
  19. Cho S.D., Lee K.W., Cazzuffi D.A., Jeon H.Y. Evaluation of combination effects of installation damage and creep behavior on long-term design strength of geogrids // *Polymer Testing*. 2006. № 25(6). Pp. 819–828.
  20. Алексеев Н.Н., Коваленко И.А., Столяров О.Н., Мельников Б.Е. Вязкоупругие свойства геосинтетических материалов // *Строительство уникальных зданий и сооружений*. 2017. № 5(56). С. 17–32.
  21. Суворова Ю.В., Алексеева С.И., Куприянов Д.Ю. Моделирование длительной ползучести георешеток типа Fortrac на основе полиэтилентерефталата // *Высокомолекулярные соединения. Серия В*. 2005. Т. 47. № 6. С. 1058–1061.
  22. Суворова Ю.В., Алексеева С.И. Экспериментальные и аналитические методы оценки долговечности геосинтетических материалов // *Проблемы машиностроения и надежности машин*. 2010. № 4. С. 105–110. (rus)
  23. Логинова И.И., Артамонова Д.А., Столяров О.Н., Мельников Б.Е. Влияние структуры на вязкоупругие свойства геосинтетических материалов // *Инженерно-строительный журнал*. 2015. № 4(56). С. 11–18.
  24. Koo H.-J., Kim Y.-K. Lifetime prediction of geogrids for reinforcement of embankments and slopes // *Polymer Testing*. 2005. № 24(2). Pp. 181–188.
  25. Cho S.D., Lee K.W., Cazzuffi D.A., Jeon H.Y. Evaluation of combination effects of installation damage and creep

