(REFEREED RESEARCH)

THE PREDICTION OF ELASTIC LIMIT OF NONWOVEN GEOTEXTILES MADE OF VIRGIN AND RECYCLED POLYESTER FIBERS

GERİ DÖNÜŞTÜRÜLMÜŞ VE NORMAL POLYESTERDEN ÜRETİLMİŞ DOKUSUZ YÜZEY JEOTEKSTİLÜRÜNLERİNİN ELASTİK LİMİTİNİN TAHMİN EDİLMESİ

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ABSTRACT

Mechanical properties of needled nonwoven geotextile materials depend on their structural solutions, as well as on the technological conditions in the production. Thereby, structural and physical-mechanical properties of fibers, surface mass of geotextiles and the needling process parameters have the most important function. The paper presents the results of the analysis of mechanical characteristics of nonwoven geotextile material made of virgin PES fibers and recycled PES fibers with surface masses of 150 g/m2, 200 g/m2, 250 g/m2, 300 g/m2 and 500 g/m2. Also, the elastic limits of deformation of needled geotextile materials are determined, which define permitted loads that geotextile materials can be subjected to, without disturbing their structure. Force intensities and work under these forces are determined at elastic limits of the geotextiles and their relationship with appropriate breaking parameters is presented. The proposed method and the results can be used to predict the permitted loads, which a non-woven geotextile material may be subjected to during exploitation.

Keywords: Deformation, Geotextiles, Elastic limit, Force, Elongation.

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1. INTRODUCTION

Geotextile materials have been used for years on many building sites worldwide. By their application, roads, railroads, drainage systems, coastal engineering and protecting walls can be cheaper to build. Thanks to its appropriate technical, mechanical and hydraulic characteristics, the geotextile has a significant role in the construction industry. Due to their convenient technical, mechanical and hydraulic characteristics, geotextiles have a significant role in construction engineering. The main functions of geotextile in construction engineering are separation, reinforcement, filtration, drainage and insulation. According to their purpose, structural and mechanical properties of geotextile materials are predicted (1, 2, 3, 4).

During the needling process, fibers in the felt are interconnected with their own fibers, using needles of special construction that transfer fibers from the surface into the felt depth. In this way a product of special structure is produced which is resistant to mechanical action and therefore finds broad and various applications. Significant impact on the performance of nonwoven geotextiles has the kind of fiber that is used for its formation (5), geotextile surface mass (6) and technological parameters of geotextiles production process (7). The action of tensile force produces deformation of geotextile with sliding between fibers and their orientation along the force action (8). Deformation of geotextile during stretching depends on technological parameters in production process of geotextile (9).

Nonwoven textile materials, produced using needles, are complex three dimensional fiber structures and have the application in many industrial fields. Anisotropic structure of needled nonwoven materials (10) contributes to various, sometimes hardly explicable behavior of nonwoven textile during stretching (11). The properties of geotextile materials could be predicted using empiric models (1), finite model theory and composite material theory (12), using computer-predicting model of nonwoven textile stretching (13) and using mechanical models (14) whereby geotextile behavior is described by differential equations. In this way, every type of real material deformation is simulated with a simple model or complex models formed by combination of simple models. Simple models used to describe elastic, viscoelastic and plastic deformations are models defining properties of ideal materials not existing in nature but their properties, under specific stress conditions and other external influence, approximately reflect the behavior of real materials.

Depending on the purpose, the structural and physical-mechanical characteristics of geotextile materials can be predicted. However, the needled geotextile is inhomogeneous anisotropic fibrous material and, therefore, its behavior during exploitation is not easy to predict.

Application of recycled fibers is always a current issue, considering the economic and environmental justification of such proceedings. Therefore, this paper contains the results of analysis of the needled geotextile materials consisting of 100% virgin polyester fibers or 100% recycled polyester fibers. The goal was to compare the mechanical properties of the needled geotextiles, differing only by the type of fibers.

For geotextile materials is of particularly significant interest to know the limit values of the forces that may cause plastic deformation. Therefore, the paper presents a method that can be used to determine the limit load values of non-woven geotextile materials.

2. MATERIALS AND METHODS

For the production of nonwoven geotextile material virgin polyester (PES A) and recycled polyester (PES B) fibers were used. Tables 1 and 2 show the main characteristics of these fibers.

