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Analysis of the Main Properties of Geotextiles Manufactured by Mechanical Two-Sided Needle Punching and by Two-Layered Needle Punching on the Fabric Underlay

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Abstract
An analysis of the basic properties of geotextiles obtained by two-sided needle punching and by two-layered needle punching on the fabric underlay is presented in this paper. The influence of geotextile production technology on their functional properties was evaluated, the parameters of geotextiles manufactured from staple fibres by mechanical needle punching were compared for both techniques, and the influence of the mass per unit area on the mechanical and hydraulic properties is shown. It was found that geotextiles obtained by two-sided needle punching had very good hydraulic properties thanks to their spatial structure, whereas geotextiles obtained by two-layered needle punching on the fabric underlay, apart from good hydraulic properties, had very good tensile strength and small elongation at a maximum load, which is particularly useful for reinforcement.

Key words: *geosynthetics, geotextiles, nonwowen geotextiles, mechanical needle punching technology.*

Introduction

Geotextiles, meaning materials applied to be in contact with soil and rocks, are the largest group of geosynthetics used in civil engineering practice [1].

The most numerous group of geotextiles are geononwovens produced from staple fibres using the technology of mechanical needle-punching. The mechanism of nonwoven geofabric structure formation consists in the use of steel intertwine needles [4 - 7]. The features of geotextiles connected with their properties of use are the effect of the resources and production technologies applied, which decide on the structure of the product. The technology of mechanical needle-punching enables the use of products with various properties depending on the requirements for drainage, filtration and separation functions of geononwovens [2, 3]. Obtaining geononwovens using the technology of mechanical needle punching by the two-sided needle punching technique and by two-layered needle punching on the fabric underlay with the same technological and resource parameters was discussed and compared, and the properties of the geononwovens obtained were described. The needle-punched nonwoven geotextiles are characterised by very good hydraulic properties resulting from their considerable porosity, but simultaneously they show lower tensile strength and static puncture resistance as well as considerable elongation.

Materials

An analysis of manufacturing technology's influence on the mechanical and hydraulic properties of nonwoven geotextiles marked out for testing was conducted. It included the designing and production of needle punched nonwoven geotexstiles of an intended mass per unit area on the basis of currently used technologies and evaluation of selected mechanical and hydraulic properties. For metrological and hydraulic tests soft nonwoven geotextiles were selected - the polypropylene nonwoven geotextiles were produced by the Lentex Public Company in Lubliniec, manufactured by two different needle punching techniques (***Table 1***):

- mechanical needle – punching on two sides (both sides)

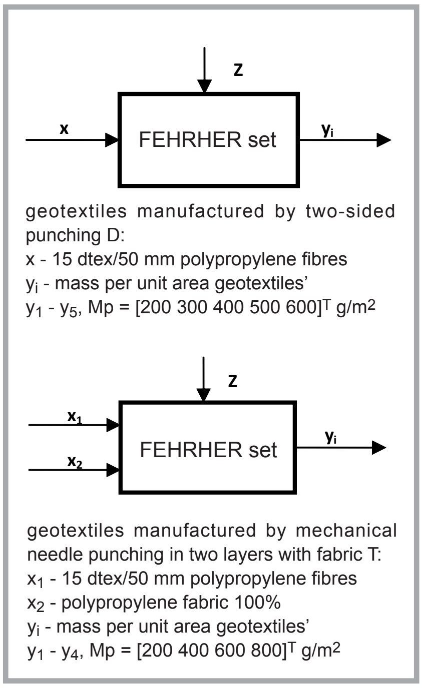

Figure 1. *Manufacturing geotextiles by mechanical two-sided needle punching and by two-layered needle punching on the fabric underlay (Malkiewicz J. 2009).*

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- mechanical needle –punching in two layers with fabric

In the experiment polypropylene staple fibres (100% PP) with a linear density of 15 dtex and a staple length of 60 mm were used. A mass per unit area of 200 - 600 g/m^2 for mechanical needle–punching on two sides and 200 - 800 g/m^2 for mechanical needle – punching in two layers with fabric was the criterion of geononwoven selection for testing. The mass per unit area of the fabric underlay of plain weave made up of polypropylene tapes was equal to 100 g/m^2 for all types of geotextiles.

