

## Compression characteristics of spunlace nonwoven fabric

R K Jain<sup>1</sup>, S K Sinha<sup>1</sup> & A Das<sup>2,a</sup>

<sup>1</sup>Department of Textile Technology, National Institute of Technology Jalandhar, Punjab 144 011, India

<sup>2</sup>Department of Textile Technology, Indian Institute of Technology Delhi, New Delhi 110 016, India

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The effect of fibre type, mass per unit area and number of cycles on compressional and recovery behaviour of spunlace nonwoven fabric has been studied in terms of compressional and recovery parameters as well as in terms of thickness loss and energy loss. The findings show that the spunlace nonwoven fabrics exhibit good compressional and recovery behaviour. The thickness loss and energy loss values reveal that the polyester viscose blended spunlace nonwoven shows better compressional and recovery behaviour. It is also found that there is rapid decrease in compressibility during initial cycles and after that it becomes stable on cyclic loading.

**Keywords:** Compression behaviour, Nonwoven, Polyester, Recovery behaviour, Resilience, Spunlace fabric, Viscose

### 1 Introduction

The growing consumer demand for apparel has forced the development of newer woven and knitted products. To meet the demand, nonwovens have also found its application in this sector<sup>1</sup>. The properties of nonwoven fabrics, however, distinguish their application area. For their application in apparel sector, parameters characterizing the wearer comfort should be taken on priority. One of the aspects of comfort is the resilient behaviour of fabric. A resilient fabric may provide good feel and eventually entrap more air, thereby influencing its thermal characteristics.

Spunlace nonwoven shows good physical and mechanical properties and hence considered as most promising alternative fabric for apparel sector. Flexural rigidity and surface properties of spunlace nonwoven fabrics are reported to be superior to that of other nonwovens, while its structural integrity is comparable with those products<sup>2</sup>.

Hydro-entanglement, commonly known as spunlacing is a mechanical type of bonding, uses high-speed jets of water to strike a web so that the fibres knot about one another<sup>3</sup>. This technology is very suitable way of converting textile fibres and their blends into nonwovens without damaging them<sup>4</sup>. Since the production does not require any binder, it can offer a great deal of softness, flexible hand, high drape and bulk. Spunlace nonwoven finds its use as bacteria proof clothing,

cleaning room clothing, wet wipes, and as interlining fabric<sup>2</sup>. Studies on its use even in fashion apparel are also available<sup>5,6</sup>.

Comfort in apparel products is generally attributed by their thermal and moisture management behaviour besides their physical and low-stress mechanical properties<sup>7</sup>. Thermal and moisture management behaviour are influenced by the inter-fibre space which is further influenced by the mode of entanglement/bonding of fibres in fabric. The low-stress mechanical properties of fabric characterised by compression, bending, tensile, shear and surface friction are important in objective evaluation of fabric comfort<sup>8,9</sup>. Fabric surface compression property can be a useful parameter to express the comfort characteristics of a fabric.

Compression of fabrics is an inevitable phenomenon during handling and processing<sup>10</sup>. Compressive properties are concerned with the surface smoothness, softness and fullness of a fabric. A fabric that compresses easily is likely to be judged as soft, possessing high value of compression<sup>10</sup>. Theories related to compressional properties of loose fibre masses are available<sup>11-13</sup> but limited reports are available on the compressional behaviour of nonwoven fabrics<sup>14-16</sup>. Van Wyk<sup>13</sup> reported the compression of fibre mass which is primarily due to bending of fibres, while Dunlop<sup>11</sup> has pointed out the fibre-to-fibre friction an important factor during compression. The stick slip nature of curves during compression and smooth inverse cube curve during recovery suggest the important role of fibre friction characteristics. However, the viscoelastic

<sup>a</sup>Corresponding author.  
E-mail: apurbadas65@gmail.com

nature of the fibre mass, especially for nonwoven fabrics, during compression and recovery has not been taken into account in any of these models. Batra and Mohamed<sup>12</sup> studied the compressional behaviour of air-laid adhesive bonded nonwoven and established an empirical equation.

Most of the proposed equations, available till date to characterize compressibility of fibre mass or woven fabric, are not applicable to nonwoven fabrics. The fibres in a nonwoven generally maintain certain degree of order and are bonded together with varying fibre arrangements, depending on its type and method of web preparation and bonding.

Kothari and Das<sup>14</sup> reported compression and recovery properties of different types of nonwoven fabrics and characterized in terms of two dimensionless independent parameters, viz  $\alpha$  (compressional parameter) and  $\beta$  (recovery parameter). The following equations were reported to represent the loading and unloading behavior of a needle-punched nonwoven fabric:

$$\frac{T}{T_0} = \left[ 1 - \alpha \log_e \frac{P}{P_0} \right] \quad \dots (1)$$

$$\frac{T}{T_f} = \left[ 1 - \alpha \log_e \frac{P}{P_f} \right] \quad \dots (2)$$

where  $T_0$  and  $T_f$  are the initial and final thicknesses at initial and final pressures  $P_0$  and  $P_f$  respectively; and  $T$ , the thickness at any arbitrary pressure  $P$ . Higher values of  $\alpha$  and  $\beta$  signify higher compressibility and recovery respectively. Failure to recover can also be interpreted from the level of loss in energy and thickness, as defined by following relationship:

$$\text{Energy loss } (E_L) = \left[ \frac{E_1 - E_2}{E_1} \right] \times 100 \quad \dots (3)$$

$$\text{Thickness loss } (T_L) = \left[ \frac{T_0 - T_r}{T_0} \right] \times 100 \quad \dots (4)$$

where  $E_1$  is the potential energy stored during loading;  $E_2$ , the potential energy recovered during unloading ( $E_2$ );  $T_0$ , the thickness at 2kPa; and  $T_r$ , the thickness after recovery at 2kPa.