Polyester fibers are produced from polyethylene terephthalate (PET). Melting points of virgin PES fibers and recycled PES fibers were determined using Ramp (from 50 °C to 300°C) method on the device DSC Q20 V24.11 Build 124. The virgin PES fibers melting point was found as 245,34 ºC, while the melting point of recycled PES fibers was 242,11 ºC.

Various geotextile materials from virgin polyester fibers and from recycled polyester fibers were produced under industrial conditions. Produced were 10 samples in geotextile group with 150 g/m^2 (5 of virgin polyester fibers, and 5 of recycled polyester fibers), then 10 samples in geotextile group with 200 g/m^2 (5 of virgin polyester fibers, and 5 of recycled polyester fibers), 10 samples in geotextile group with 250 g/m^2 (5 of virgin polyester fibers, and 5 of recycled polyester fibers), 10 samples in geotextile group with 300 g/m^2 (5 of virgin polyester fibers, and 5 of recycled polyester fibers) and 10 samples in geotextile group with 500 g/m^2 (5 of virgin polyester fibers, and 5 of recycled polyester fibers).

All geotextile samples analyzed were made using the needlefelting method. The felt is formed by laying web into the felt using equipment for web crosslaying. The crossed fiber position is accomplished in the way that the web from carding machine is placed on a transporter moving square to felt direction. In such a laying, the position of fibers could not be exactly square because the web is laid in layers, which are, due to the moving of the transporter with the felt, placed under a certain angle.

The same technical and technological parameters were used for specific surface weights of geotextiles during production. It was easier to understand the impact of fiber type on the quality of obtained geotextiles using the same technological parameters in the production of geotextiles with the same surface weights but from different fibers. Table 3 shows the needling parameters, i.e. needle type, depth and the density of needling.

Table 1. The characteristics of virgin PES fibers used for the production of geotextiles

Fiber type	The mean length of fibers [mm]	Fiber fineness [dtex]	Relative fiber breaking force [cN/tex]	CV [%]	Elongation at break [%]	CV [%]
PES A	62,0	6	44,3	8,9	32,7	22,0

Table 2. The characteristics of recycled PES B fibers used for the production of geotextiles

Fiber type	The mean length of fibers [mm]	Fiber fineness [dtex]	Relative fiber breaking force [cN/tex]	CV [%]	Elongation at break [%]	CV [%]
PES B	83,1	6	37,7	19,4	63,5	24,8

PES A - virgin PES fibers
PES B - recycled PES fibers
CV - coefficient of variation

Table 3. The needling parameters

Geotextile	Needling parameters			
	Needle type		Depth of needling (mm)	Density of needling (cm^{-2})
	Input board	Output board		
Geotextile 150 PES A	15x18x36x3R333 G1002	15x18x36x3R333 G1002	15,5	91,4
Geotextile 150 PES B	15x18x36x3R333 G1002	15x18x36x3R333 G1002	15,5	91,4
Geotextile 200 PES A	15x18x36x3R333 G1002	15x18x36x3R333 G1002	16,0	109,7
Geotextile 200 PES B	15x18x36x3R333 G1002	15x18x36x3R333 G1002	16,0	109,7
Geotextile 250 PES A	15x18x36x3R333 G1002	15x18x36x3R333 G1002	16,5	115,5
Geotextile 250 PES B	15x18x36x3R333 G1002	15x18x36x3R333 G1002	16,5	115,5
Geotextile 300 PES A	15x18x32x3R333 G1002	15x18x36x3R333 G1002	17,0	120,4
Geotextile 300 PES B	15x18x32x3R333 G1002	15x18x36x3R333 G1002	17,0	120,4
Geotextile 500 PES A	15x18x32x3R333 G1002	15x18x36x3R333 G1002	17,5	169,7
Geotextile 500 PES B	15x18x32x3R333 G1002	15x18x36x3R333 G1002	17,5	169,7

The following test methods were used for testing geotextile materials.
SRPS EN ISO 9864 - Geotextile - Determination of the mass per unit area
SRPS EN ISO 10319 - Geotextile - Tension testing with wide laboratory sample

Testing of breaking force and deformation at maximum load was measured with a preload of 0,02 kN, the distance between the grips was 100 mm and grips moving speed was 20 mm/min (Tensolab strength tester 2510). The sampling was done in accordance with ISO 9862:2005 standard. From each roll of geotextile 5 samples were taken in the direction of the longitudinal axis of geotextiles and 5 samples in the direction of the transverse axis. The samples size was 200 mm×200 mm±1 mm.

