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Compression and strength behaviour of viscose/polypropylene nonwoven fabrics

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Compression and strength properties of viscose/polypropylene nonwoven fabrics has been studied. Compression behavior of the nonwoven samples (sample compressibility, sample thickness loss & sample compressive resilience) have been analyzed considering the magnitude of applied pressure, fabric weight, fabric thickness, and the porosity of the samples. Based on the calculated porosity of the samples, pore compression behavior (pore compressibility, porosity loss & pore compressive resilience) are determined. Equations for the determination of pore compressibility, porosity loss, and pore compressive resilience, are established. Tensile strength and elongation as well as bursting strength and ball traverse elongation are also determined. The results show that the sample compression behavior as well as pore compression behavior depend on the magnitude of applied pressure. At the high level of applied pressure, a sample with higher compressibility has the lower sample compressive resilience. Differences in pore compressibility and porosity loss between investigated samples have also been registered, except in pore compressive resilience. Sample with the higher fabric weight, higher thickness, and lower porosity shows the lower sample compressibility, pore compressibility, sample thickness loss, porosity loss, and tensile elongation, but the higher tensile strength, bursting strength, and ball traverse elongation.

Keywords: Compression properties, Nonwoven fabrics, Porosity, Strength properties, Viscose/polypropylene

1 Introduction

Nonwoven fabrics are one of the oldest and simplest textile fabrics[1]. Applications of the nonwoven fabrics are multifold, such as personal care and hygiene, healthcare, clothing, home, automotive, construction, geotextiles, filtration, industrial, agriculture, home furnishing, leisure & travel, school & office, etc[2]. One of the frequent applications of nonwoven fabrics is for home applications, such as cleaning cloth. Nonwoven fabrics are highly porous material, and therefore found suitable for cleaning cloth[3]. For cleaning cloth, among the others the important end-usage properties are softness and strength.

The softness of fabric can be judged through the change in fabric thickness under the influence of compression load[4]. So, a fabric that compresses easily is likely to be judged as soft[5,6]. According to Kothari and Das[7], compressibility is dependent of the porosity of the fabric, mode of bonding and the characteristics of constituent fibres. They also reported that the compressibility increases initially with increase in finer-fibre content but then decreases as the percentage of finer fibres is further increased in a layered needle-punched nonwoven fabric[8]. Besides, Kothari and Das[9] also observed that as the rate of deformation increases, the compressibility of the nonwoven fabrics decreases due to less time available for compression. They found that the compressibility decreases sharply after the first cycle. However, after a few cycles the compressibility remains unchanged. Kothari and Das also observed that the size of pressure foot has no effect on the compression behavior of nonwoven fabrics.

Debnath and Madhusoothanan[10] noticed that the fabric thickness reduces with the increase in needling density. The increase in needling density or fabric weight reduces the compressibility of the fabric. They also observed that the thickness loss decreases with

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the increase in fabric weight. They found that for the fabric with no reinforcing material, the compressibility and thickness loss are higher than that for fabrics with reinforcing material, irrespective of fibre cross-section, and that compression resilience shows the reverse trend[11]. Also, they found that the compressibility and thickness loss decrease with the increase in fabric weight, irrespective of fibre cross-sectional shapes, both in dry and wet conditions[12].

Along with the compression properties, strength properties of nonwoven fabrics are also very important. Hou *et al.*[13] found that the pattern of bond points and fibre orientation have a significant effect on the behavior of nonwoven fabrics under tensile loading. Also, they found that the specimen size has a significant effect on the results even for the same shape factor. Rakshit *et al.*[14] found that with the increase in fabric weight, the tensile and bursting strengths increase. Das and Raghav[15] concluded that the tensile strength increases with the increase in fabric weight, and that the tensile strength reduces after the application of cycling pressure. The increase in the pressure level during cyclic loading significantly decreases the tensile strength.

Based on the above facts, it is evident that till now no attention has been devoted to examine the influence of applied pressure on the change of porosity in nonwoven fabrics. Knowing that the majority of nonwoven fabrics have porosities greater than 50 % and usually above 80 %[16], the aim of this study was to evaluate the change in porosity of nonwoven fabrics with respect to applied pressures, as well as the influence of fabric porosity, weight, thickness and the magnitude of applied pressure on the compression behavior of nonwoven fabrics. Also, knowing that the strength properties are one of the most important properties of fabrics, a part of the research was dedicated to the determination of some strength properties (tensile strength and elongation, bursting strength and ball traverse elongation) of nonwoven fabrics.

