Dunja Šajn Gorjanc, Žanin Bernjak, Lidija Černe Hočevar
University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles, Graphic Arts and Design, Snežniška 5, 1000 Ljubljana, Slovenia

Influence of some Structural Properties of Incontinence Diapers on their Functionality

Vpliv nekaterih strukturnih lastnosti plenic za inkontinenco na njihovo funkcionalnost

Original Scientific Article/*Izvirni znanstveni članek*
Received/*Prispelo* 06-2016 • Accepted/*Sprejeto* 10-2016

Abstract

Incontinence affects millions of people all over the world; however, it is more common in women overall. The urinary incontinence is common, especially in old age. Several statistics indicate that 5–10 percent of all people are affected by urinary incontinence, two thirds of them being over the age of 60. Based on the abovementioned facts, the presented research focuses on multilayer nonwoven textiles for incontinence diapers, especially on their functionality during wearing and using. The investigated incontinence diapers consist of three layers. The upper layer is made of PP spunbond nonwovens. The second, inner part of the diaper consists of cellulose pulp that contains a super absorber polymer (SAP). The third, last layer consists of a polymer-coated spunbond PP nonwoven that is fastened to the underwear with an adhesive strip and protected with a paper prior to the use. In the research, the elastic recovery after compression loading, water vapour transmission, absorbency, bending rigidity and pore size of incontinence diapers from two different producers offered by Sanolabor, d. d., were analysed and compared. The results of the research show that sample A 10 with the highest mass and thickness, and the lowest diameter of fibres (consequently with the highest number of pores in cellulose pulp (absorptive core) and in the first layer from PP fibres) expresses the highest water vapour transmission and absorbency, mainly due to the highest number of pores on the sample.
Keywords: incontinence diapers, elastic recovery, absorbency, porosity

Izvleček

Inkontinenca prizadene milijone ljudi po vsem svetu. Je pogostejša težava pri ženski populaciji v poznejšem življenjskem obdobju. Statistični podatki kažejo, da ima težave z urinsko inkontinenco od 5 do 10 odstotkov svetovnega prebivalstva, med katerimi je dve tretjini starejših od 60 let. Na podlagi omenjenih dejstev se pričujoča raziskava osredinja na večplastne vlaknovine, ki so namenjene za inkontinenčne plenice, in na njihovo funkcionalnost pri uporabi. Raziskovalne inkontinenčne plenice so sestavljene iz treh slojev. Vrhnji sloj je izdelan iz PP-vlaknovine, izdelane po ekstrudiranem postopku in termično utrjene (vlaknovina spunbond), notranji sloj je izdelan iz celulozne pulpe in vsebuje absorber (polimer z odličnimi absorpcijskimi lastnostmi, t. i. SAP). Zadnji, spodnji sloj ravno tako sestavlja vlaknovina PP spunbond, ki ima nanesen lepilni sloj, da se pri nošenju lahko pritrdi na spodnje oblačilo. V okviru raziskave funkcionalnih lastnosti so bile izvedene naslednje preiskave: elastični povratek po kompresijskem obremenjevanju, prepustnost vodne pare, absorpcijske lastnosti, upogibna togost in poroznost. Raziskave so bile izvedene na inkontinenčnih izdelkih dveh različnih izdelovalcev v okviru praktičnega usposabljanja. Raziskava je pokazala, da vzorec A 10, ki ima največjo maso, debelino in najmanjši premer vlaken celulozne pulpe, posledično tudi največje število por v celulozni pulpi (absorptivno jedro plenice) in vrhnjem sloju iz vlaknovine PP spunbond, izkazuje posledično največjo prepustnost vodne pare in absorpcijo. Najverjetnejši razlog je v največjem številu por vzorca A 10.
Ključne besede: plenice za inkontinenco, elastični povratek, absorpcija, poroznost

Corresponding author/*Korespondenčna avtorica:*
Assistant Prof DrSc Dunja Šajn Gorjanc
E-mail: dunja.sajn@ntf.uni-lj.si

DOI: 10.14502/Tekstilec2016.59.298-310

1 Introduction

More than 25% of female population occasionally face incontinence in their lives. One of the reasons for incontinence in women is the weakening of muscles that occurs during pregnancy and after giving birth. About 4% of men experience incontinence; however, with age, the number rises to 17%. Male incontinence is often associated with prostate.
Incontinence affects millions of people all over the world, but it is overall more common in women. The urinary incontinence is common, especially in old age. Various statistics indicate that urinary incontinence affects 5–10% of all people, two thirds being over the age of 60 [1–3].
Incontinence diapers are made of two layers produced with the spunlaid process and are thermobonded (first and protective layer) in the so-called spunbond process. The first layer presents about 10% of the total mass of the diaper and is in many cases produced from PP or PE fibres. The inner part (absorptive core) of the diaper consists of cellulose pulp from very short cellulose fibres (less than 4 mm in length) and a super absorber polymer (SAP). The cellulose pulp presents about 64% of the total mass of the diaper. The super absorber polymer (SAP) absorbs liquid to up to about 300-times according to its weight.
The super absorber polymer (SAP) is produced with the polymerisation of acrylic acid to polyacrylic acid that is in a further process neutralised with sodium hydroxide. SAP is found dispersed into the fluff in the form of a white, granular solid. SAP can hold up to about 20–30 times its mass of urine.
The bottom layer is a protective layer with an adhesive application, which facilitates the attachment to the underwear [1–6].
The first technological process in the production of nonwovens is the web formation to form a web from staple fibres or filaments. The orientation of fibres in the web is either longitudinal (anisotropic), accidental (isotropic) or cross-directed [7–9].
The spunbond (extruded) web formation and thermal bonding include the following major elements of the process:

- Preparation of polymer melt in extruder.
- Filtering polymer melt.
- Spinning: The melt passes through the porous filtration layer, arrives at the spinneret nozzle with a high degree of homogeneity and is ideally suited for the spinning process. The spinneret usually consists of a perforated plate arranged across the width of the line. The resin is forced through the many small holes in the spinneret plate to form continuous filaments, using cooling with air.
- Drawing the filaments in an attenuation zone that results in increased orientation of polymer chains making up the continuous filament. Such orientation leads to increased filament strength, along with the modification of other filament properties, including filament denier or thickness.
- Laydown on forming web: Filaments are deposited in a random manner on a moving, porous forming belt. The vacuum under the belt assists in forming the filament web on the forming belt and in removing the air used in the extrusion/orientation operation.
- Web bonding: The continuous filament web is delivered to the bonding section, where one of several bonding methods can be used to bond the loose filaments into a strong, integrated textile.
- Roll up: The web is finally rolled up [7].

