Indian Journal of Fibre & Textile Research
Vol. 43, June 2018, pp. 158-163

Predicting behavior of needled geotextile materials made of recycled polyester fibres up to yield point

Dušan Trajković[1], Jovan Stepanović[1,a], Dragan Stojiljković[1] & Dragan Đorđić[2]
[1]Faculty of Technology, University of Nis, Leskovac 16000,Serbia
[2]CIS Institute, Belgrade 11000, Serbia

Received 27 February 2016; revised received and accepted 5 December 2016

The paper reports the results of the analysis of mechanical properties of nonwoven geotextile material from recycled polyester fibres of areal density 150, 200, 250, 300 and 500 g/m^2. Also, the limits to yield point of needled geotextile materials, which define the permissible loads of geotextiles, are determined. Using mechanical models (model of Lethersich) and experimental results, the behavior of needled geotextiles made of recycled polyester fibres in the region up to the yield point can be described. The proposed method and the results can be used to predict the acceptable loads that nonwoven geotextile materials made from recycled polyester fibres can be subjected to exploitation with application.

Keywords: Geotextiles, Limit of elasticity, Recycled polyester, Nonwoven, Needle punching

1 Introduction

The needled nonwovens are complex three-dimensional fibre structures[1-5] that have intensive applications in various spheres of industry[6-9]. Anisotropic structure of needled nonwovens[10] contributes to different, sometimes difficult to explain, behavior during tension[11]. The properties of geotextile materials can be predicted by the empirical models[1], using the finite element method and by the theory of composite materials[12], using computer models to predict the stretching of nonwovens[13], and also using rheological models[14-15]. In this way, each type of deformation of real material is simulated by a simple model or this simulation is presented by complex models developed by combining simple models. Simple models for describing elastic, viscoelastic and plastic deformations are the models which define the properties of ideal materials not existing in nature but their properties, under specific load conditions and other external conditions, reflect approximately the behavior of real materials. In this work[14], an attempt was made to apply Lethersich model to describe the behavior of geotextile materials. The relationship graph of tensile force - elongation was analyzed and an attempt was made to apply Lethersich model to describe the force-elongation relationship up to the maximum strength of geotextile. It was concluded that the shape of force-elongation curve, obtained on tensometer, and the curve shape of Lethersich model do not coincide after the elasticity limit. However, up to the elasticity limit, the Lethersich model describes geotextile behavior correctly. Therefore, the aim of this study was to develop a model that could describe the behavior of needled textile in the elastic deformation zone, i.e. to the yield point[16], because it defines the permissible load during exploitation with application.

The needled nonwoven textile is a fibrous product where even the smallest stress can cause the sliding between the fibres, resulting in plastic deformation. The term "yield point" defines the upper limit of domination of elastic deformations of the needled geotextile. This is the limit where the material starts to deform faster under stress. Therefore, it should be regarded as the limit of permissible loads under stress. The Lethersich model, having generally a viscoelastic character, was selected to describe the geotextile behavior up to the yield point. The experimental results [14,15] confirm the viscoelastic behavior of needled geotextiles from the beginning of stretching up to the yield point; that is why this model was selected. Combining the basic rheological models, a rheological model - Lethersich body was established (Fig. 1).

[a]Coresponding author.
E-mail: jovan64@yahoo.com

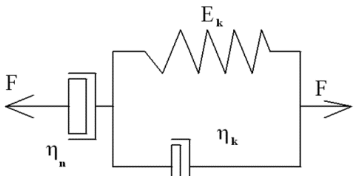

Fig. 1 — Model of Lethersich body

Lethersich body (L) represents a serial link between Newton (N) and Kelvin models (*K*)[14, 15]:
L = *N*---*K*

Rheological model is described by a differential equation:

$$\ddot{\varepsilon}\cdot\eta_K+\dot{\varepsilon}\cdot E_K\cdot\eta_K=\dot{\sigma}(\eta_N+\eta_K)+\sigma\cdot E_K \quad \ldots (1)$$

where $\dot{\varepsilon},\ddot{\varepsilon}$ is the first and the second derivative of the deformation-time function; $\sigma,\dot{\sigma}$, the stress and the first derivative by time; E_K, the kelvin model elasticity modulus; η_K the kelvin model viscosity coefficient; and η_N the newton body viscosity coefficient.