2 Materials and Methods

2.1 Materials

Two commercially-produced viscose/polypropylene nonwoven fabrics, for home applications as cleaning cloth, were used as experimental material. Basic characteristics of investigated nonwoven fabrics are given in Table 1. The investigated Sample B has approximately twice the mass per unit area and twice the thickness as compared to Sample A. Also, the investigated samples are different concerning porosity. Table 1 shows that the increase in thickness and fabric weight of tested samples is accompanied by a decrease in their porosity.

2.2 Test Methods

2.2.1 Determination of Structural Properties

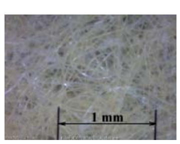
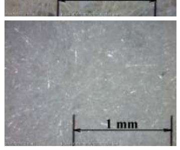
Mass per unit area (fabric weight) of nonwoven fabrics was determined according to standard ISO 9073-1. Thickness of nonwoven fabrics was determined with a thickness tester (AMES, type 414-10, USA).

The porosity of the samples, defined as the total amount of air in the samples, was calculated using the following equation[17]:

$$P = \left(1 - \frac{\delta}{\rho_f} \right) \times 100 \qquad ...(1)$$

where ρ_f is the density of fibre (g·cm^{-3}); and δ, the bulk density of nonwoven fabric (g·cm^{-3}). Bulk density (fabric density) of nonwoven fabrics (δ, g·cm^{-3}) was calculated using the following equation[18]:

Table 1 — Structural characteristics of investigated nonwoven fabrics

Sample	Appearance	Material composition	*M*, g·m^{-2}	τ, mm		*P*, %	
				LP	HP	LP	HP
Sample A		viscose/polypropylene (66/34)	104	1.05	0.95	92.47	91.65
Sample B		viscose/polypropylene (73/27)	239	2.03	1.95	91.23	91.04

M – fabric weight (g·m^{-2}), τ – fabric thickness (mm), LP – low pressure (0.66 kPa), HP – high pressure (9.81 kPa), and *P* – porosity.

$$\delta = \frac{M_a}{T} \times 10^{-3} \quad ...(2)$$

where M_a is the fabric weight of nonwoven fabrics (g·m^{-2}); and T, the thickness of nonwoven fabrics (mm).

Investigated nonwoven fabrics are obtained from viscose/polypropylene fibre blends. Because of that, in Eq. (1) for the porosity of the samples, the weight average density of fibres (ρ_{fm}) was used instead of fibre density (ρ_f). The weight average density of fibres (ρ_{fm}) was calculated using the following equation[19]:

$$\rho_{fm} = \frac{P_{vis} \cdot \rho_{vis} + P_{pp} \cdot \rho_{pp}}{P_{vis} + P_{pp}} \quad ...(3)$$

where P_{vis} and P_{pp} are the percentage blend proportion of viscose and polypropylene fibres respectively (%); and ρ_{vis} and ρ_{pp}, the densities of viscose (1.52 g·cm^{-3})[3] and polypropylene (0.91 g·cm^{-3})[20] respectively.

2.2.2 Determination of Compression Properties of Nonwoven Fabrics

A thickness tester (AMES, type 414-10, USA) was used for the investigation of compression properties (compressibility, thickness loss, compression work, compression work recovery, compressive resilience) of nonwoven fabrics. The nonwoven fabric thickness was measured at different pressures in two conditions, viz low pressure (LP) and high pressure (HP). Under the condition of low pressure, the samples were compressed starting with the initial pressure of 0.66 kPa, which was progressively increased in steps of 1.07, 1.89, 2.71, 3.61, 5.01 and 6.65 kPa. Under the condition of high pressure, the samples were compressed starting with the initial pressure of 9.81 kPa, which was progressively increased in steps of 17.47, 32.81, 48.13, 64.84, 90.90 and 121.55 kPa. After attaining the maximum pressure, the test was reversed in the same way till the complete recovery of the sample, in both the conditions.

Sample compressibility is defined as a decrease of fabric thickness with an increase in normal force applied to its surface. Sample compressibility (C, %) was calculated according to the following equation[4,21-23]:

$$C = \frac{T_{0c} - T_{max}}{T_{0c}} \times 100 \quad …(4)$$

where T_{0c} (mm) is the thickness of nonwoven fabric at the initial pressure of 0.66 or 9.81 kPa; and T_{max} (mm), the thickness of nonwoven fabric under the maximum pressure of 6.65 or 121.55 kPa.