The following geotextiles were taken into account:

- obtained by two-sided needle punching: mass per unit area M_p = [200 300 400 500 600]^T g/m^2,
- obtained by mechanical needle – punching in two layers with fabric: mass per unit area M_p = [200 400 600 800]^T g/m^2.

A plan of experiment

The geotextiles were manufactured by a FEHRHER set according to the manufacturing cycle illustrated in ***Figure 1***.

These are the following parts of the cycle: preparing the raw material, nonwoven fibre web forming on an aerodynamic carding machine, implementation of the base in the form of woven fabric (in the case of geotextile manufactured by two-layered needle punching on the fabric underlay), needle punching of a geononwoven fibre web by means of a mechanical device for needling, cutting off the edges, winding and packing.

Methods of investigation

The geotextiles were investigated. The scope and kind of testing of the geotextiles' properties were adjusted to the function which the materials fulfil in the construction. Nonwoven geotextiles are mainly applied as dranage filtration and a separation layer as well as in fabric for reinforcement. The tests concerned physical, mechanical and hydraulic properties. All tests were performed on the basis of harmonised European Standards. The physical and mechanical properties of the geotextiles were characterised by the following parameters: mass per unit area (PN-EN ISO 9864), thickness

Table 1. *Parameters of manufacturing geononwovens.*

No.	Parameter	Geonwovens - two-sided needle punching	Geonwovens -two-layered needle punching on the fabric underlay
1.	Raw materials:	PP100% PP 15 dtex/60 mm	1. PP100% PP 15 dtex/60 mm 2. fabric PP -100 g/m^2
2.	Preparation of raw material:	Device for precise defining percentage of fibres	Device for precise defining percentage of fibres
3	Process of manufacturing	FEHRER set	FEHRER set
4.	Speed of needling in m/min	K - 3,0	K - 3,0
5.	Type of needles	FOSTER F 206/3B	FOSTER F 206/3B
6.	Depth of needling in mm)	10	10
7.	Punching density in lp/cm^2	30	30
8.	Mass per unit area after needling in g/m^2	D/200 - 210.1 D/300 - 316.5 D/400 - 406.8 D/500 - 500.6 D/600 - 581.7	T/200 - 229.8 T/400 - 411.1 T/600 - 576.0 T/800 - 813.7
9.	Width after needling in cm	320	320
10.	Length of winding in mb	35 - 40	35 - 40

Table 2. *Statistical parameters of the mechanical properties of geotextiles manufactured by two-sided needle punching D;* ***Legend****: description for* ***Tables 2*** and ***3****;* M_p *– mass per unit area,* $e_{2\,kPa}$ *– thickness at pressure 2 kPa,* $e_{20\,kPa}$ *- thickness at pressure 20 kPa,* $e_{200\,kPa}$ *- thickness at pressure 200 kPa,* $F_{r\,MD}$ *– tensile strength in machine direction,* $F_{r\,XMD}$ *- tensile strength in cross machine direction,* E_{MD} *– elongation at maximum load in machine direction,* E_{XMD} *- elongation at maximum load in cross machine direction th,* F_{CBR} *– static puncture ,resistance,* F_D *– dynamic puncture resistance, statistics:* $\bar{X}$ *- mean value,* $V_{\%}$ *coefficient of variation, U – mean error, geotextile direction: MD – machine direction, XMD – cross machine direction, D – geotextiles manufactured two sided needle punching, T – geotextiles manufactured by two – layered needle punching on the fabric underlay.*