Using F-ε curve, the force values and relative elongations at elastic limits were determined, the values that can be numerically determined from the maximum of the first derivative of F(ε) when *F''* (ε) = 0 (14, 15).

Moreover, by using the results obtained, the work up to the maximum value of tension force was determined, and the work up to the elastic limits of virgin and recycled PES geotextiles.

3. RESULTS AND DISCUSSION

Tables 4 and 5 show elaborated results of the testing of geotextile materials.

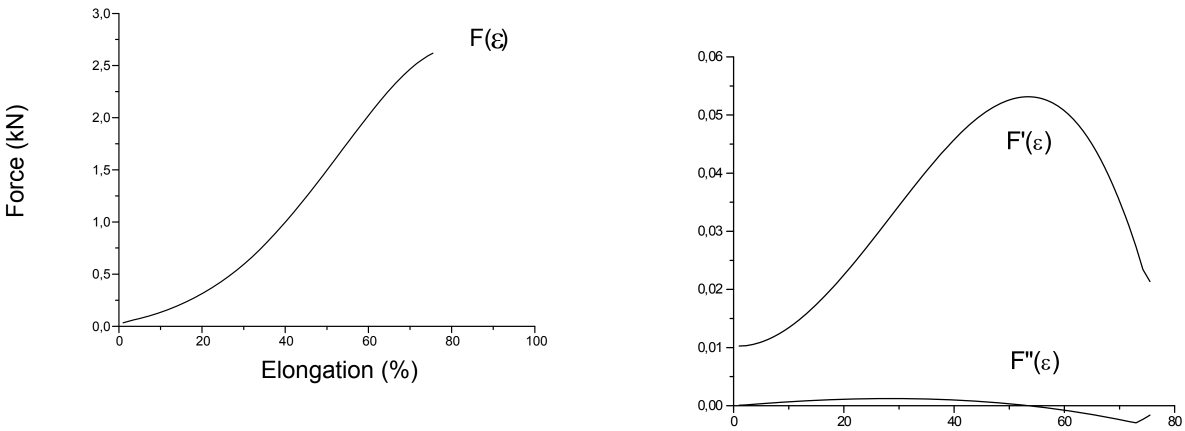


Figure 1. The plots of the force-elongation dependence F(ε), the first F'(ε) and the second F''(ε) derivative of the function

Table 4. The test results (mean values) of geotextile materials of virgin PES fibers

Title	Direction	The breaking force -max (kN)	The elongation to max force (%)	The force at elastic limit (kN)	The elongation at elastic limit (%)	Work up to the break (J)	Work up to elastic limit (J)
Geotextile 150 PES A	Length	0,53	96,6	0,31	66,7	19,7	7,4
	Width	0,89	76,1	0,583	59,6	22,97	10,9
Geotextile 200 PES A	Length	0,84	96,1	0,512	66,0	32,9	12,2
	Width	1,513	77,9	1,003	59,3	43,3	20,1
Geotextile 250 PES A	Length	1,709	65,8	1,054	43,5	49,9	17,9
	Width	2,065	73,4	1,328	52,8	62,1	26,0
Geotextile 300 PES A	Length	1,83	81,1	1,114	54,5	63,5	23,2
	Width	2,61	78,0	1,716	57,1	82,03	35,7
Geotextile 500 PES A	Length	3,79	64,9	2,008	38,1	110,18	33,5
	Width	4,12	70,4	2,465	43,5	136,91	45,9

Table 5. The test results (mean values) of geotextile materials of recycled PES fibers

Title	Direction	The breaking force -max (kN)	The elongation to max force (%)	The force at elastic limit (kN)	The elongation at elastic limit (%)	Work up to the break (J)	Work up to elastic limit (J)
Geotextile 150 PES B	Length	0,26	99,1	0,151	67,7	10,5	3,9
	Width	0,47	88,4	0,27	60,2	16,5	5,8
Geotextile 200PES B	Length	0,90	95,6	0,50	61,2	35,6	10,5
	Width	1,41	80,1	0,68	47,1	46,5	10,2
Geotextile 250 PES B	Length	0,85	99,9	0,49	62,4	37,6	11,9
	Width	1,37	81,3	0,72	47,7	49,7	12,6
Geotextile 300 PES B	Length	1,31	79,7	0,67	43,3	50,0	11,9
	Width	1,99	67,8	1,09	40,8	60,9	17,2
Geotextile 500 PES B	Length	2,46	69,0	1,33	35,4	88,8	22,3
	Width	3,49	61,4	1,81	32,4	110,9	25,5

Length - sample was taken in the direction of the longitudinal axis of geotextiles
Width - sample was taken in the direction of the transverse axis of geotextiles

Figure 2 shows the relation between forces at the elastic limit and breaking force of analyzed geotextiles materials of PES A fiber.