Nonwovens that are produced from staple fibres or filaments to form a web that is finally bonded by different bonding techniques play an important role in the medical textile production. Medical textiles (Medtech) represent an important part of technical textiles. From the documents that are published by the European organisation EDANA, which covers the field of nonwovens [6], is can be seen that the nonwovens for hygiene products present around 32% of today's market, while the nonwovens for medical textiles present around 3% of the market. The research of medical textiles became nowadays very important and is relatively new.
Due to the above written facts, several researches have been presented in the literature in the last few years.
The research by the authors Das, D. et al entitled *Liquid Sorption Behavior of Superabsorbent Fiber Based Nonwoven Media* from 2013 [10] deals with the absorption of nonwovens from superabsorbent fibres. In the last few years, many researches were dealing with the relation between the fibre diameter, pore size of the nonwoven fabric and the ability of absorption [11–16]. In the last four years, many researches have dealt with nonwoven products for hygiene that contain the super absorbent polymer (SAP) [11–16].
Since its development in the late 1970s and early 1980s, the use of SAP has revolutionised the diaper industry as diaper manufacturers soon began to

design diapers that were thinner, more absorbent and comfortable than ever before [17].

Early SAP-containing diapers contained only one to two grams of the material, whereas its weight increased to the mass of 15–16 grams per diaper as the amount of fluff pulp diminished – some modern diapers have virtually no fluff pulp at all [17].

1.1 Compression behaviour of incontinence diaper

Since incontinence diapers consist of three layers, where one of the layers presents the cellulose pulp from short fibres and a super absorbent polymer, the comfort properties besides their functionality are very important as well, e.g. compression behaviour during wear and elasticity.

The elasticity of incontinence diapers refers to the elastic recovery (E_e) of the sample to the thickness or height prior to the loading. The height of the sample is marked in that case as h_0, while the height of the sample after the compression loading and time of relaxation 1 min is marked as h_1. Elastic recovery is determined as the difference between the height of the sample prior to and after the loading ($h_0 – h_1$), related to the height of the sample prior to the loading ($h_0 – h_1/h_0$) and is expressed in percentage [18].

1.2 Absorption of incontinence diaper

The main property of incontinence diapers is their absorbency. Absorbency depends on the structural properties of incontinence diapers (mass, thickness, characteristics of fibres). A thicker diaper usually has a higher absorbency rate. From the structural properties, the type, diameter and fibre length, as well as the diameter and number of pores in the nonwoven web (diaper) are important as well. Thinner fibres also ensure a higher surface contact, higher number of contact points between the fibres in the web, and consequently the friction between fibres, which prevents the absorption of liquid. The diameter and the number of pores influence the absorbency. The hydrophilic or hydrophobic polymer type of fibres influences the inherent absorbent properties of the nonwoven fabric. For example, cellulose fibres that are mostly used as the inner layer have moisture regain of 13% and increase by length 3–5% when they are immersed into water, while the moisture regain of PE or PP fibres equals zero percent. The nonwovens from PP and PE fibres are mostly used as spunbond nonwovens, especially for the first or last (protection) layer in incontinence diapers. Hydrophilic fibres have the capacity to absorb liquid via fibre imbibitions, giving rise to fibre swelling. This also attracts and holds liquid external to the fibre, in capillaries and structure voids. On the other hand, hydrophobic fibres increase absorption according to their shape (round, trilobal etc), thickness and length. The fibre linear density and its cross-section area affect void volume, capillary dimensions and the total number of capillaries per unit mass in nonwoven fabrics which affects the absorbency increase [14–16]. Absorbency is determined in percentage as the difference between the wet mass of a sample (after absorption of liquid) and the dry mass of a sample [18].

The absorbency of incontinence diapers mostly depends on cellulose pulp that represents about 64% of the total mass of the diaper. The cellulose pulp filler contains the super absorber polymer (SAP), which absorbs liquid to up to about 30 times of its weight [9].

Based on the above-mentioned facts, the presented research focuses on multilayer nonwoven textiles used for incontinence diapers, especially their functionality during wear and end use. With the presented research, the incontinence diapers of two producers were analysed and compared.

2 Experimental

2.1 Materials and methods

With the presented research, the incontinence diapers of two producers were analysed (offered by the company for medical, pharmaceutical and laboratory marketing, and distribution Sanolabor, d. d.). Sample A 10 is from the first producer, while the samples I 9 and I 10+ are from the second producer – sample I 9 is intended for daily use, whereas sample I 10+ is intended for night-time use.

Incontinence diapers consist of three layers. The upper layer is made of a nonwoven fabric produced from extruded web formation and is thermobonded, i.e. the so-called spunbond web formation. The upper layer consists of PP fibres in the isotropic orientation, with the mass and thickness from 43.57 g/m^2 and 0.712 mm (sample A 10), to 70.92 g/m^2 and 0.543 mm (sample L 9), and 54.46 g/m^2 and 0.666 mm (sample I 10+).