Parameter		M_p, g/m^2	e_{2kPa}, mm	e_{20kPa}, mm	e_{200kPa}, mm	F_r MD, kN/m	F_r XMD, kN/m	E MD, %	E_{XMD}, %	F_{CBR}, kN	F_D, mm
D/200	$\bar{x}$	210.8	2.54	1.84	1.0	7.3	12.2	119.2	109.0	1.3	22.4
	$V_{\%}$	0.28	1.89	1.18	3.65	1.23	0.82	0.34	0.42	2.64	3.12
	u	8.51	0.03	0.02	0.03	0.11	0.12	0.50	0.57	0.04	0.57
D/300	$\bar{x}$	316.5	3.0	2.2	1.23	13.8	19.9	120.2	115.6	2.2	18.0
	$V_{\%}$	1.12	6.21	4.04	5.05	0.69	0.49	0.09	0.38	4.7	2.62
	u	8.51	0.09	0.03	0.04	0.12	0.12	0.14	0.55	0.13	0.59
D/400	$\bar{x}$	406.8	3.2	2.8	1.8	16.9	25.7	130.3	121.3	3.2	12.0
	$V_{\%}$	0.32	1.09	2.66	4.15	0.48	1.24	0.37	0.22	5.43	3.93
	u	8.51	0.02	0.05	0.05	0.10	1.40	0.60	0.33	0.22	0.59
D/500	$\bar{x}$	500.6	4.3	3.7	2.4	21.8	35.0	139.0	129.0	4.5	8.5
	$V_{\%}$	1.48	4.69	6.82	3.23	0.75	0.22	0.61	0.56	5.44	0.32
	u	8.51	0.15	0.18	0.06	0.20	0.10	1.05	0.90	0.31	0.88
D/600	$\bar{x}$	581.7	4.57	3.91	2.57	23.4	38.5	147.2	131.4	5.8	7.5
	$V_{\%}$	0.63	3.01	3.79	5.21	2.59	0.98	2.64	0.60	5.21	7.03
	u	8.51	0.10	0.11	0.10	0.75	0.47	4.83	0.98	0.38	0.66

Table 3. *Statistical parameters of the mechanical properties of geotextiles manufactured by two-layered needle punching on the fabric underlay T.*

Parameter		M_p, g/m^2	e_{2kPa}, mm	e_{20kPa}, mm	e_{200kPa}, mm	F_r MD, kN/m	F_r XMD, kN/m	E MD, %	E_{XMD}, %	F_{CBR}, kN	F_D, mm
T/200	$\bar{x}$	229.8	2.56	1.63	0.89	12.8	8.1	9.9	5.9	1.42	15.4
	$V_{\%}$	0.67	1.17	1.58	1.40	3.44	1.69	1.50	2.78	3.18	4.54
	u	8.51	0.02	0.02	0.01	0.55	0.17	0.18	0.20	0.06	0.57
T/400	$\bar{x}$	411.0	3.89	2.77	1.49	16.2	11.8	12.3	9.3	1.83	8.6
	$V_{\%}$	0.21	3.33	4.01	0.76	3.79	2.63	4.08	5.38	3.87	6.0
	u	8.51	0.09	0.08	0.01	0.76	0.39	0.63	0.62	0.09	0.64
T/600	$\bar{x}$	576.0	4.77	3.73	2.16	16.7	12.8	12.5	9.8	2.65	5.5
	$V_{\%}$	0.54	1.60	3.93	5.53	0.68	2.78	2.70	2.46	5.97	9.58
	u	8.51	0.05	0.10	0.09	0.14	0.44	0.42	0.30	0.20	0.66
T/800	$\bar{x}$	813.7	6.56	5.28	2.98	18.8	14.1	17.0	10.7	3.51	1.6
	$V_{\%}$	0.55	1.74	9.01	10.2	2.13	1.04	2.85	1.48	5.09	32.3
	u	8.51	0.08	0.34	0.22	0.50	0.18	0.60	0.20	0.22	0.64