The solution of differential Eq. (1) gives:

$$\sigma=\eta_N\cdot\dot{\varepsilon}\cdot\left[1-\exp\left(\frac{l_o}{100\cdot v\cdot\tau_r}\cdot\varepsilon\right)\right] \quad \ldots (2)$$

where l_o is the starting sample length; v, the moving speed of tensometer grips; τ_r, the relaxation time; and ε, the relative elongation.

Since the zone of elastic deformations of geotextiles from recycled fibres is insufficiently studied, this study aims to contribute to the development of a method that can be used to predict the behavior of needled nonwoven geotextile materials from recycled PES fibres in the region up to the yield point.

2 Materials and Methods

Recycled polyester fibres were used for making needled geotextile. Polyester fibers were made of polyethylene terephthalate (PES). The melting points of recycled PES fibres were determined by Ramp method from 50 °C to 300 °C on a DSC Q20 V24.11 Build 124 instrument. The melting point of recycled PES fibres was found to be 242.11 °C. Using Video Analyser 2000, it is found that PES fibres have circular cross-section. Charecteritics of recycled polyester (PES R) are :

Property		Value
Average fibre length	:	83.1mm
Fibre fineness	:	6dtex
Relative fibre breaking force (CV%)	:	37.7 cN/tex (19.4)
Breakin elongation (CV%)	:	63.5% (24.8)

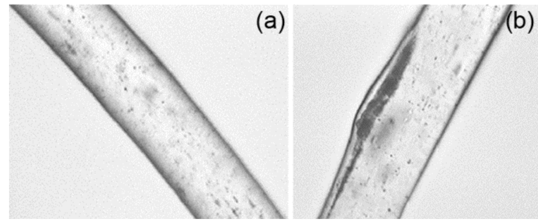

Fig. 2 — Microscopic view of PES R fibres at a magnification of ×1000 [(a) impurities and (b) cracks]

Microscopic view of fibres used for production of tested geotextile material is shown in Fig. 2. Observing the microscopic image of fibres it can be noticed that on the individual PES R fibres (Fig. 2), there is visible presence of impurities and cracks. This fact, inter alia, is reflected on the mechanical properties and quality of PES R fibres as well as on the quality of geotextiles.

The geotextile materials were produced of 100% recycled PES fibres, under industrial conditions as shown above. The geotextile materials were made with areal density of 150, 200, 250, 300 and 500 g/m^2.

PES R geotextile of areal density 150-250 g/m^2 is mainly used for repair of minor damage on lowland local roads fifth class (up to 1000 vehicles per 24 h), which is intended for light traffic. PES R geotextile of areal density 300-500 g/m^2 is mainly used for repair of major damage on lowland local roads third class (from 3000-7000 vehicles per 24 h) which is intended for medium traffic. These types of needled geotextiles can be used in the construction of sports fields, car parks and flat roofs.

The samples of geotextile materials were formed using the needle felting method. The felt is formed by laying web into the felt using equipment for web crosslaying. The crossed fibres position is accomplished in the way that the web from the carding machine is placed on a transporter moving square to felt direction. In such a laying, the position of fibres could not be exactly square because the web is laid in layers which are, due to the moving of the transporter with felt, placed under a certain angle. The web laying angle in the felt can be obtained from the following relation:

$$\alpha=\text{arc tg}\frac{v_p}{v_k}\quad[\text{deg}] \quad \ldots (3)$$

where α is the web laying angle in the felt (deg); v_p, the felt moving speed (the speed of the transporter with felt) (m/min); and v_k, the web moving speed (the speed of the transporter with the web) (m/min).

Table 1 shows characteristics of the needles used, needling depth and density and the web laying angle in the felt. The needling was performed on a machine by “DILO”.