The second, inner part of the diaper consists of cellulose pulp with very short cellulose fibres with around 4 mm in length and contains the super

Table 1: Properties of incontinence diapers

Sample	Mass per unit area [g/m^2]	Thickness [mm]	Diameter of fibres in upper layer [μm]	Average diameter of pores [μm]	Number of pores with average diameter	Diameter of fibres in cellulose pulp (absorbent core) [μm]
A 10	1661.6	10.483	16.79	125.29	681	29.38
I 9	939.0	8.123	18.66	158.97	512	35.76
I 10+	640.6	8.633	18.31	219.06	530	33.31

absorber polymer (SAP). The inner part of the diaper represents about 64% of the total mass of the diaper and functions as the filler of the diaper. The inner part of the diaper, with the pulp from very short cellulose fibres and super absorber polymer, plays an important part in liquid (urine) absorption. The diameter of cellulose fibres of the inner part of the diaper ranges from 29.38 μm (sample A 10) to 35.76 μm (sample I 9) (Table 1). SAP is dispersed into the cellulose pulp in the form of a white, granular solid, and can hold about 20–30 times its mass of urine.
The last layer is also made of a nonwoven produced from extruded web formation and is thermobonded. The last layer is a protective layer with an adhesive application, which facilitates the attachment to a textile material (e.g. underwear).
The web of the last layer consists of PP fibres in the isotropic orientation that is intended only for protection, preventing the passage of liquid (urine) from the diaper to the textile material (Figure 1).

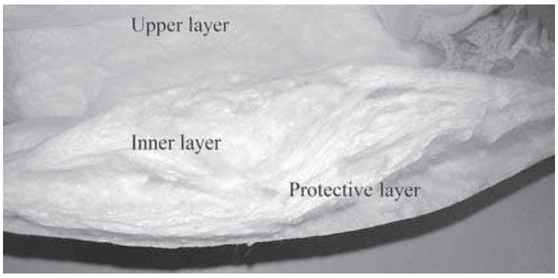


Figure 1: Incontinence diaper layers

The mass and thickness of samples as well as the diameter of fibres in the top sheet layer and cellulose pulp are listed in Table 1.
Table 2 includes the photos of a cross-sectional and upper view of samples analysed in the dry and wet condition after the wetting with 200 mL of distilled water, recorded during the determination of elastic recovery after the compression loading analysis.

The SEM images of incontinence diapers are presented in Table 3.
In the research of the functionality (elastic recovery after compression loading, water vapour transmission, absorbency – MDS and Rothwell methods) and porosity of incontinence diapers from two different producers, the methods which are described below were used.

Elastic recovery after compression loading
The elastic recovery of incontinence diapers was determined according to the modification of the method by ASTM D6571 – Standard Test Method for Determination of Compression Resistance and Recovery Properties of Highloft Nonwoven Fabric Using Static Force Loading [19]. The elastic recovery, E_e, after compression loading was determined at an incontinence diaper in dry and wet condition. After measuring the elastic recovery, E_e, after compression loading in dry condition, the specimen was poured with 200 mL of synthetic urine (0.9% NaCl solution).
The specimen was loaded to the maximum load of 40 N, which was chosen according to the MDS method (part 2 and part 3), where the wet sample was loaded with the weight of 4 kg for 10 minutes.
During compression loading of the sample to the maximum load of 40 N (approx. 4 kg), the height of the sample with the load of 40 N (h_1) was observed (loading time = 1 min). Afterwards, the sample was relaxed (0 N; relaxation time = 1 min), and the controlled cycle was performed and the height of the relaxed sample was determined (h_2). Finally, the elastic recovery was calculated (Equation (1)).

$$E_e = \frac{h_0 - h_2}{h_0} \cdot 100\ (\%) \qquad (1),$$

where E_e is elastic recovery after compression loading in %, h_0 the height of the sample in the starting point of the test in mm and h_2 the height of the relaxed sample (after compression loading of 40 N and relaxation time of 1 min) in mm.

Table 2: Upper and cross-sectional view of samples analysed in dry and wet condition (after wetting with 200 mL of distilled water) with determination of elastic recovery after compression loading analysis