Table 4. *Results of variance analysis test according to double classification in the case of geotextiles manufactured by two-sided needle punching.*

- considerable influence has not been proved
- considerable influence of the factor

Parameter analysed	N_H		M_p	
	$F_{A.\alpha}$	F_{kr}	$F_{E.\alpha}$	F_{kr}
$q_{ngMD\ i=0,1}$	1.70	3.49	1.09	3.26
$q_{ngXMD\ i=0,1}$	6.33	3.49	2.01	3.26
$q_{ngMD\ i=1}$	10.41	3.49	2.79	3.26
$q_{ngXMD\ i=1}$	26.69	3.49	2.43	3.26

Tabela 5. *Results of the variance analysis test according to double classification for geotextiles manufactured by two-layered needle punching with fabric;*

- considerable influence has not been proved
- considerable influence of the factor

Analyzed parameter	N_H		M_p	
	$F_{A.\alpha}$	F_{kr}	$F_{E.\alpha}$	F_{kr}
$q_{ngMD\ i=0,1}$	11.47	3.26	0.83	3.86
$q_{ngXMD\ i=0,1}$	15.95	3.26	1.58	3.86
$q_{ngMD\ i=1}$	17.73	3.26	0.73	3.86
$q_{ngXMD\ i=1}$	25.19	3.26	1.25	3.86

at a particular pressure - 2, 20, 200 kPa (PN-EN ISO 9863), tensile strength, elongation at a maximum load (PN-EN ISO 10319), static puncture resistance - CBR method (PN-EN ISO 12236), and dynamic puncture resistance - cone drop test (PN-EN ISO 13433). The hydraulic properties were characterised by the water flow capacity (PN-EN ISO 11058), water permeability in the plane (PN-EN ISO 12958), and characteristic opening size (PN-EN ISO 12956).

Results and discussion

According to the research programme (***Figure 1***) and methods of investigation and analysis of experimental data, the research was conducted in order to determine the influence of the mass per unit area on the basic mechanical and hydraulic parameters of the geotextiles.

Statistical parameters of the mechanical properties for two-sided needle punching and two-layered needle punching are shown in ***Tables 2*** and ***3*** (see page 95).

Analysing the data shown in ***Tables 2*** and ***3***, it can be assumed that when the mass per unit area increases:

- The thickness of geotextiles manufactured by two-sided and two-layered needle punching on the fabric underlay at pressures 2, 20 and 200 kPa increases, whereas under the influence of changing pressures the thickness decreases.
- In the case of geotextiles manufactured by two-sided needle punching, the tensile strength in the machine direction – $F_{r\ MD}$ and in the cross machine direction $F_{r\ XMD}$ increases, then the static puncture resistance – F_{CBR} increases, whereas the dynamic puncture resistance F_D decreases. In the case of geotextiles manufactured by two-layered needle punching on the fabric underlay, the tensile strength depends on the fabric, which causes an increase in both directions, with the value of tensile strength being similar for both directions
- In the case of geotextiles manufactured by two-sided needle punching, the elongation at a maximum load in the machine direction -E_{rMD} and in the cross machine direction – E_{rXMD} increases, whereas in the case of geotextiles manufactured by two-layered needle punching on the fabric underlay, the elongation is independent of M_p; the elongations in the machine and cross machine directions are very little and similar to each other, and the fabric underlay considerably reduces the elongations, which is very essential for reinforcement.

Determination of water flow capacity in the plane

Determination of the water flow capacity in the plane was performed for two hydraulic gradients i = 0.1 and i = 1 under a load of $[2\ 20\ 50\ 100]^T$ in kPa for the machine and cross machine directions.

A variance analysis test was carried out according to double classification to check the changes occurring. Values of the statistics are presented in ***Tables 4*** and ***5***.