For the testing of geotextile materials, the following test methods were used:

- SRPS EN ISO 9864 - Geotextile - Determination of mass per unit area
- SRPS EN ISO 10319 - Geotextile - Tensile testing by the method with broad laboratory sample

Determination of breaking force and deformation at the highest load were measured with a preload of 0.02 kN, at grips distance of 100 mm and the speed of 20 mm/min (Tensolab strength tester 2510). The sampling was done in accordance with ISO 9862:2005. 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.

From F-ε graph, the values of forces and relative elongations at yield point were determined, which can be numerically determined at the maximum of the first derivative of F(ε) function where $F''(\varepsilon) = 0$[15].

Figure 3 presents a force-elongation function [Fig. 3(a)], and the function first derivative and its second derivative. The first derivative maximum [Fig. 3(b)] indicates the limit of permissible loads. Up to this point, geotextile material exhibits higher resistance to stretching forces [F’(ε) function grows]. When the first derivative function reaches the maximum, the second derivative at that point is 0 [Fig. 3(c)]. Then, a faster geotextile deformation is set in, up to material destruction [F’(ε) function declines].

3 Results and Discussion

Table 2 shows the processed test results of geotextile materials. Figure 4 shows the relationship between forces at yield point and maximum breaking forces of the analyzed geotextile materials made of recycled PES fibres.

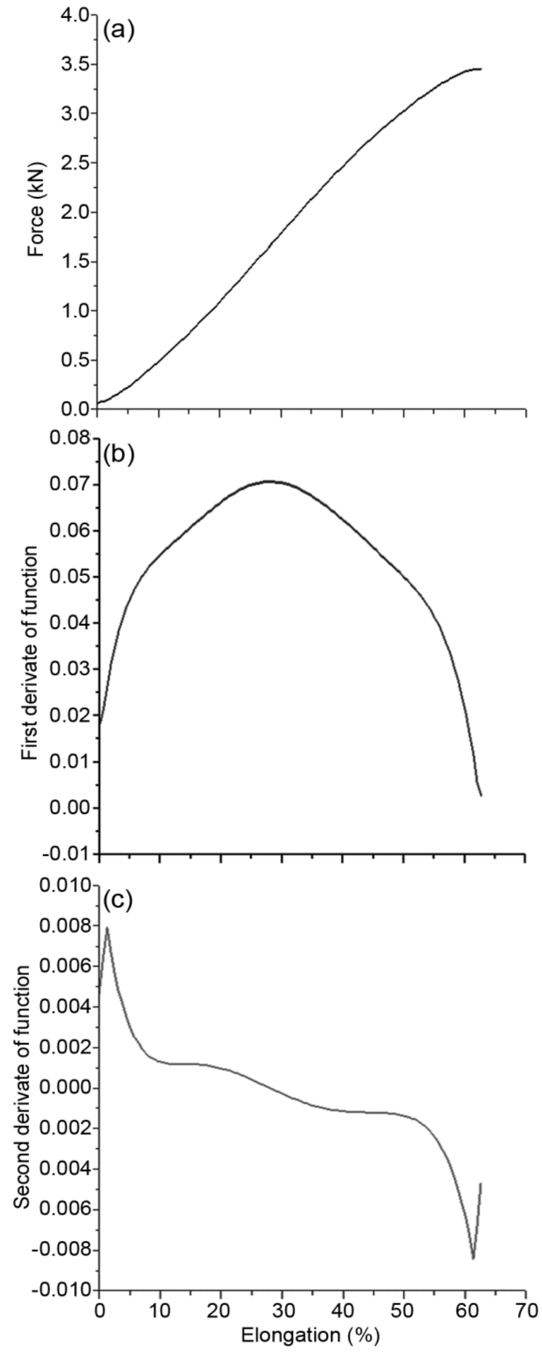

Fig. 3 — Graph of force-elongation function (a) F(ε), (b) first F’(ε) and (c) second F’’(ε) derivatives of function