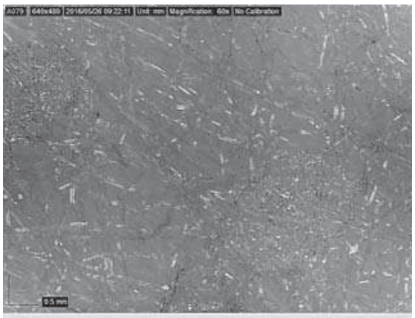
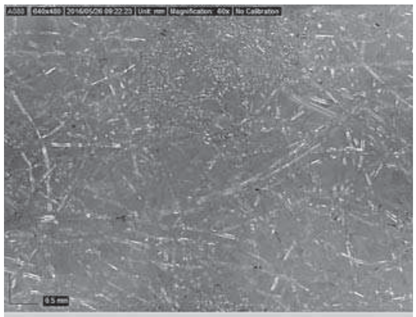
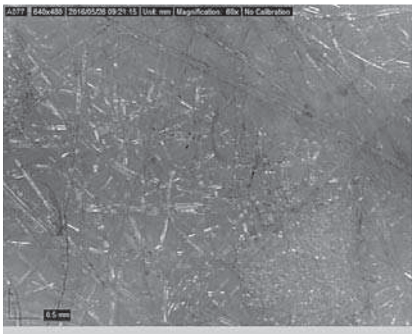
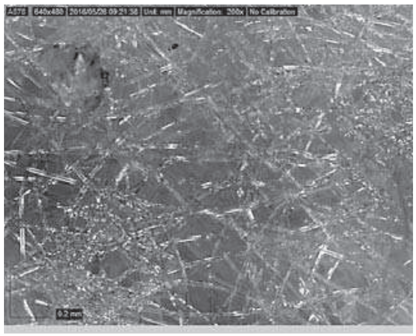
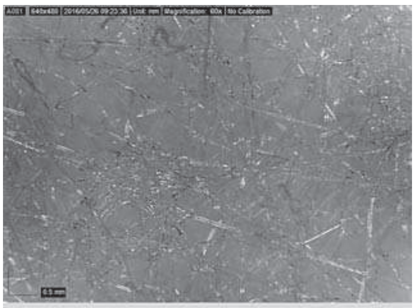
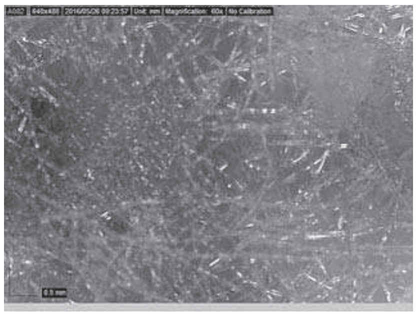
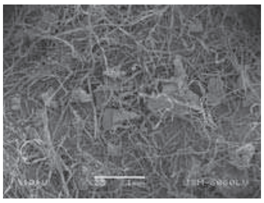
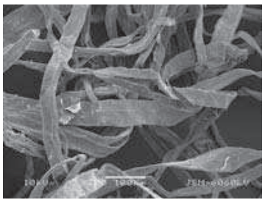
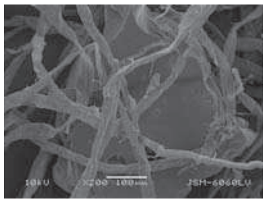
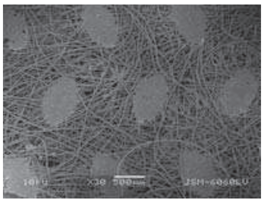
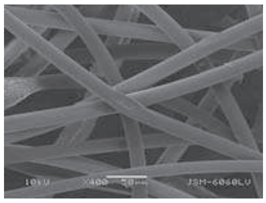
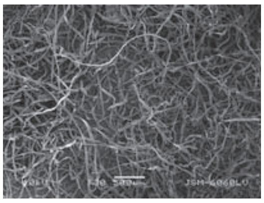
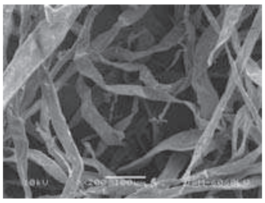
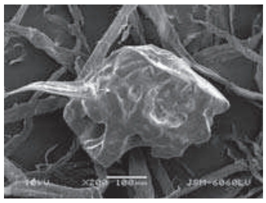
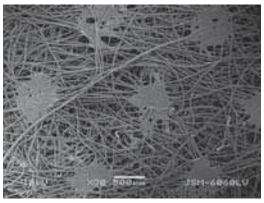
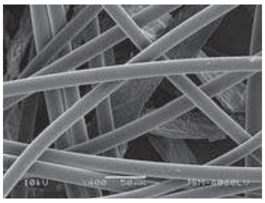
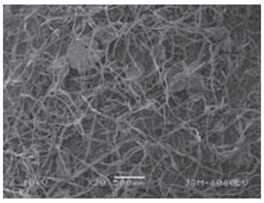
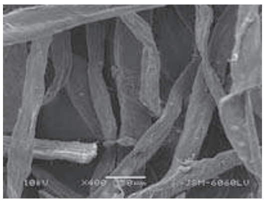
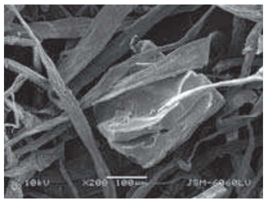
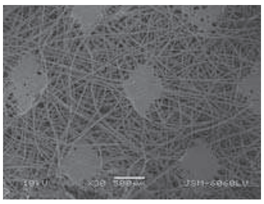
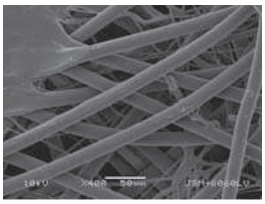
Sample	View	Dry	Wet
A 10	Cross-sectional		
	Upper (200× magnification)		
I 9	Cross-sectional		
	Upper (200× magnification)		
I 10+	Cross-sectional		
	Upper (200× magnification)		

Table 3: SEM images of analysed incontinence diapers

Sample	Layer	Component 1	Component 2
A 10	Inner	  Cellulose pulp (magnification: left 30x, right 200x)	 SAP (magnification 200x)
	Upper	 PP spunbond layer (magnification 30x)	 PP spunbond layer (magnification 400x)
I 9	Inner	  Cellulose pulp (magnification: left 30x, right 200x)	 SAP (magnification 200x)
	Upper	  PP spunbond layer (magnification: left 30x, right 200x)	
I 10+	Inner	  Cellulose pulp (magnification: left 30x, right 400x)	 SAP (magnification 200x)
	Upper	  PP spunbond layer (magnification: left 30x, right 400x)	

Bending rigidity

Bending rigidity of incontinence diapers was determined according to ISO 9073-7 (Textiles – Test methods for nonwovens – Part 7: Determination of bending length) [20]. The sample dimensions were 2.5 cm × 25 cm in both directions (longitudinal and transversal). To determine bending rigidity, the mass of the sample, *M*, in g/m² was measured. Finally, bending length, *c* (cm), was calculated. Bending length presents a half of the length of the overhang, *O* (cm), of the specimen. The length of the overhang was measured on a cantilever tester at the angle of 41.5° and bending rigidity, *G*, in $\mu N \cdot m$ was determined in Equation (2).

$$G = M \cdot c^3 \cdot 9.81 \cdot 10^{-3} \qquad (2),$$

where *G* is bending rigidity in $\mu N \cdot m$, *c* bending length in cm and *M* mass per unit area in g/m².

Water vapour transmission

Water vapour transmission was determined according to ASTM E96/E96M [21]. The test specimen was sealed to the open mouth of a test dish with the diameter of 3 cm, containing 7 mL of water, the assembly being placed in a controlled atmosphere (T = 23 °C, RH = 50%). The sample was weighed after one (m_1) and 24 hours (m_2) in a controlled atmosphere. Finally, the water vapour transmission (*WVT*) was calculated in g/m²h (Equation (3)).

$$WVT = \frac{(m_1 - m_2)}{A \cdot t} \qquad (3),$$

where *WVT* represents water vapour transmission in g/m²h, m_1 mass of the sample after one hour in a controlled atmosphere in *g*, m_2 mass of the sample after 24 hours in a controlled atmosphere in *g*, *A* represents the area of the open mouth of a test dish with the diameter of 3 cm in m² and *t* the measuring time (24 hours) (h).

Absorbency according to MDS method (part 2 and part 3)

The absorbency of incontinence diapers according to the method MDS, part 2 was determined on a sample with the dimensions 105 × 105 mm. The sample was covered by stainless steel plate with a round opening and thickness of 1 cm. Finally, the absorbency time of 5 mL of synthetic urine (0.9% NaCl solution) was determined with a stopwatch.