Sample thickness loss, in fact, represents residual deformation component after the cessation of normal force action. Sample thickness loss (T_l, %) was calculated according to the following equation[11,12,23]:

$$T_l = \frac{T_{0c} - T_{rec}}{T_{0c}} \times 100 \quad …(5)$$

where T_{rec} (mm) is the recovered thickness, i.e. the nonwoven fabric thickness measured at the initial pressure of 0.66 or 9.81 kPa after removing the pressure of 6.65 or 121.55 kPa and the rest of 60 s.

The thickness of the tested samples was changed during the experiment, both in compression, and decompression phase and hysteresis of thickness was obtained. Sample compression work and sample compression work recovery of the tested nonwoven fabrics were investigated through the change in the fabrics' thickness.

Sample compression work (W_C, Pa·m) of nonwoven fabrics, in both conditions of pressure, was calculated according to the following equation[4,21,23]:

$$W_C = \int_{T_{0c}}^{T_{max}} P_c \cdot dT_c \quad …(6)$$

where P_c (Pa) is the magnitude of pressure which causes compression of the sample; and dT_c, the change of sample thickness under the compression phase.

Sample compression work recovery (W'_C, Pa·m) of nonwoven fabrics, also in both conditions of pressures, was calculated using the following equation[4,21,23]:

$$W'_C = \int_{T_{max}}^{T_{rec}} P_r \cdot dT_r \quad …(7)$$

where P_r (Pa) is the magnitude of pressure under recovery conditions (i.e. under decompression of the sample); and dT_r, the change of sample thickness under the decompression phase.

On the basis of the calculation of sample compression work (W_C, Pa·m) and sample compression work recovery (W'_C, Pa·m), the sample compressive resilience was calculated. Sample compressive resilience presents the percentage energy recovery from deformation due to lateral compression and can help to determine the recoverability of the fabric after compression[24]. Sample compressive resilience (RC, %) of nonwoven fabrics, in both conditions of pressures, was calculated using the following equation[4,21-23]:

$$RC = \frac{W'_C}{W_C} \times 100 \quad \ldots(8)$$

2.2.3 Determination of Pore Compression Properties

One of the indicators of the structure of the material is porosity. Since the porosity decreases as pressure increases during the compression phase[20], the pore compressibility (C_{por},%) was calculated using the following equation:

$$C_{por} = \frac{P_0 - P_{max}}{P_0} \times 100 \quad \ldots(9)$$

where P_0 (%) is the porosity of nonwoven fabric calculated at the initial pressure of 0.66 kPa for the condition of low pressure or 9.81 kPa for the condition of high pressure and $P_{\max}$ (%), the porosity of nonwoven fabric calculated under the maximum pressure of 6.65 kPa for the condition of low pressure or 121.55 kPa for the condition of high pressure.

The porosity of the samples is changing during the decompression phase, i.e. during the relaxation of samples. Porosity loss (P_l, %) was calculated using the following equation:

$$P_l = \frac{P_0 - P_{rec}}{P_0} \times 100 \quad \ldots(10)$$

where P_{rec} (%) is the recovered porosity, i.e. fabric porosity determined at the initial pressure of 0.66 or 9.81 kPa after removing the pressure of 6.65 or 121.55 kPa and the rest of 60 s.

During successive increases, followed by a gradual decrease of pressure on the nonwoven fabric, hysteresis was also obtained for porosity (Fig. 1). The surface below the compression curve designates the work necessary for deformation of the pores in the nonwoven sample (Wc_{por}), and the surface below the decompression curve represents the energy that the