In order to illustrate simultaneous changes in the pressure N_H and mass per unit area M_p of the geotextiles for hydraulic gradients i = 0,1 and i = 1 in the machine and cross machine directions, the following form of substitute characteristics was determined:

$$\hat{q}_{ng} = f\left(N_H; M_p\right)$$

Analysing the data presented in ***Figure 2***, it can be assumed that the biggest water permeability in the plane of the product – q_{ng} in the machine direction for geotextiles manufactured by two-sided needle punching, where i = 1, is obtained at low pressures - N_H and at a mass per unit area amounting to 200 – 800 g/m^2. In the range – N_H = 0 – 55 kPa, the more the pressure increases, the more the water permeability in the plane of the geotextiles – q_{ng} decreases; in the range – N_H = 55 – 90 kPa the water permeability does not change, and in the range – N_H = 90 – 100 kPa parameter q_{ngMD} slightly increases. When the mass per unit area of the geotextiles analysed increases, the water permeability slightly increases to M_p = 0 – 300 g/m^2, does not change in the range – M_p = 300 – 500 g/m^2, and slightly decreases in the range - M_p = 500 – 600 g/m^2. As for the use of geotextiles manufactured by two-sided needle punching, pressures in the range – N_H = 0 – 20 kPa and mass per unit area – M_p = 200 – 800 g/m^2 should be used.

In the case of the cross machine direction, it can be assumed that the biggest water permeability in the plane of the product – q_{ng} of geotextiles manufactured by two-sided needle punching is obtained at pressures in the range of – N_H = 0 – 20 kPa, regardless of the M_p value. The more the pressure increases in the range of N_H = 0 – 50 kPa, the more the water permeability decreases; in the range of N_H = 50 – 90 kPa the water permeability does not change, whereas in the range of N_H = 90 – 100 kPa the water permeability of the geotextiles slightly increases. Changing the mass per unit area – M_p of the geotextile slightly influences the water permeability. As for the use of geotextiles manufactured by two-sided needle punching, pressures – N_H = 0 – 20 kPa should be used regardless of the mass per unit area – M_p value.

Analysing the data presented in ***Figure 3***, it can be assumed that the biggest water permeability in the plane of the product – q_{ng} in the machine direction of geotextiles manufactured by two-layered needle punching on the fabric underlay, where i = 0,1, is obtained at pressures – N_H = = 0 – 20 kPa and mass per unit area – M_p = 200 – 300 g/m^2. As for use of the geotextiles analysed, these are the most useful value ranges of both the parameters. At pressure – N_H = 80 kPa and at mass per unit area – M_p = 400 g/m^2 the least favourable local minimum of the water permeability is obtained, whereas the biggest water permeability in the