The absorbency according to the method MDS, part 3 was determined using four layers of filter paper with the dimensions 100 × 100 mm, which was weighed. Afterwards, 10 mL of synthetic urine was poured onto the sample. The wet sample was loaded with the weight of 4 kg for 10 minutes. After that time, the filter paper was placed on the sample surface and loaded with the weight of 4 kg again for 2 minutes. Finally, the wetted filter paper was weighed again and the absorbency of water on the filter paper surface was determined. Higher absorbency on the filter paper surface also means a wetter diaper on the surface of the first layer and higher mass of the liquid on the incontinence diaper surface [22].

Absorbency according to Rothwell method (ISO 11948)

The Rothwell method is based on the total absorbency of the liquid (synthetic urine). With this method, the dry diaper was weighed (m_1). The diaper was then immersed into a synthetic urine solution (0.9% NaCl solution) for 30 minutes. After draining the diaper on a grid for 5 minutes, the wet diaper was weighed again (m_2). The absorbency was determined and expressed in percentage in Equation (4) [23].

$$A = \frac{m_2 - m_1}{m_1} \cdot 100\ (\%) \qquad (4),$$

where m_1 stands for mass of the dry sample [g] and m_2 for mass of the wet sample [g].

Porosity according to J-method

The porosity (average diameter and number of pores) was determined according to the so-called J-method, which was elaborated by the research laboratory of the Department of Textiles, Graphic Arts and Design at the Faculty of Natural Sciences and Engineering under the leadership of Prof Jakšić, D. [24].

The method is based on selective squeezing out of the fluid from the pores of wet fabrics with air pressure. We were able to estimate the porosity parameters such as the hydraulic diameter of pores, distribution of pores, the open area for the fluid flow and the number of hydraulic pores. The parameters were estimated based on the measurement of air volume velocity through dry and wet samples as a function of air pressure. All measured data were fed into the computer program called PoreP [24], developed especially for that purpose. The whole procedure took about 20 minutes and the results obtained with this method were in good agreement with those gained optically.

Statistical analysis

The impact of multilayer hygiene nonwoven fabric structure on their functionality (elastic recovery, bending rigidity, water vapour transmission, absorbency) was tested using the analysis of variance (ANOVA) to determine the significance of multilayer hygiene nonwoven fabric structure on the elastic recovery, bending rigidity, water vapour transmission and absorbency.

The basis of the one-factor ANOVA is represented by the partitioning of sums of squares into between-class (SSb) and within-class (SSw). This technique enables all classes to be compared with each other simultaneously, rather than individually. This method also assumes that the samples are normally distributed. The one-factor analysis is calculated in three steps. The sums of squares are first determined for all samples, and then for the within-class and between-class cases. For each stage, the degrees of freedom (df) are determined as well, where df is the number of independent pieces of information involved in the estimate of a parameter. These calculations are used with Fisher statistics to analyse the null hypothesis. The null hypothesis states that there are no differences between the means of different classes, suggesting that the variance of the within-class samples should be identical to that of the between-class samples. If $F \geq 1$, then the differences are likely to exist between the class means. These results are then tested for statistical significance or p-value, where the p-value is the probability that a variate assumes a value greater than or equal to the value observed strictly by chance. If the p-value is low (e.g. $p \leq 0.05$ or $p \leq 5\%$), then the null hypothesis is rejected, indicating that differences exist between the classes and that these differences are statistically significant. If the p-value is greater than 0.05 (e.g. $p \geq 0.05$ or $p \geq 5\%$), then the null hypothesis is accepted, indicating that the differences between classes are accidental. [25]

3 Results and discussion

3.1 Results of elastic recovery after compression loading

The results of researching elastic recovery after compression loading show that elastic recovery of incontinence diapers after the loading with the load of 40 N, which corresponds to the weight of about 4 kg, is lower than 50% (Table 4). Incontinence diapers consist of three layers, the inside layer presenting cellulose pulp that influences lower elastic recovery. The lowest elastic recovery was determined at sample A 10 (37.2%), while samples I 10+ and I 9 expressed higher elastic recovery (from 42.0% to 43.1%). The results of elastic recovery after compression loading of samples I 10+ and I 9 show a very small difference between sample I 10+, which is intended for daily use, and sample I 9, which is intended for night-time use. The reason for lower elastic recovery of sample A 10 lies in its highest mass (1661.6 g/m^2) and thickness (10.48 mm). The statistical analysis ANOVA showed significant differences in elastic recovery after compression loading of the analysed dry samples (p-value = 0.28).

Table 4: Results of elastic recovery after compression loading of dry samples

Sample	Elastic recovery of dry sample, E_e [%]	Coefficient of variation of elastic recovery [%]
A 10	37.2	11.5
I 9	43.1	7.45
I10+	42.0	7.60

The results of elastic recovery after compression loading were interesting after wetting the samples with 200 mL of synthetic urine (0.9% NaCl solution) (Table 5). The results of researching elastic recovery after compression loading show that sample A 10 expressed the highest elastic recovery in wet condition (40.2%). Samples I 10+ and I 9 expressed smaller elastic recovery in wet condition (28.9% and 17.9%). The results also showed that elastic recovery in wet condition of sample I 10+, which is intended for night-time use, amounted to 28.9%, which is between the values of sample A 10 and sample I 9. Sample A 10 had the lowest diameter of cellulose fibres of the inner layer or absorbent core (29.38 µm, Table 1), and consequently higher specific surface, and number of cellulose fibres and pores of the absorbent core that affect higher absorption. Based on the above mentioned facts about the absorption of hydrophilic fibres, i.e. cellulose fibres, it can be stated that a hydrophilic fibre provides the capacity to absorb liquid via fibre imbibitions, giving rise to fibre swelling. It also attracts and holds liquid external to the fibre, in the capillaries and structure voids. Higher absorption increases the mass and thickness of sample A 10. Elastic recovery after compression loading of an incontinence diaper in wet condition increases as well. The statistical analysis ANOVA showed significant differences in the elastic recovery after compression loading of the analysed wet samples (p-value = 0.74).