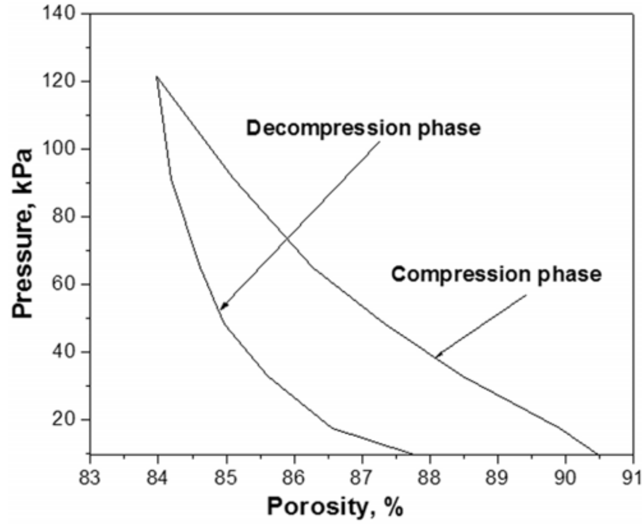


Fig. 1 — Compression hysteresis for porosity of nonwoven fabrics

pores in the nonwoven sample returns in a single cycle during unloading (W'_{Cpor}). Pore compressive resilience (RC_{por}, %) was calculated using the following equation:

$$RC_{por} = \frac{W'_{Cpor}}{W_{Cpor}} \times 100 \quad \ldots(11)$$

2.2.4 Determination of Strength Properties

Tensile strength and tensile elongation of nonwoven fabrics were determined according to standard ISO 9073-3 using dynamometer *Textest*, Switzerland. This test method examines the behaviour of nonwoven fabrics when subjected to tensile stress. Samples were cut in the machine direction (MD), as well as in cross-direction (CD). Tensile strength in both directions [F_p(MD), N and F_p(CD), N] and tensile elongation, also in both directions [l_p(MD), % and l_p(CD), %], were determined. The test was carried out on a 50 mm wide specimen.

The bursting strength and ball traverse elongation of nonwoven fabrics were determined using the device mounted in clamps of the dynamometer *AVK*, SZ type KG-2, Hungary. Bursting strength (F_b, N), i.e. the maximal bursting force in which the ball breaks through the circular specimen (radius 12.5 mm), was registered by using a metal ball (radius 9.5 mm). Ball traverse elongation (l_b, mm), i.e. the elongation at maximum bursting force (displacement of the ball from the beginning of the test till the end of it), was also registered.

All properties of the investigated nonwoven fabrics were determined at room temperature (20ºC). The average of 5 measurements for each sample was considered.

3 Results and Discussion

3.1 Compression Properties of Nonwoven Fabrics and Pores

Results of sample compressibility and pore compressibility, determined in conditions of low and high pressure, are presented in Figs 2(a) and (b). It is observed that the sample compressibility and pore compressibility depend on the magnitude of the applied pressure. A higher percentage of compressibility indicates a better ability of the fabric to be compressed[21]. As expected, the samples tested at higher pressures show higher sample compressibility compared to samples tested at lower pressure. The