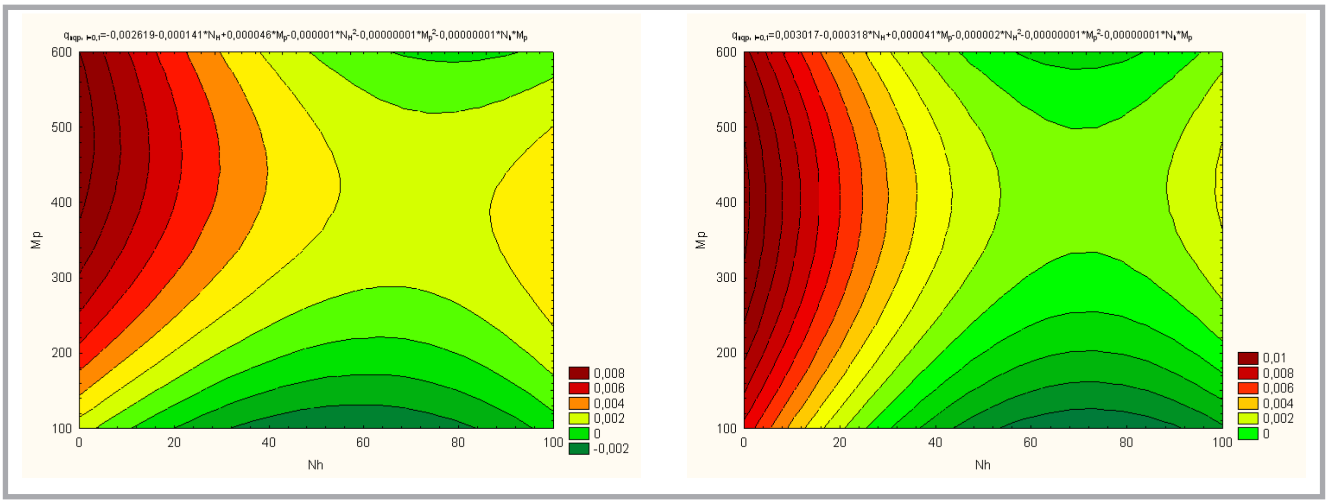

Figure 2. *Water permeability regression of geotextiles manufactured by two-sided needle punching* $\hat{q}_{ngMD} = f(N_H; M_p)$, *here* $i = 1$; $R^2 = 0.626$; $R = 0.791$; $F_{calc.} = 4.69$; $F_{crit,} = 2.96$, $\hat{q}_{ngXMD} = f(N_H; M_p)$, *where* $i = 1$; $R^2 = 0.737$; $R = 0.858$; $F_{calc.} = 7.85$; $F_{crit.} = 2.96$.

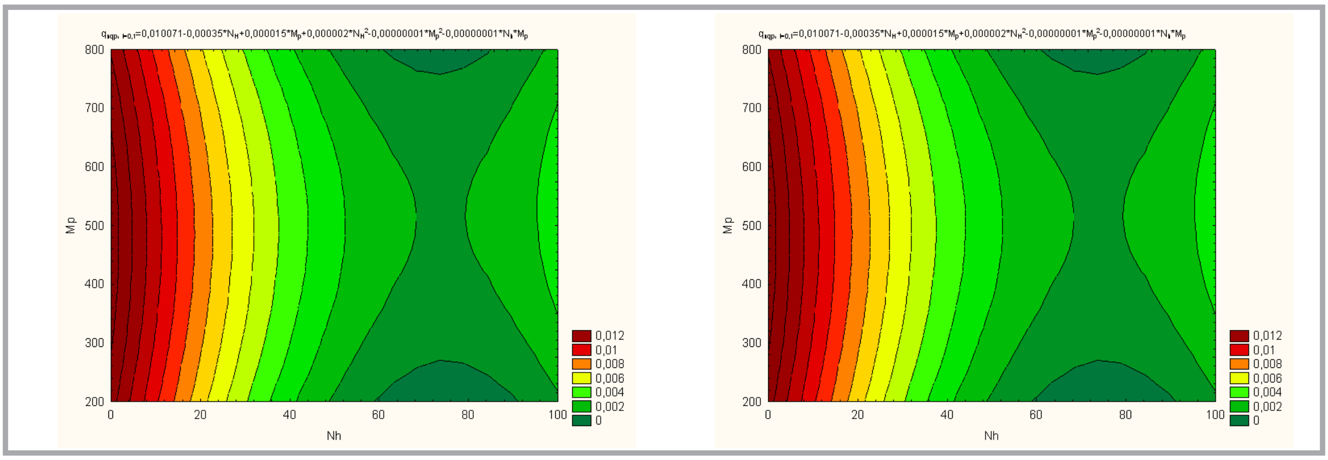

Figure 3. *Water permeability regression of geotextiles manufactured by two-layered needle punching on the fabric underlay* $\hat{q}_{ngMD} = f(N_H; M_p)$, *where* $i = 0.1$; $R^2 = 0.84$; $R = 0.910$; $F_{calc.} = 10.78$; $F_{crit.} = 3.33$, $\hat{q}_{ngXMD} = f(N_H; M_p)$, *where* $i=0.1$; $R^2 = 0.74$; $R=0.86$ $F_{calc.} = 5.89$, $F_{crit.} = 3.33$.