Table 5: Results of elastic recovery after compression loading of wet samples

Sample	Elastic recovery of the wet sample, E_e [%]	Coefficient of variation of elastic recovery [%]
A 10	40.2	11.3
I 9	17.9	13.6
I10+	28.9	14.8

3.2 Results of bending rigidity

The results of bending rigidity of the analysed incontinence diapers are in close connection with the mass and thickness of the samples specified in Table 1. Sample A 10 with the highest mass (1661.6 g/m^2) and thickness (10.48 mm) expressed also the highest bending rigidity (23587.04 $\mu N \cdot m$). The bending rigidity of sample A 10 was by about 50% higher than the bending rigidity of samples I 10+ and I 9, which have lower mass and thickness (Table 6). The incontinence diaper with the highest bending rigidity expressed lower flexibility to the movements of the body while wearing the diaper. Sample I 10+, which is intended for night-time use, expressed due to higher thickness than sample I 9 (intended for daily use) also higher bending rigidity than sample I 9. The statistical analysis ANOVA showed significant differences in bending rigidity of the analysed samples (p-value = 0.49).

Table 6: Bending rigidity of samples

Sample	Bending rigidity of analysed samples, G [μN·m]	Coefficient of variation of bending rigidity [%]
A 10	23587.04	1.11
I 9	10836.63	1.50
I10+	12776.91	3.50

3.3 Results of water vapour transmission (WVT)

The water vapour transmission of the analysed incontinence diapers was moving at around 30 g/m$^2 \cdot$ h. This means that 30 mL of water vapour passes in one hour from the skin surface through one square meter (1 m^2) surface of an incontinence diaper to the environment. Incontinence diapers consist of three layers, the inner layer presenting the absorptive core from cellulose pulp and super absorber polymer (SAP) that also absorbs water vapour. That is the reason for a low value (30 g/m$^2 \cdot$ h) of water vapour which passes through the incontinence diaper surface.

The highest water vapour transmission was determined at sample A 10, which had the highest mass (1661.6 g/m^2) and thickness (10.48 mm), and the smallest diameter of cellulose fibres in cellulose pulp (29.4 μm) and PP fibres in the first (upper) layer (16.8 μm). Sample A 10 had the highest number of pores in the upper layer (681 pores, with the average diameter of 125.29 μm) (Table 7). At samples I 10+ and I 9, the diameter was larger in cellulose fibres in the cellulose pulp (around 35 μm) and PP fibres in the first (upper) layer (around 18 μm), as was larger the average diameter of pores in the upper layer (from 158.97 to 219.06 μm), whereas the number of pores was smaller (512 to 530 pores). The lowest diameter in cellulose fibres in the cellulose pulp (29.4 μm) and in PP fibres in the upper (top sheet) layer of the thickest incontinence diaper influenced the highest number of pores (around 45%) with the average diameter of 125.29 μm at sample A 10. The latter increased the water vapour transmission of sample A 10 (30.3 g/m^2·h). Sample I 10 + for night-time use had almost the same water vapour transmission as sample I 9, which is intended for daily use.

Table 7: Water vapour transmission of samples

Sample	Water vapour transmission, WVT [g/m^2·h]	Coefficient of variation of water vapour transmission [%]
A 10	30.3	7.2
I 9	26.5	8.9
I10+	25.8	9.5

The statistical analysis ANOVA showed significant differences in the water vapour transmission of the analysed samples (p-value = 0.38).

3.4 Results of absorbency according to MDS method (part 2 and 3)

The results of absorbency time of 5 mL of synthetic urine (MDS method, part 2) of the analysed incontinence diapers show that all samples had very short absorbency time required for the absorption of 5 mL of synthetic urine. The absorption time for all analysed samples was one second, which means that all incontinence diapers absorbed 5 mL of synthetic urine in only one second.

Absorbency according to the method MDS, part 3 was determined with the absorption of synthetic urine by filter paper on a sample in wet condition (poured with 10 mL of synthetic urine), which was loaded with the weight of 4 kg. The wetted filter paper was weighed and the absorbency of water on the filter paper surface was determined.

The highest absorption of filter paper was determined at sample A 10 (3.9%) which had the highest mass (1661.6 g/m^2), thickness (10.48 mm) and the lowest diameter of cellulose fibres in the cellulose pulp (29.4 µm) and the lowest average diameter of pores (125.29 µm). Sample A 10 had the highest number of pores in the cross-sectional area of the sample (681 pores) with the smallest average diameter (125.29 µm). Higher absorbency on the filter paper of sample A 10 surface means lower absorbency in the inner part (absorbent core) of the incontinence diaper and a higher volume of synthetic urine on the surface of the incontinence diaper. The absorbency of the filter paper of samples I 10+ and I 9 in the wet condition was 3.2%, i.e. by 20% lower than the absorbency of the filter paper of sample A 10 in wet condition.

While wearing an incontinence diaper, it is very important that the person retains the dry feeling, meaning that samples I 10+ and I 9, which expressed lower absorbency on the filter paper surface, had by about 20% dryer upper layer which is in contact with the skin during wearing, than sample A 10 (Table 8) and in this way proved better. Sample A 10 also had the smallest diameter of cellulose fibres in the inner layer or absorbent core (29.38 µm), and consequently higher specific surface and number of cellulose fibres as well as the number of pores (681 pores) in the absorbent core, causing higher absorption of the diaper. Based on the above mentioned facts about the absorption of hydrophilic fibres, higher absorbency of the filter paper on the surface of such a sample is expected. The statistical analysis ANOVA showed significant differences in the absorbency of filter paper between samples I 9, I 10+ and A 10 (p-value = 0.50).

Table 8: Filter paper absorbency on incontinence diaper surface (MDS method, part 3)

Sample	Absorbency of filter paper (below 4 kg), A [%]	Coefficient of variation of absorbency of filter paper [%]
A 10	3.9	0.81
I 9	3.2	0.32
I10+	3.2	0.15

3.5 Results of absorbency according to ISO 11948 (Rothwell method)

The results of absorbency by the Rothwell method, which is based on the total absorbency with the immersion of the incontinence diaper into a synthetic urine solution (0.9% NaCl solution) for 30 minutes, show the highest absorbency at sample A 10 (492.5%). Sample A 10 absorbed 5 times its weight of synthetic urine. The absorbency of sample I 10+ amounted to 486.4%, while sample I 9 had the lowest absorbency (377.7%).