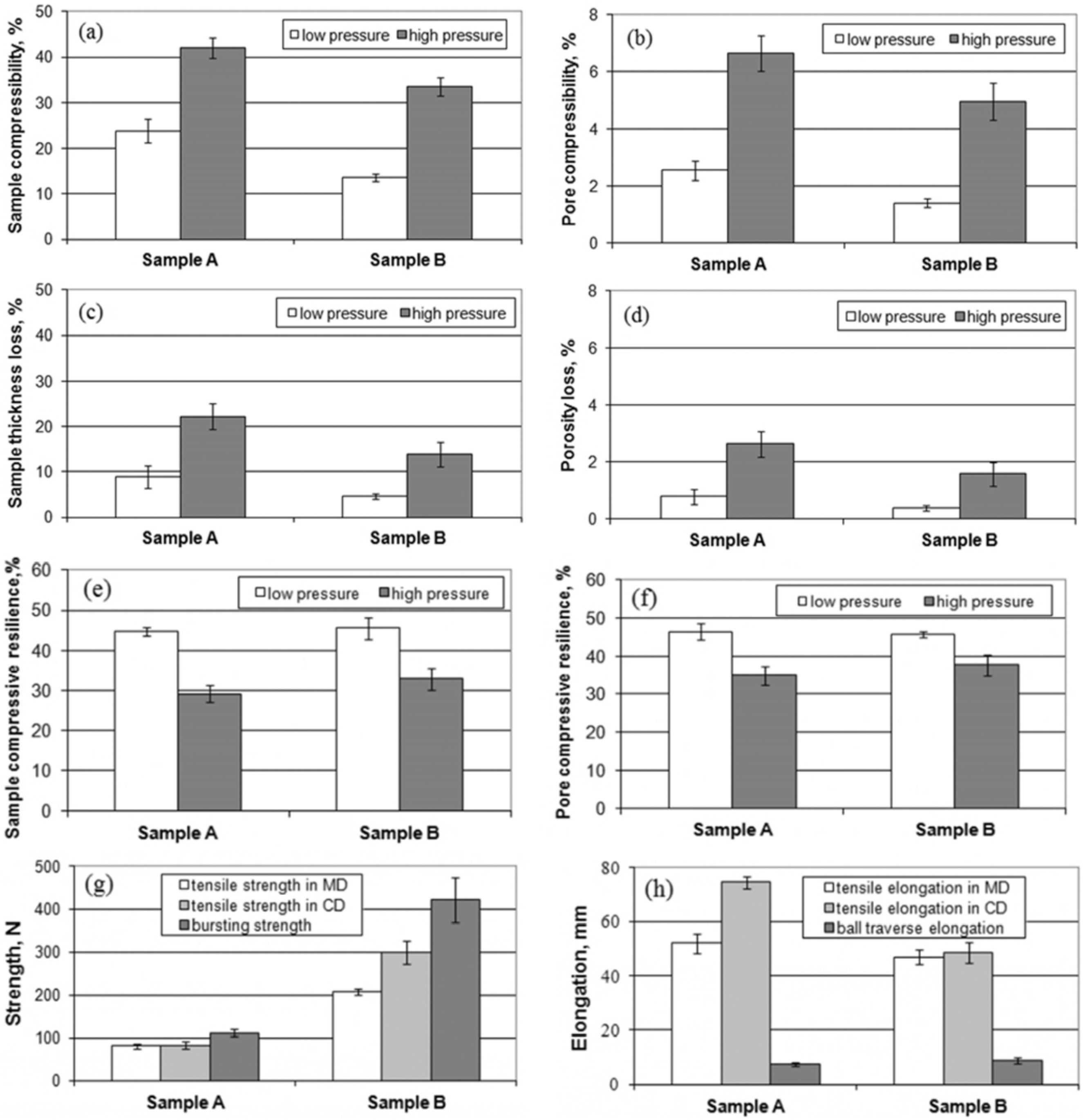


Fig. 2 — Properties of nonwoven fabrics

same behavior has been observed for pore compressibility. Using *t*-test, a statistically significant difference between the values of sample compressibility as well as between the values of pore compressibility, at low and high applied pressure for both investigated samples, has been noticed (Table 2).

As shown in Fig. 2(a), Sample A with the higher porosity (Table 1) shows the higher sample compressibility compared to Sample B which has the lower porosity. Concerning the pore compressibility, Sample B has the lower pore compressibility compared to Sample A under the both magnitudes of applied pressure [Fig. 2(b)]. The findings presented in Fig. 2(a) are found in accordance with the findings of Debnath and Madhusoothanan[11,12]. Increase in weight and thickness of nonwoven fabric is accompanied by an increase in the number of fibres that are in contact with each other. As a result, there is an increase in frictional forces between fibres in nonwoven material, which makes slipping and movement of fibres difficult. Also, an increase in a number of contact points between the fibres means the decrease in sample porosity. Because of that, Sample B with the lower porosity (Table 1) has the lower sample compressibility [Fig. 2(a)]. Application of *t* - test (Table 2) shows that there is a statistically significant difference in sample compressibility between Sample A and Sample B, as well as in pore compressibility between the investigated samples under the both magnitudes of applied pressure.

Results of the sample thickness loss, as well as the porosity loss, determined under conditions of low and high pressure, are presented in Figs 2(c) and (d). It is observed that the samples investigated at higher pressure have greater values of the sample thickness loss and the porosity loss, compared to the samples tested at the lower pressure. Lower recovery of deformation results in higher sample thickness loss[7,12]. An increased percentage of the sample thickness loss, as well as the porosity loss, indicates the lesser ability of the samples to retain their starting thickness or starting porosity. Application of *t*-test confirms a statistically significant difference between the values of sample thickness loss as well as between the values of porosity loss, both at low and high applied pressures and for both investigated samples (Table 2). Figure 2(c) also shows that Sample A has higher sample thickness loss than Sample B. Decrease in sample thickness loss with the increase in fabric weight is found in accordance with the earlier findings[10-12]. Statistically significant difference in sample thickness loss and porosity loss between Sample A and Sample B is found at both levels of applied pressure (Table 2).