Table 1 — Needling parameters

Geotextile	Needle type		Depth of needling mm	Density of needling, cm^{-2}	Web laying angle in the felt, deg
	Input board	Output board			
150 PES R	15*18*36*3R333 G1002	15*18*36*3R333 G1002	15.5	91.4	4.6
200 PES R	15*18*36*3R333 G1002	15*18*36*3R333 G1002	16.0	109.7	3.8
250 PES R	15*18*36*3R333 G1002	15*18*36*3R333 G1002	16.5	115.5	3.6
300 PES R	15*18*32*3R333 G1002	15*18*36*3R333 G1002	17.0	120.4	3.3
500 PES R	15*18*32*3R333 G1002	15*18*36*3R333 G1002	17.5	169.7	1.9

Table 2 — Test results (mean values) of geotextile materials made of recycled PES fibres

Samples	Direction	Maximum breaking force		Deformation at maximum load		Force at yield point		Elongation at yield point	
		Value, kN	CV %	Value, %	CV %	Value, kN	CV %	Value, %	CV %
Geotextile 150 PES R	MD	0.26	29.8	99.1	28.9	0.15	27.4	67.7	34.2
	CMD	0.47	6.8	88.4	21.3	0.27	23.7	60.2	29.5
Geotextile 200 PES R	MD	0.90	6.5	95.6	10.3	0.50	3.9	61.2	14.3
	CMD	1.41	9.5	80.1	12.5	0.68	9.6	47.1	17.9
Geotextile 250 PES R	MD	0.85	14.0	99.9	11.1	0.49	15.4	62.4	10.2
	CMD	1.37	11.9	81.3	3.8	0.72	18.3	47.7	14.4
Geotextile 300 PES R	MD	1.31	11.7	79.7	6.5	0.67	9.0	43.3	13.7
	CMD	1.99	15.1	67.8	6.5	1.09	11.9	40.8	15.1
Geotextile 500 PES R	MD	2.46	7.1	69.0	9.4	1.33	9.9	35.4	5.1
	CMD	3.49	11.7	61.4	14.8	1.81	9.3	32.4	2.7

Machine direction (MD) – The sample taken along longitudinal axis of geotextile.
Cross machine direction (CMD) – The sample taken along transverse axis of geotextile.

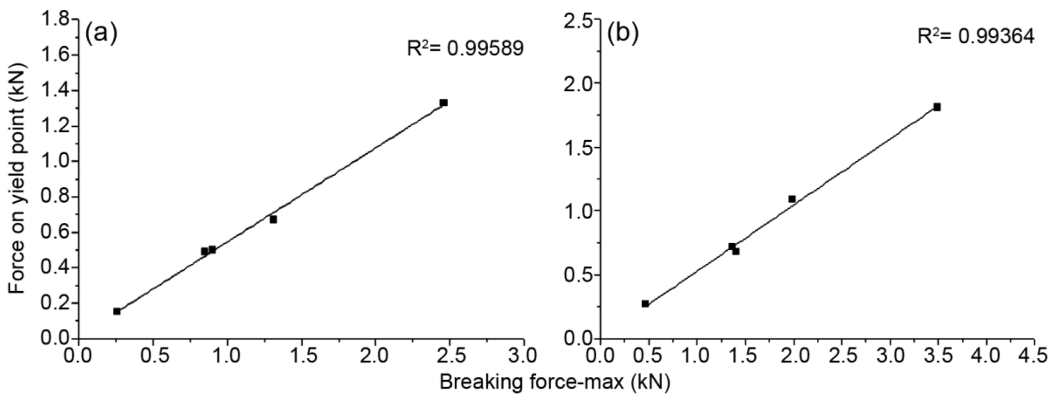

Fig. 4 — Relationship between forces at yield point and maximum breaking forces of geotextile made of recycled PES fibres in (a) machine direction, and (b) cross machine direction

The relationship of the force at yield point and maximum breaking force of needled nonwoven geotextile materials made of recycled PES fibres can be presented by following regression equations:

$F_y = a + bF_b$ (kN) ...(4)

where F_y is the force at yield point of geotextile (kN); F_b, the breaking force of geotextile (kN); a = 0.01467 (SE = 0.02333) in machine direction; a = 0.01048 (SE = 0.04160) in cross machine direction; b = 0.53056 (SE = 0.01704) in machine direction; and b = 0.51748 (SE = 0.02069) in cross machine direction.