Sample A 10 had the highest absorbency (492.5%) due to its highest mass (1661.6 g/m^2), thickness (10.48 mm) and the lowest diameter of cellulose fibres in the cellulose pulp (29.4 µm), and consequently the highest number of pores (681 pores, average diameter 125.29 µm) in the cross-sectional area. The sample with the lowest absorbency, i.e. sample I 9 (377.7%), had the mass of 939.0 g/m^2 and thickness of 8.12 mm, and the highest diameter of cellulose fibres in the cellulose pulp (35.8 µm). Sample I 9 is intended for daily use. The average pore diameter of sample I 9 was 158.97 µm; therefore, the main reason for lower absorbency lies in the smaller number of pores (512 pores with the diameter 158.97 µm) in the cross-sectional area of sample I 9. The mass and thickness of sample I 10+ were 640.6 g/m^2 and 8.63 mm. The diameter of cellulose fibres in the cellulose pulp was 33.3 µm. Sample I 10+ included 530 pores with the diameter 219.06 µm. The absorbency of sample I 10+ equalled 477.4 %, mainly due to cellulose pulp fibres being thinner than at sample I 9 (Table 9). Sample I 10 + is intended for night-time use. The absorbency of analysed incontinence diapers depends on the quantity of super absorber polymer (SAP) in the inner part of the diaper, which was impossible to weigh. It is expected that a thicker sample (e.g. sample A 10) can have a higher quantity of the super absorber polymer incorporated into its inner part (i.e. absorbent core).

The statistical analysis ANOVA showed significant differences in the absorbency (Rothwell method) of the analysed samples (p-value = 0.46).

Table 9: Absorbency of incontinence diaper according to ISO 11948 (Rothwell method)

Sample	Absorbency (Rothwell method), A [%]	Coefficient of variation of absorbency (Rothwell method) [%]
A 10	492.5	0.61
I 9	377.7	0.65
I10+	486.4	0.63

4 Conclusion

From the research on the functionality (elastic recovery after compression loading, water vapour transmission, absorbency) of incontinence diapers from two different producers, the following conclusions can be drawn:

- The structure properties of incontinence diapers, e.g. mass, thickness, diameter of cellulose fibres in the pulp influence the elastic recovery after compression loading. Thicker incontinence diapers expressed a very low value of elastic recovery ranging from 37 to 43%. On the other hand, in wet condition, thicker incontinence diapers with thinner cellulose pulp fibres expressed the highest elastic recovery after compression loading (40.2%).
- The mass and thickness of incontinence diapers increased the bending rigidity and consequently lowered the flexibility (comfort) of diapers during wear.
- Water vapour transmission of incontinence diapers depends mainly on the diameter of cellulose fibres in the cellulose pulp in the absorptive core that presents about 64% of the total mass of incontinence diapers.
- Water vapour transmission of analysed incontinence diapers was moving from 25.8 to 30.3 g/m^2 · h and was the highest at sample A 10. The main reason for that lies in the smallest diameter of cellulose pulp fibres, the highest mass and thickness, and consequently the highest number of pores at sample A 10.
- The absorbency of incontinence diapers depends on the mass and thickness of the diaper and the quantity of the super absorber polymer (SAP) in the absorptive core. Sample A 10 with the highest absorbency (492.5%) also had the highest mass (1661.6 g/m^2) and thickness (10.48 mm), as well as the lowest diameter of cellulose fibres in the cellulose pulp (29.4 μm) of the absorptive core. The above-mentioned facts are the reason for the highest number of pores (681 pores) at sample A 10 that increased the absorbency of the incontinence diaper.
- The absorbency of the filter paper on the surface of the incontinence diaper was also the highest at sample A 10. At incontinence diapers with thicker cellulose pulp (absorptive core) with thinner cellulose fibres expressed higher filter paper absorbency, mainly due to the increasing length of the swollen cellulose fibres in the cellulose pulp. The latter also implies uncomfortable feeling while wearing the incontinence diaper A 10, while samples I 9 and I 10+ boasted of by about 20% dryer surface of the PP-spunbond first layer.

From the conclusions drawn above, it is clear that apart from the incontinence diaper mass and thickness, which are very important in the absorbency of the diaper, the diameter of cellulose fibres and the diameter of pores of the absorptive core, which represents about 64% of the mass of an incontinence diaper, are of the essence as well. Thinner cellulose fibres in the pulp have larger specific surface and ensure a larger number of cellulose fibres in the pulp and a larger number of pores between the fibres, which consequently leads to better absorbency. On the other hand, the thicker absorptive cellulose core increases in its volume in wet condition and the hydrophilic cellulose fibres increase in length and affect the first PP-spunbond layer wetting and consequently cause an uncomfortable feeling while wearing an incontinence diaper. Moreover, the absorbency of analysed incontinence diapers depends on the quantity of the super absorber polymer (SAP) in the inner part of the diaper, which was not investigated in the presented research.

It is expected that the thicker sample (i.e. sample A 10) had a larger quantity of the super absorber polymer incorporated into its inner part (absorbent core). Besides the absorbency of the incontinence diaper, the dryness of the first PP-spunbond layer is very important for the person using the incontinence diaper. From that point of view, samples I 9 and I 10+ that have by about 20% dryer first PP-spunbond layer than sample A 10 are more suitable for use.

With the research, the elastic recovery after compression loading, water vapour transmission, absorbency, bending rigidity and pore size of incontinence diapers, which are designed for heavy (samples A 10 and I 10+) and regular (sample I 9) urinary and faecal incontinence, were analysed and compared.

Furthermore, the absorbency of the analysed incontinence diapers depends on the quantity of the super absorber polymer (SAP) in the inner part of the diaper, which was not investigated in the presented research.

Acknowledgements

The authors gratefully acknowledge the company specialised in the sale of medical, laboratory and pharmaceutical products, Sanolabor, d. d., which supported the study with the samples which were examined in the context of experimental work.