Statistically significant differences in pore compressibility and porosity loss between Sample A and Sample B suggest that the size, orientation, and connectivity of pores influence the pore compressibility and porosity loss. Confirmation of this assumption requires additional testing, which is not the subject of this paper.

As mentioned above, during the compression and subsequent decompression phase of the samples, thickness and porosity are changing (Fig. 3). It is observed that applying high pressure causes much more pronounced changes in the thickness and porosity of the samples.

Results of the sample compressive resilience of nonwoven fabrics, as well as pore compressive resilience, determined in conditions of low and high pressure, are presented in Figs 2(e) and (f). It is observed that nonwoven fabrics have greater sample compressive resilience and pore compressive resilience at low pressure than at high pressure. A higher percentage of compressive resilience indicates a better recovery ability[25]. Statistical analysis using

Table 2 — Statistical results of the determination of sample compression properties and pore compression properties in conditions of low and high pressure by using t – test

Compression properties	$\lvert t\rvert_{A(LP)/A(HP)}$ (df = 4)	$\lvert t\rvert_{B(LP)/B(HP)}$ (df = 4)	$\lvert t\rvert_{A(LP)/B(LP)}$ (df = 8)	$\lvert t\rvert_{A(HP)/B(HP)}$ (df = 8)
Sample compressibility	13.96 ***	22.70 ***	9.85 ***	7.32 ***
Sample thickness loss	9.09 ***	8.54 **	4.32 **	5.46 ***
Sample compressive resilience	16.89 ***	8.47 **	0.77	2.75 *
Pore compressibility	14.88 ***	13.99 ***	7.92 ***	4.84 **
Porosity loss	8.97 ***	7.23 **	3.71**	4.40 **
Pore compressive resilience	8.06 **	6.32 **	0.67	1.69

A, B – sample code, LP – low pressure, HP – high pressure, (*) – level of significance of 0.05, (**) – level of significance of 0.01, (***) – level of significance of 0.001, and *df* – degrees of freedom.