Based on the results obtained it can be concluded that the needled geotextiles have better breaking characteristics in cross machine direction than in machine direction, as a result of the web laying method in the felt before the needling process. In this case, the angle of web laying in the felt ranges from 1.9^o (geotextile 500 g/m^2) to 4.6^o (geotextile 150 g/m^2) relative to transverse axis of the felt.

As a result of such web laying in the felt, fibres are oriented across the longitudinal axis of the felt, this being the cause of higher geotextile strength in the cross machine direction relative to machine direction (Fig. 5).

Figure 5 shows the relationship between the force at yield point and the areal density of geotextile made of recycled PES fibers [Fig. 5(a)] and the relationship between the force at yield point and web laying angle in the felt [Fig. 5(b)].

Analyzing the results from Table 2 it could be concluded that the limit up to the yield point of PES R geotextile ranges from 51.14% to 58.08% of the maximum tensile force in the machine direction and from 48.23% to 57.45% of the maximum tensile force in the cross machine direction.

High values of correlation coefficient indicate that the regression equations obtained can be used for the prediction of yield point of needled geotextile

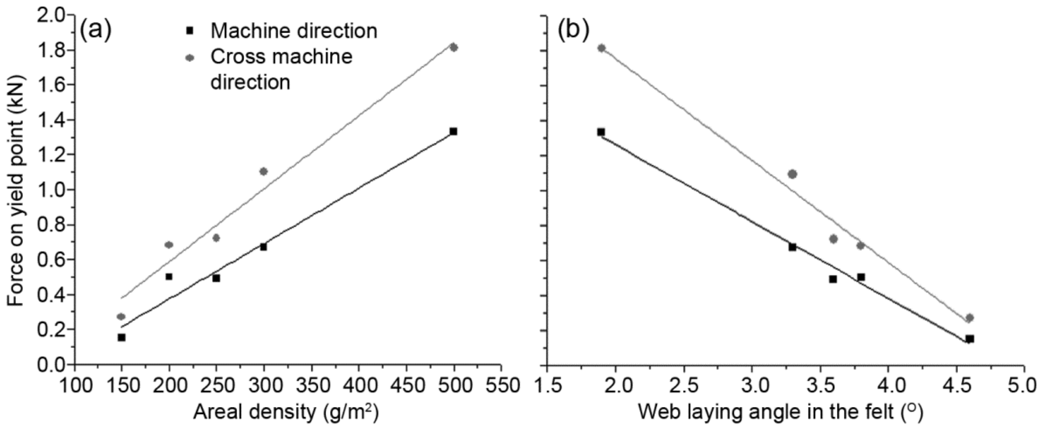

Fig. 5 — Force at yield point of geotextile of recycled PES R fibres depending on (a) areal density and (b) web laying angle in the felt

materials. Thereby, the aim is particularly to define permissible loads that would not give rise to permanent deformation of geotextile materials. The yield point of nonwoven geotextile materials, defined in this way, served as limit values during composing of mathematical models. The behavior of geotextile was described in the region to yield point whereby the model describes the behavior of material from the start of straining to yield point. During stretching on a tensometer the rate of deformation has a constant value. Starting sample length is 0.1 m and the moving speed of tensometer grips is 0.000333333 m/s. Introducing these data to Eq. (2) and with the assumption that viscosity coefficients are the same ($\eta_N = \eta_k$), the following equation is obtained:

$$\sigma = a \cdot [1 - \exp(-b \cdot \varepsilon)] \quad \ldots(5)$$

By fitting experimental data in the form of Eq. (5), using appropriate software package, the values of coefficients "*a*" and "*b*" are determined.

Table 3 shows the values of model coefficients "*a*" and "*b*" obtained on the basis of rheological model, set on the basis of experimental data for geotextile materials of recycled PES fibres.