References

1. SHUMAKER, Sally A., WYMAN, J. F., UEBERSAX, J. S, McCLISH, D., FANTL, J. A. Health-related quality of life measures for women with urinary incontinence: the incontinence impact questionnaire and the urogenital distress inventory. *Quality of Life Research*, 1994, **3**(5), 291–306, doi: 10.1007/bf00451721.
2. LEACH, Gary E., DMOCHOWSKI, Roger R., APPELL, Rodney, BLAIVAS, Jerry G., HADLEY, H. Roger, LUBER, Karl M., MOSTWIN, Jacek L., O'DONNELL, Pat D., ROEHRBORN, Claus G. Female stress urinary incontinence clinical guidelines panel summary report on surgical management of female stress urinary incontinence. *The Journal of urology*, 1997, **158**(3), 875–880, doi: 10.1097/00005392-199709000- 00054.
3. HUNSKAAR, Steinar, BURGIO, Kathryn, DIOKNO, Ananias, HERZOG, A. Regula, HJÄLMÅS, Kelm, LAPITAN, Marie Carmela. Epidemiology and natural history of urinary incontinence in women. *Urology*, 2003, **62**(4),16–23, doi: 10.1016/s0090-4295(03)00755-6.
4. COTTENDEN, A. Management Using Continence products [online]. *International Continence Society*, 2008, 1519–1642 [accessed 1. 10. 2016]. Available on World Wide Web: <http://www.ics.org/publications/ici_4/files-book/comite-20.pdf>.
5. European Disposables and Nonwovens organisation [online], 2015, [accessed 1. 10. 2016]. Available on World Wide Web: <http://www.edana.org/docs/default-source/default-document-library/fact-sheet-incontinence-products.pdf?sfvrsn=2>.
6. RUSSELL, Stephen, J. *Handbook of nonwovens*. Woodhead Publishing, Cambridge, 2006, 16–329.
7. AJMERI, C. AJMERI, Joshi. Nonwoven materials and technologies for medical applications. In *Handbook of medical textiles. 1st Edition*. Edited by V. Bartels. Cambridge : Woodhead Publishing, 2011, 106–126.
8. DAS, Dipayan, POURDEYHIMI, Behnam. *Composite nonwoven materials. 1st Edition. Structure, properties and applications.* Cambridge : Woodhead Publishing, 2014, 74–87.
9. DAS, Dipayan, RENGASAMY, R. S., KUMAR, Mritunjay. Liquid sorption behavior of superabsorbent fiber based nonwoven media. *Fibers and Polymers*, 2013, **14**(7), 1165–1171, doi: 10.1007/s12221-013-1165-5.
10. IRZMANSKA, Emilia, DUTKIEWICZ, Jacek. Preliminary evaluation of airlaid nonwovens with superabsorbent for use in protective footwear: tests involving a thermal foot model and climatic chamber. *Fibres and Textiles in Eastern Europe*, 2015, **23**(6), 138–142.
11. DAS, Dipayan, PRADHAN, Arun Kumar, POURDEYHIMI, Behnam. Dependence of the liquid absorption behaviour of nonwovens on their material and structural characteristics modeling and experiments. *Journal of Applied Polymer Science*, 2012, **126**(3), 1053–1060, doi: 10.1002/app.36635.
12. LI, Yue, CHANG WHAN, Joo. Pore structure and liquid behavior of nonwovens composed of nanosized fibers by conjugate spinning. *Journal of Applied Polymer Science,* 2012, **126**(2), 252–259, doi: 10.1002/app.36627.

13. GUPTA, Bhupender S., SMITH, D. K. Nonwovens in absorbent materials. *Textile Science and Technology*, 2002, **13**, 349–388.
14. ČUNKO, Ružica, PEZELJ, Emira, SOMOGYI, Maja. Characterisation of incontinence diaper efficiency. *Tekstilec,* 2005, **48**(4–6), 98–103.
15. CHEN, Xiao, VROMAN, Philippe, LEWANDOWSKI, Maryline, PERWUELZ, Anne, ZHANG, Yan. Study of the influence of fiber diameter and fiber blending on liquid absorption inside nonwoven structures. *Textile Research Journal,* 2009, **79**(15), 1364–1370, doi: 10.1177/0040517508099386.
16. MCINTYRE, Karen. SAP Market Report [online]. *Nonwovens Industry Magazine*, april 2015 [accessed 1. 10. 2016]. Available on World Wide Web: <http://www.nonwovens-industry.com/issues/2015-04-01/view_features/sap-market-report/>.
17. DEBNATH, Sanjoy, MADHUSOOTHANAN, M. Compression properties of polyester needlepunched fabric. *Journal of Engineered Fibres and Fabrics*, 2009, **4**(4), 14–19.
18. HEARLE, J. W. S., MORTON, Wiliam, Ernest. *Physical properties of textile fibres*. Fourth edition. Boca Raton, Boston, New York, Washington DC : CRC Press; Cambridge : Woodhead Publishing, 2008, 97–356.
19. *ASTM D6571: Standard Test Method for Determination of Compression Resistance and Recovery Properties of Highloft Nonwoven Fabric Using Static Force Loading, 2001, 6 p.*
20. *ISO 9073-7: Textiles - Test methods for nonwovens – Part 7: Determination of bending length, 1995, 5 p.*
21. *ASTM E96 / E96M: Standard Test Methods for Water Vapor Transmission of Materials, 2016, 14 p.*
22. MDS test. [online]. The impact of rewetting on skin health [accessed 1. 10. 2016]. Available on World Wide Web: <http://www.skin-health.eu/standardtests/mdstest.aspx>.
23. *ISO 11948-1: Urine absorbing aids -- Part 1: Whole-product testing, 1996, 7 p.*
24. JAKŠIĆ, Danilo, JAKŠIĆ, Nikola. Assessment of porosity of flat textile fabrics. *Textile Research Journal*, 2007, **77**(2), 105–110, doi: 10.1177/0040517506065892.
25. CLARKE, D. M., COOKE, D. *A basic course of statistics*. London : John Wiley & Sons, 2004, pp. 571–593.