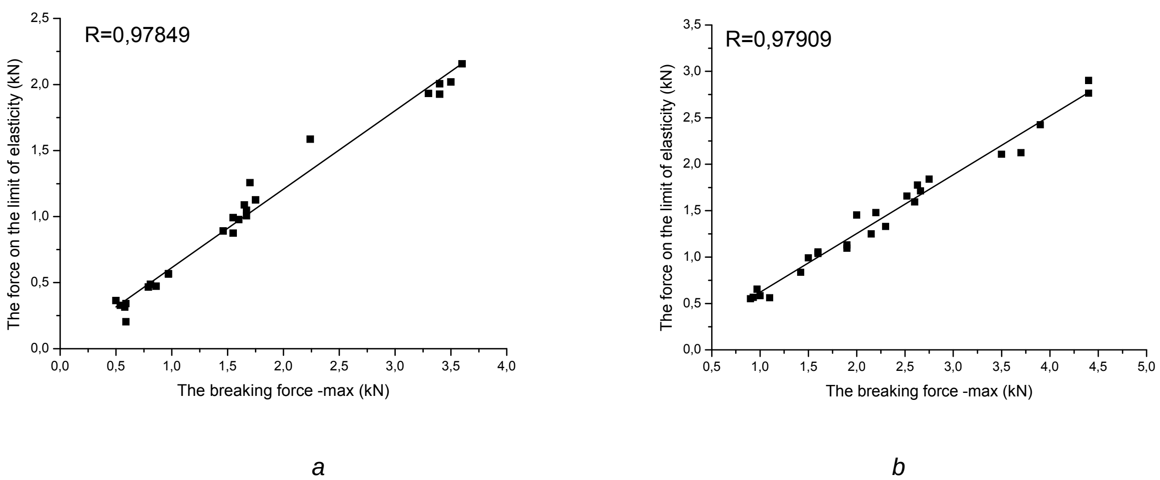
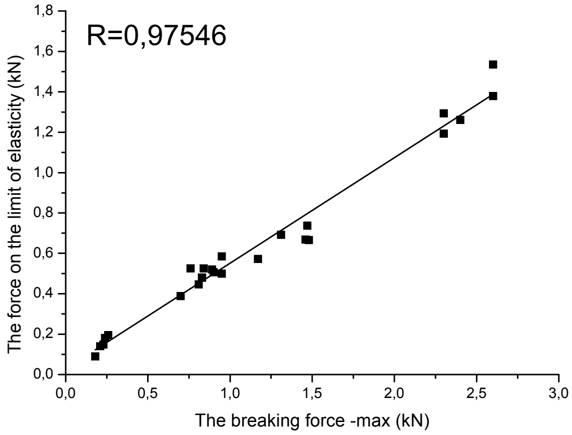
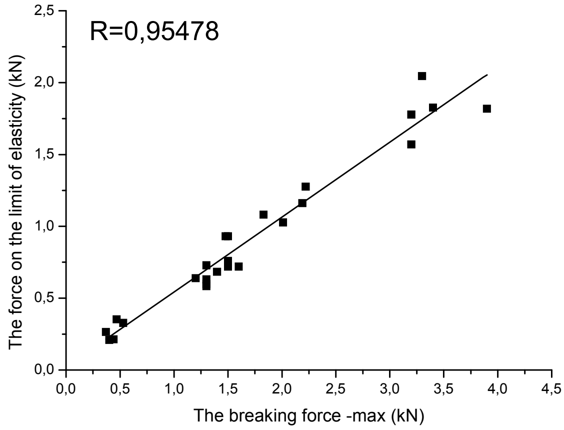


Figure 2. Relation of force at the elastic limit and breaking forces of the geotextile PES A fibers *a* - in the longitudinal direction, *b* - in the width direction