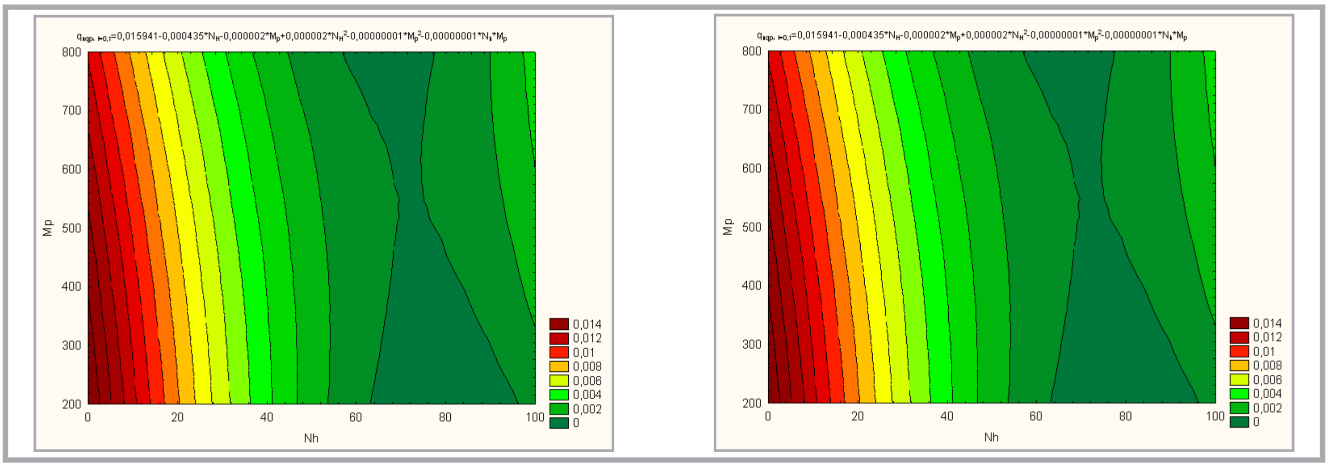

Figure 4. *Water permeability regression of geotextiles manufactured by two-layered needle punching on the fabric underlay;* $\hat{q}_{ngMD} = f(N_H; M_p)$, *where* $i = 1$; $R^2 = 0.820$; $R=0.91$; $F_{calc.} = 9.68$; $F_{crit..} = 3.33$, $\hat{q}_{ngXMD} = f(N_H; M_p)$, *where* $i = 1$; $R^2 = 0.835$; $R = 0.91$; $F_{calc.} = 10.38$; $F_{crit..} = 3.33$.

plane of the product – q_{ng} is obtained at pressures in the range – $N_H = 0 – 20$ kPa, regardless of the mass per unit area – M_p. The more the pressure increases in the range – $N_H = 0 – 50$ kPa, the more the water permeability decreases; in the range – $N_H = 50 – 100$ kPa the water permeability does not change, whereas in the range $N_H = 90 – 100$ kPa the water permeability of the geotextiles slightly increases. Changing the mass per unit area – M_p slightly influences the water

Table 4. Hydraulic parameters of geotextiles obtained by two-sided needle punching.

Parameter	D/200	D/300	D/400	D/500	D/600
Water permeability characteristics normal to the plane, without load VI_{H50}, m/s	2.3 × 10^{-2}	2.2 × 10^{-2}	2.1 × 10^{-2}	1.9 × 10^{-2}	1.8 × 10^{-2}
Characteristic opening size 0_{90}, mm	0.110	0.095	0.089	0.081	0.074

Table 5. Hydraulic parameters of geotextiles obtained by two – layered needle punching on the fabric underlay.