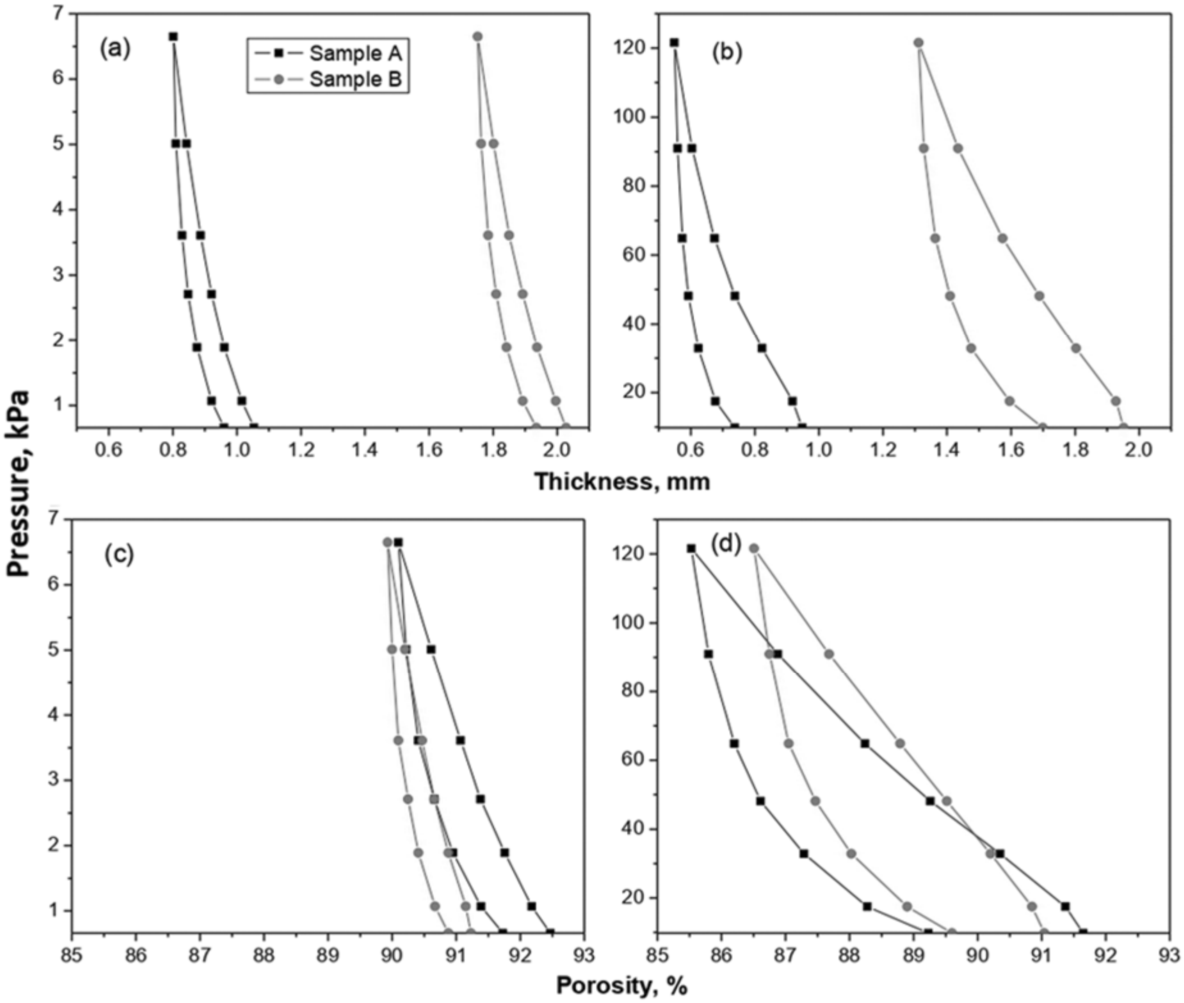


Fig. 3 – Compression hysteresis for thickness [(a) low pressure, (b) high pressure], and for porosity [(c) low pressure, (d) high pressure]

Student's *t*-test shows a statistically significant difference between the sample compressive resilience, as well as pore compressive resilience, both at low and high applied pressure and for both investigated samples (Table 2). Obtained results indicate better recovery of nonwoven fabrics and pores after the cessation of low pressure. There is a small mutual displacement of fibres observed in the sample under low pressure, and between fibres; friction forces of lower intensity are developed. Also, these small mutual displacements of fibres lead to small changes in porosity of the sample. For this reason, small changes in the structure, allow easier recovery of the sample during decompression after applying lower pressure. The results presented in Figs 2(e) and (f) also show that the pore compressive resilience is higher in regard to sample compressive resilience. This means greater pore elastic recovery than the sample elastic recovery.

Conducted statistical analysis between Sample A and Sample B shows statistically significant difference only between the values of sample compressive resilience at high pressure (Table 2). The absence of statistically significant differences in pore compressive resilience between Sample A and Sample B suggests that size, orientation, and connectivity of pores have no effect on pore compressive resilience. However, confirmation of this assumption requires additional testing, which is not the subject of this paper.

At the high level of applied pressure, Sample A with the greater sample compressibility [Fig. 2(a)] has the lower sample compressive resilience [Fig. 2(e)]. This means lower ability of elastic recovery of Sample A as compared to Sample B.

3.2 Strength Properties of Nonwoven Fabrics

Results of the determination of strength properties of the investigated nonwoven fabrics are given in

Figs 2(g) and (h). It is observed that both investigated samples have greater tensile strength in the cross-direction [F_p(CD)] as compared to that in machine direction [F_p(MD)]. Applying the Student's *t*-test, a statistically significant difference between the tensile strength in the machine direction and that in the cross-direction is observed for Sample B. However, there is no statistically significant difference between the tensile strength in the machine direction and that in the cross-direction for Sample A (Table 3). Hou *et al.*[13] stated that different behavior of samples in machine and cross-direction suggests that fibre orientation has a significant influence on the behavior of the nonwoven material under tensile loading. Therefore, greater tensile strength of Sample B in the cross-direction is probably due to the preferential fibre orientation in the cross-direction in regard to the machine direction. The absence of statistically significant differences between the tensile strength in the cross-direction and that in the machine direction for Sample A is probably the result of isotropic fibre orientation in the web.