Figure 3 shows the relation between forces at the elastic limit and breaking force of analyzed geotextiles materials of PES B fibers.



a



b

Figure 3. Relation of force at the elastic limit and breaking forces of the geotextile PES B fibers *a* - in the longitudinal direction, *b* - in the width direction

Dependence of the forces at the elastic limit and breaking forces of needled nonwoven geotextiles materials of PES fibers can be displayed with regression equations (Table 6):

Table 6. Correlation between forces at the elastic limit and breaking forces of geotextile

Geotextile	$F_e = a + bF_b$ (kN)				
	Direction	*a*	Standard error	*b*	Standard error
PES A	Length	0,01938	0,03478	0,59424	0,01798
	Width	-0,01295	0,04697	0,63327	0,01888
PES B	Length	0,02930	0,02315	0,52227	0,01690
	Width	0,02171	0,04578	0,52123	0,02313

F_e - Force at the elastic limit - (kN)
F_b - Breaking force of geotextile - (kN)

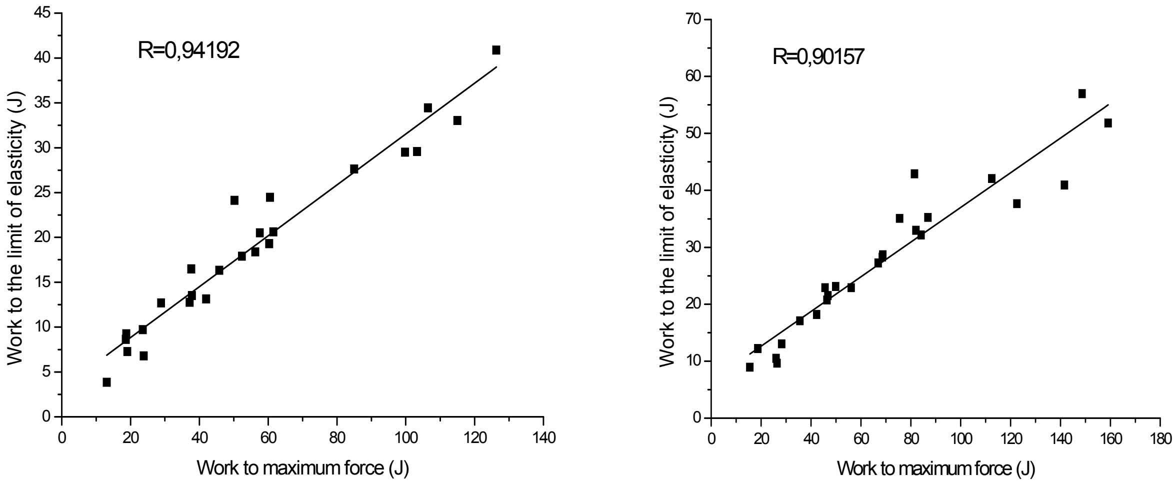
It can be concluded, from the results obtained, that all types of geotextiles have better breaking characteristics along the width than along the length, which is the result of web laying method on the felt before needling. In the given case, the angle of web laying in the felt ranged from 1.9^o (geotextile 500 g/m^2) to 4,6^o (geotextile 150 g/m^2) square to the transverse axis of the felt. As a result of such web laying, the fibers are „transversally“ oriented with respect to the longitudinal axis of the felt, which is the cause of greater geotextile strength in the transversal direction as compared to the strength in the longitudinal direction (Tables 4 and 5). It can also be concluded that geotextiles made of virgin PES fibers have higher breaking force than those made of recycled PES fibers as a result of higher fiber strength (Tables 1 and 2).

Analyzing the results in Tables 4 and 5, it can be concluded that the elastic limit along length of PES A geotextiles ranges from 52,98% to 61,67% relative to maximum force, while along the width, the force at the elastic limit is 59,83% to 66,29% relative to maximum force of stretching. With PES B geotextile, the force at the elastic limit amounts to 51,14% to 58,08% relative to maximum stretching force along the length and 48,23% to 57,45% relative to maximum stretching force along the width.

In addition, analyzing the results in Table 4 and 5, it can be concluded that the work of force to the elastic limit along the length direction with PES A geotextile, ranges from 30,40% to 37,56% compared to the work of force to the break, while in the width direction participation of work of force to the elastic limit range 33,53% to 47,45% in relation to the value of the mechanical work up to the maximum elongation force.