Relative error of the model is calculated from:

$$r_e\,(\%) = \frac{F_e - F_m}{F_e} \cdot 100 \quad \ldots(6)$$

where r_e is the model relative error (%); F_e the real value of stretching force of geotextile (measured on tensometer); and F_m the stretching force determined by mathematical model.

Analyzing the result it can be concluded that the model describes correctly the behavior of geotextile of recycled PES fibres in the region to yield point [relative error of the model by Eq. (6) is lower than 10%].

Table 3 — Model coefficients up to the yield point

Samples	Machine direction		Cross machine direction	
	a	*b*	*a*	*b*
Geotextile 150 PES R	-0.03980	-0.02215	-0.02885	-0.03900
Geotextile 200 PES R	-0.05886	-0.03536	-0.06310	-0.05222
Geotextile 250 PES R	-0.23251	-0.01746	-0.21033	-0.03167
Geotextile 300 PES R	-0.27000	-0.02899	-0.26432	-0.03987
Geotextile 500 PES R	-1.25566	-0.02111	-0.26457	-0.03997

Yield point is essentially the limit of elastic deformation in material. Beyond the yield point faster deformation of material occurs and the structure of needled geotextile is disturbed. Therefore, the yield point of geotextile represents the limit of the load, at which the resulted deformations in geotextile will not significantly affect the structure stability and the durability of material.

4 Conclusion

Defining yield point of nonwoven geotextile provides data on the maximum force intensities that can be applied to geotextiles without disturbing their quality. The results obtained indicate that the permanent deformation of geotextile made of recycled PES fibres in machine direction occurs under loads which is 51.14 - 58.08% of the maximum tensile force, while in cross machine direction the limits to yield point range from 48.23% to 57.45% of the maximum tensile force.

Analyzing the relationship of parameters at break limit of needled geotextiles and the data at yield point, the relationships are proposed by which permissible loads during stretching of geotextile of recycled fibres can be predicted.

Based on physical models and experimental results a rheological model is developed which can be used for simulation of the behavior of nonwoven geotextile materials made of recycled PES fibres. The model describes the behavior of geotextile under loads up to the limits to yield point. The developed models can also be used for predicting limit loads of nonwoven geotextiles of recycled PES fibres, after which the irreversible deformation of these materials occurs.

Acknowledgement

Authors acknowledge with thanks the funding support by the Ministry of Education and Science of the Republic of Serbia [No. TR 34020].

References

1 Rawal A &Anandjiwala R D, *J Industrial Text*, 35 (2006) 271.
2 Antoine R &Courard L, *Geotext Geomembr*, 14 (1996) 585.
3 Adolphe D, Lopes M & Sigli D, *Text Res J*, 64 (1994) 176.
4 Cincik E & Koc E, *Text Res J*, 82 (2012) 430.
5 Rawal A, Anand S & Shah T, *J Industrial Text*, 37 (2008) 341.
6 Zhai H, Mallick S B, Elton D & Adanur S, *Text Res J*, 66 (1996) 269.
7 Saidi M A, Drean J Y & Adolphe D, *Text Res J*, 69 (1999) 10.
8 Youjiang W, *J Industrial Text*, 30 (2001) 289.
9 Ghosh T K, *Geotext Geomembr*, 16 (1998) 293.
10 Gautier K B, Kocher C W & Drean J Y, *Text Res J*, 77 (2007) 20.
11 Rawal A, Patel S K, Kumar V, Saraswat H & Sayeed A M M, *Text Res J*, 83 (2013) 1103.
12 Erdogan U H & Erdem N, *Ind Textila*, 62 (2011) 227.
13 Liao T, Adanur S & Drea J Y, *Text Res J*, 67 (1997) 753.
14 Stepanovic J, Stojiljkovic D, Djordjic D & Trajkovic D, *Ind Textila*, 65(2014) 90.
15 Stepanovic J, Trajkovic D, Stojiljkovic D & Djordjic D, *Text Res J*, 86 (2016) 1385.
16 Trajkovic D, Stepanovic J, Stojiljkovic D & Djordjic D, *Tekst Konfeksiyon*, 25 (2015) 229.