Figure 2(g) shows that Sample B has higher tensile strength, in both investigated directions, as compared to Sample A. The same observation also applies to bursting strength. Statistically significant greater values of both tensile strengths and the bursting strength of Sample B as compared to the Sample A (Table 4) can be correlated with the greater fabric weight and thickness, as well as the lower porosity of Sample B in comparison to the Sample A. Results, regarding the tensile strength increase with the fabric weight increase, are also confirmed by Das and Raghav[15]. Obtained results for bursting strength are in agreement with the earlier findings[14]. An increase in fabric weight and fabric thickness causes an increase in the number of fibres in the unit volume of the tested sample. This increases the number of contacts between the fibres, and thus the frictional forces that hold together the fibres in the sample. Therefore, the worse mobility of the fibres due to the better compactness of fabric, could explain the greater tensile strength and bursting strength of Sample B.

Both investigated samples have the greater tensile elongation in the cross-direction than that in the machine direction. Based on the application of *t*-test, a statistically significant difference between the tensile elongation in the machine direction and that in cross-direction is found for Sample A (Table 3, $|t|$=13.62) but not in Sample B (Table 3, $|t|$=0.86).

Table 3 — Statistical results of determination of tensile strength and tensile elongation between the samples in machine direction and cross-direction using *t* – test

Sample	$\lvert t\rvert_{Fp(MD)/Fp(CD)}$ (df = 4)	$\lvert t\rvert_{lp(MD)/lp(CD)}$ (df = 4)
Sample A	0.66	13.62***
Sample B	8.53**	0.86

Fp(MD) – tensile strength in MD, *Fp*(CD) – tensile strength in CD, *lp*(MD) – tensile elongation in MD, *lp*(CD) – tensile elongation in CD, (**) – level of significance of 0.01, (***) – level of significance of 0.001, and *df* – degrees of freedom.

Table 4 — Statistical analysis of tensile properties of samples using *t* – test

Tensile properties	$\lvert t\rvert_{A/B}$ (df = 8)
Tensile strength in MD	32.18***
Tensile strength in CD	20.07***
Bursting strength	14.67***
Tensile elongation in MD	2.84*
Tensile elongation in CD	14.73***
Ball traverse elongation	2.41*

A, B – sample code, (*) – level of significance of 0.05, (***) – level of significance of 0.001, and *df* – degrees of freedom.

Figure 2(h) shows that Sample A with the lower fabric weight and the thickness compared to Sample B has the greater tensile elongation. This is in agreement with the results of Midha and Mukhopadyay[26]. The reason for decrease in tensile elongation with the increase in fabric weight and thickness is attributed to the better compactness of fibres in fabrics, causing reduced slippage, thereafter the decrease may be attributed to the fibre breakage which reduces fibre length and hence fibre-to-fibre cohesion. The decrease in tensile elongation with the increase in fabric weight and thickness is specifically expressed in cross-direction of the sample. Results (Table 4) show that the Sample B has statistically significant lower value of the tensile elongation as compared to Sample A. It is possible to register greater ball traverse elongation for Sample B. Application of *t*-test confirms that there is statistically significant difference between Sample A and Sample B for tensile and ball traverse elongation (Table 4).

4 Conclusion

The following inferences are drawn:

4.1 Sample compressibility, pore compressibility, sample thickness loss, and porosity loss, are of greater values at high pressure, for both the investigated samples. On the other hand, the sample compressive resilience and pore compressive resilience are of greater value at low pressure, also for both investigated samples.

4.2 The lower sample compressibility, sample thickness loss, pore compressibility, and porosity loss are found for Sample B which has higher fabric weight and thickness, and lower porosity.

4.3 Statistically significant differences in pore compressibility and porosity loss between Sample A and Sample B, at both levels of applied pressure, are observed. However, the absence of statistically significant differences in pore compressive resilience between Sample A and Sample B, also at both levels of applied pressure, is found.

4.4 At the high level of applied pressure, Sample A with greater sample compressibility has lower sample compressive resilience, i.e. worse ability of elastic recovery.

4.5 Both investigated samples show higher tensile strength and tensile elongation in cross-direction than in machine direction.

4.6 Sample B posseses greater fabric weight and fabric thickness. But lower porosity manifests greater tensile strength, bursting strength and ball traverse elongation, and the lower tensile elongation.

The above findings cannot be generalized due to the limited number of the experimental material. However, even this limited study provides the opportunity to investigate more closely the change in the porosity of the material under the compression based on the equations for pore compressibility, porosity loss, and pore compressive resilience. Also, the obtained results for pore compressibility, porosity loss, and pore compressive resilience suggest that the size, orientation, and connectivity of the pores have influence on pore compressibility and porosity loss, but not on the pore compressive resilience.

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