With PES B geotextile, work of force, up to the elastic limit, ranges from 23,8% to 37,14% in relation to the work up to the maximum force measured in the longitudinal direction. Measured in width direction, work of force ranged from 21,93% to 35,15% in relation to the work up to the maximum elongation force.

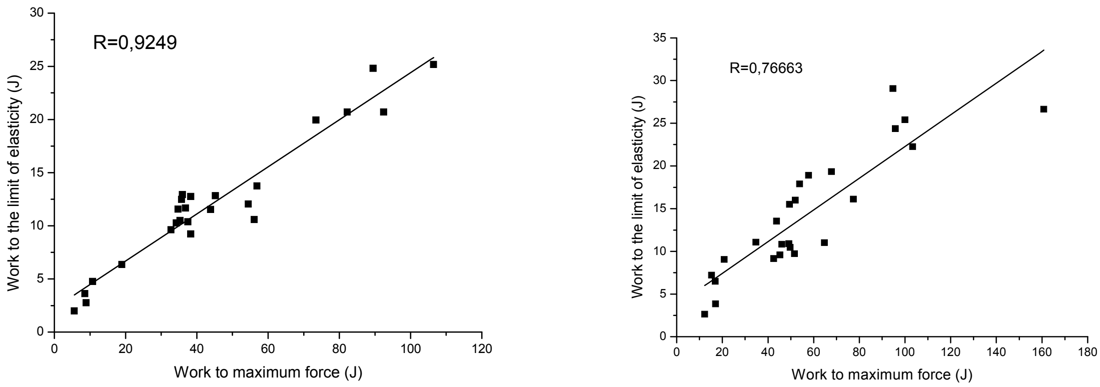
Figures 4 and 5 show the relationship between work up to the elastic limit and work to the break of the analyzed geotextile materials.



a *b*

Figure 4. Relation of work up to maximum force and work up to the elastic limit of the geotextile A PES fibers *a* - in length direction, *b* - in width direction

Figure 5 shows the relationship of work up to the maximum force and work up to the elastic limit of the analyzed geotextiles materials of PES B fibers.



a *b*

Figure 5. Relation of work up to the maximum force and work up to the elastic limit of geotextiles PES B fibers *a* - in length direction, *b* - in width direction

The relationship between work up to the maximum force and work up to the elastic limit for needled nonwoven geotextiles of PES A and PES B fibers can be described by regression equations (Table 7):

Table 7. The relationship of work up to the maximum force and work up to the elastic limit for geotextiles

Geotextile	$W_e = a + bW_m$ (J)				
	Direction	*a*	Standard error	*b*	Standard error
PES A	Length	3,16729	0,91915	0,28358	0,01436
	Width	6,55674	1,64228	0,30438	0,02048
PES B	Length	2,25983	0,66523	0,22143	0,01285
	Width	3,7173	1,37095	0,18563	0,02077

W_m -Work up to the maximum force of geotextiles - (J)

W_e - Work up to the elastic limit of geotextiles - (J)

The high values of correlation coefficients suggest that regression equations obtained could be used for predicting geotextile behavior during exploitation. Therefore, the aim is to define permissible loads that would not bring about permanent deformations of geotextile material.

4. CONCLUSIONS

Analyzing close correlations between mechanical characteristics of nonwoven geotextile materials we can fulfill the requirements for correct designing of geotextiles depending on their application. Defining the elastic limit of nonwoven geotextile we can find out the limit force intensities that can be applied to geotextile without disturbing its quality. The results obtained suggest that permanent deformation of geotextile, made of virgin PES fibers, along the length, appear under loads of 52,98% to 61,67% related to maximum tensile force. Along the width, elastic limit ranges from 48,23% to 57,45% related to maximum tensile force. The work up to the elastic limit, along the length of virgin PES geotextile, ranges from 30,40% to 37,56% related to work up to the maximum tensile force; along the width, it ranges from 33,53% to 47,45%. With geotextile made of recycled PES fibers, along the length, the work ranges from 23,8% to 37,14% related to work up to maximum tensile force; along the width, it ranges from 21,93% to 35,15%.

Based on the analysis of parameters correlation at the break point of needled geotextiles and data at the elastic limit, proposed are dependences by which we can predict permissible tensile loads of geotextiles made of virgin polyester fibers and geotextiles made of recycled polyester fibers.

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