- reinforcement of embankments and slopes. *Polymer Testing*. 2005. No. 24(2). Pp. 181–188.
25. Cho S.D., Lee K.W., Cazzuffi D.A., Jeon H.Y. Evaluation of combination effects of installation damage and creep behavior on long-term design strength of geogrids. *Polymer Testing*. 2006. No. 25(6). Pp. 819–828.
  26. Zou C., Wang Y., Lin J., Chen Y. Creep behaviors and constitutive model for high density polyethylene geogrid and its application to reinforced soil retaining wall on soft soil foundation. *Construction and Building Materials*. 2016. No. 114. Pp. 763–771.
  27. Zhang Z., Zhu D.Y., Chen T.F., Wang T. Confined-accelerated creep tests to determine the creep reduction factor. *Applied Mechanics and Materials*. 2014. No. 539. Pp. 769–773.
  28. Hsuan Y.G., Yeo S.S. Comparing the creep behavior of high density polyethylene geogrid using two acceleration methods. *Geotechnical Special Publication*. 2005. No. 130(142). Pp. 2887–2901.
  29. Jin Y.C., Jeon H.Y. Analysis of creep deformation behavior of geogrids by limited creep strain and rupture. *10th International Conference on Geosynthetics*. 2014.
  30. Tong J., Gong B., Liu J. Experimental study and prediction on the long-term creep properties for geogrids at different temperatures. *9th International Conference on Geosynthetics - Geosynthetics: Advanced Solutions for a Challenging World*. 2010. Pp. 873–876.
  31. Giannopoulos I.P., Burgoyne C.J. Accelerated and real-time creep and creep-rupture results for aramid fibers. *Journal of Applied Polymer Science*. 2012. No. 125(5). Pp. 3856–3870.
  32. Lee K.W., Jung S.G., Koo H.J., Cho H.W., Lee J.S. The evaluation of creep reduction factor for geosynthetic strip by conventional creep test and stepped isothermal method. *10th International conference on geosynthetics*. Berlin. 2014.
  33. Zornberg J.G., Byler B.R., Knudsen J.W. Creep of geotextiles using time-temperature superposition methods. *Journal of Geotechnical and Geoenvironmental Engineering*. 2004. Vol. 130(11). Pp. 1158–1168.
  34. Mok M.S., Blond, E., Mylnarek J., Jeon H.Y. New approach to evaluate the long-term designing normal pressure of geonets using a short-term accelerated compressive creep test method. *Geotextiles and Geomembranes*. 2012. No. 30. Pp. 2–7.
  35. Allen S.R. Geotextile durability. *Geotextiles*. Cambridge: Elsevier. 2016. Pp. 177–215.
  36. GRI Test Method GS10 Standard Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method. 2000.
  - behavior on long-term design strength of geogrids // *Polymer Testing*. 2006. № 25(6). Pp. 819–828.
  26. Zou C., Wang Y., Lin J., Chen Y. Creep behaviors and constitutive model for high density polyethylene geogrid and its application to reinforced soil retaining wall on soft soil foundation // *Construction and Building Materials*. 2016. № 114. Pp. 763–771.
  27. Zhang Z., Zhu D.Y., Chen T.F., Wang T. Confined-accelerated creep tests to determine the creep reduction factor // *Applied Mechanics and Materials*. 2014. № 539. Pp. 769–773.
  28. Hsuan Y.G., Yeo S.S. Comparing the creep behavior of high density polyethylene geogrid using two acceleration methods // *Geotechnical Special Publication*. 2005. № 130(142). Pp. 2887–2901.
  29. Jin Y.C., Jeon H.Y. Analysis of creep deformation behavior of geogrids by limited creep strain and rupture // *10th International Conference on Geosynthetics*. 2014.
  30. Tong J., Gong B., Liu J. Experimental study and prediction on the long-term creep properties for geogrids at different temperatures // *9th International Conference on Geosynthetics - Geosynthetics: Advanced Solutions for a Challenging World*. 2010. Pp. 873–876.
  31. Giannopoulos I.P., Burgoyne C.J. Accelerated and real-time creep and creep-rupture results for aramid fibers // *Journal of Applied Polymer Science*. 2012. № 125(5). Pp. 3856–3870.
  32. Lee K.W., Jung S.G., Koo H.J., Cho H.W., Lee J.S. The evaluation of creep reduction factor for geosynthetic strip by conventional creep test and stepped isothermal method // *10th International conference on geosynthetics*. Berlin. 2014.
  33. Zornberg J.G., Byler B.R., Knudsen J.W. Creep of geotextiles using time-temperature superposition methods // *Journal of Geotechnical and Geoenvironmental Engineering*. 2004. Vol. 130(11). Pp. 1158–1168.
  34. Mok M.S., Blond, E., Mylnarek J., Jeon H.Y. New approach to evaluate the long-term designing normal pressure of geonets using a short-term accelerated compressive creep test method // *Geotextiles and Geomembranes*. 2012. № 30. Pp. 2–7.
  35. Allen S.R. Geotextile durability // *Geotextiles*. Cambridge: Elsevier. 2016. Pp. 177–215.
  36. GRI Test Method GS10 Standard Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method. 2000.

Sanjeev Gautham Sringeri,  
+7(931)270-59-65; sanjeevgautham18@gmail.com

Nikolai Alekseev,  
+7(999)239-71-54; nikolas.alexeeff@yandex.ru

Ilya Kovalenko,  
+7(906)262-52-47; ilyako27@mail.ru

Oleg Stolyarov,  
+7(812)552-63-03; oleg.stolyarov@rambler.ru

Санджив Гаутам Срунгерри,  
+7(931)270-59-65;  
эл. почта: sanjeevgautham18@gmail.com

Николай Николаевич Алексеев,  
+7(999)239-71-54;  
эл. почта: nikolas.alexeeff@yandex.ru

Илья Александрович Коваленко,  
+7(906)262-52-47; эл. почта: ilyako27@mail.ru

Олег Николаевич Столяров,  
+7(812)552-63-03;  
эл. почта: oleg.stolyarov@rambler.ru

© Sringeri S.G., Alekseev N.N., Kovalenko I.A., Stolyarov O.N., 2017

Срунгерри С., Алексеев Н.Н., Коваленко И.А., Столяров О.Н. Ползучесть геосинтетических материалов при ускоренных температурных испытаниях // *Инженерно-строительный журнал*. 2017. № 8(76). С. 255–265.