Parametr	T/200	T/400	T/600	T/800
Water permeability characteristics normal to the plane, without load VI_{H50}, m/s	1.9 × 10^{-2}	1.2 × 10^{-2}	1.1 × 10^{-2}	1.1 × 10^{-2}
Characteristic opening size 0_{90}, mm	0.110	0.089	0.085	0.081

permeability of the geotextiles. As for the use of these geotextiles, pressures – N_H = 0 – 20 kPa should be used regardless of the mass per unit area – M_p value.

Analysing the data presented in ***Figure 3***, it can be assumed that the biggest water permeability in the plane of the product – q_{ng} in the cross machine direction of geotextiles manufactured by two-layered needle punching on the fabric underlay, where i = 0.1, is obtained at pressures – N_H = 0 – 20 kPa, regardless of the M_p value. When the pressure increases, the water permeability decreases in the range N_H = 0 - 50 kPa, does not change in the range N_H = 50 - 90 kPa and slightly increases in the range 90 - 100 kPa. The influence of the mass per unit area on water permeability is very little. As for use of the geotextiles, pressures of N_H = = 0 - 20 kPa should be used regardless of the M_p value.

Analysing the data presented in ***Figure 4*** (see page 97), it can be assumed that the biggest water permeability in the plane of the product – q_{ng} in the machine direction of geotextiles manufactured by two-layered needle punching on the fabric underlay, where i = 1, is obtained at pressure – N_H = 0 – 20 kPa regardless of the mass per unit area – M_p value. As for use of the geotextiles analysed, this is the most useful range of the value of both the parameters. At pressure – N_H = 75 kPa and mass per unit area M_p = 500 g/m^2 the least favourable local minimum is obtained, whereas the biggest water permeability in the plane of the product – q_{ng} is obtained at pressure – N_H = 0 – 20 kPa and mass per unit area in the range – M_p = 200 – 700 g/m^2. These are the most useful ranges of the value of both the parameters. The more the pressure – N_H increases, regardless of the mass per unit area of the geotextile analysed – M_p, the water permeability of the geotextile decreases in the range N_H = 0 – 40 kPa , and in the range N_H = = 40 – 100 kPa parameter – q_{ng} does not change.

The biggest water permeability in the plane of the product q_{nq} in the cross machine direction of geotextiles manufactured by two-layered needle punching on the fabric underlay, where i = 1, is obtained at pressure – N_H = 0 – 20 kPa and mass per unit area M_p=200-700 g/m^2. These are the most useful value ranges for both parameters. When the pressure increases, the water permeability decreases in the range N_H = 0 - 40 kPa and does not change in the range N_H = 40 - 100 kPa, regardless of the mass per unit area value.

Determination of water permeability characteristics normal to the plane without a load and determination of the characteristic opening size

Determination of water permeability characteristics normal to the plane without a load and determination of the characteristic opening size 0_{90} were conducted in order to check the influence of the mass per unit area on filtration properties. The results of the investigation are presented in ***Tables 4*** and ***5***.

Analysing the data from ***Tables 4*** and ***5***, it can be assumed that the increase in the mass per unit area is accompanied by a decrease in water permeability normal to the plane for both geotextiles, whereas a rise in the mass per unit area is accompanied by a fall in the characteristic opening size - 0_{90} for both geotextiles, which directly impacts the filtration and drainage functions. Higher values of these parameters were obtained for geotextiles manufactured by two sided needle punching.

Conclusions

According to the investigation conducted and analysis of measurement results, it can be assumed that:

1. Geotextiles manufactured by two-sided needle punching have very good hydraulic properties thanks to their spatial structure. The limited level of tensile strength, static and dynamic puncture resistance as well as significant elongations are their disadvantages.
2. Geotextiles manufactured by two-layered needle punching on the fabric underlay, apart from good hydraulic properties, have very good mechanical properties thanks to the fabric underlay.
3. Geotextiles obtained by mechanical needle punching can be successfully applied to drainage and filtration, whereas geotextiles manufactured by two-layered needle punching on the fabric underlay are particularly useful for reinforcement mainly in civil engineering, in which, apart from drainage and filtration functions, reinforcement is essential.

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