Compression resilience is a parameter which may be used to characterize handle of fabric. As compression resilience signifies the ability of the fabric to recover from compression, a higher resilience should lead to less loss of energy and soft handle of the product<sup>17</sup>. It is measured by the area of the hysteresis loop on subjecting the fabric to compression and allowing it to recover. Compression resilience, compressibility and recovery can be calculated using following relationship:

$$\text{Compression resilience} = \left[ \frac{E_2}{E_1} \right] \times 100 \quad \dots (5)$$

$$\text{Compressibility } \% = \left[ \frac{T_0 - T_f}{T_0} \right] \times 100 \quad \dots (6)$$

$$\text{Recovery } \% = \left[ \frac{T_r}{T_0} \right] \times 100 \quad \dots (7)$$

Reports are thus available on compression behaviour of fibre masses and to a limited extent on nonwoven fabrics, but the compression behaviour of spunlace nonwoven fabrics, in particular, has not been studied and no attempt has been made to characterize its compression and recovery characteristics. In the present study, an attempt has been made for a detailed study on the compressional and recovery characteristics of spunlace nonwoven fabrics.

## 2 Materials and Methods

### 2.1 Materials

Six fabrics were produced at the Bombay Textile Research Association, Mumbai, India considering variation in composition and fabric weight (Table 1).

The fibres were procured from Ginni Filament Ltd. and then used for producing spunlace nonwoven. The linear densities of polyester and viscose fibres were 1.4dtex and 3.3 dtex; and fibre lengths were 41 mm and 38 mm respectively. The theoretical flexural rigidity of polyester fibre is less compared to viscose fibre due to higher linear density of viscose fibre.

Process parameters such as 100 bars water pressure, plain weave based conveyor belt and 1 mt/min conveyor belt speed were used for the production of nonwoven fabrics. The other process parameters, such as diameter of jet orifice, nozzle to nozzle distance, and discharge coefficient were kept constant.

### 2.2 Test Procedure

The thickness of the fabrics was measured using an Essdiel thickness tester. Fabrics were placed on an anvil plate and a pressure foot of 20 mm diameter was brought down to apply a pressure of 2 kPa on the

Table 1 — Fabric preparation plan

Sample code	Weight, g/m <sup>2</sup>	Fibre
S <sub>1</sub>	45	100% Polyester
S <sub>2</sub>	80	100% Polyester
S <sub>3</sub>	45	Polyester/Viscose (50/50)
S <sub>4</sub>	80	Polyester/Viscose (50/50)
S <sub>5</sub>	45	100% Viscose
S <sub>6</sub>	80	100% Viscose

fabric for 30 s and the thickness was measured as initial thickness ( $T_0$ ). The compressive loads were increased in steps and corresponding thicknesses were recorded after an interval of 30 s. After reaching a pressure of 200 kPa, the pressure was gradually reduced in steps and the corresponding thickness at each step was recorded in the same way during the recovery cycles. This test was repeated for at least five times at different places for each sample.

A cyclic loading test was carried out to characterize the behaviour of the fabrics under repeated loading. The loading range in this case was also from 2 kPa to 200 kPa. The loading and unloading were done in the same manner as stated above, but in this case the test was repeated for ten cycles and the load was applied at a fixed position of the fabric.

**2.3 Experimental Data and Analysis**

A set of data (pressure and thickness) during loading and recovery cycles for all six samples was recorded. Figure 1 shows a pressure-thickness relation during loading and unloading typically for fabric  $S_1$ .

MATLAB curve fitting by least square technique carried out for loading as well as for unloading experimental data and is represented in Fig.1. Experimental data exhibit very good correlation with Eqs (1) & (2) ( $R^2=0.9866$ ). Figures 2(a) and (b) represent the curve fitting of loading and unloading cycle for fabric  $S_1$ . Curve fitting by least square technique is also applied to each mean set of loading and unloading data for all samples using Eqs (1) & (2).

Each set of experimental data exhibits very good correlation with Eqs (1) & (2). The value of dimensionless constant ( $\alpha$ ) as compressional parameter and ( $\beta$ ) as recovery parameter is obtained with 95% confidence by fitting the set of pressure- thickness data in Eqs (1) & (2) using MATLAB.

**3 Results and Discussion**

Table 2 shows the initial thickness, compressional and recovery parameters and recovered thickness values, percentage energy loss, and thickness loss. The thickness of  $S_1$  fabric is found approximately

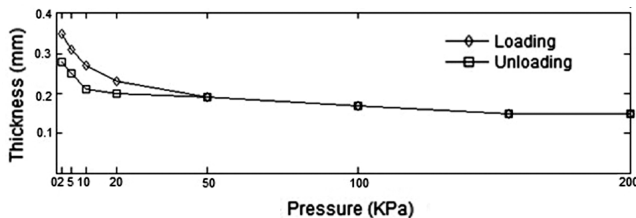


Fig. 1 — Value of mean thickness with respect to pressure for  $S_1$  sample

same as that of  $S_5$  fabric. This may be due to the difference in fibre linear density and fibre length which nullify the effect of fibre density. But with increase in mass per unit area, effect of fibre density plays major role and hence the thickness of  $S_2$  fabric is higher than that of  $S_6$  fabric. It is observed that as the mass per unit area increases, the compression parameters ( $\alpha$ ) and thickness loss decrease. However, there is initial increase then decrease in the energy loss with increase in mass per unit area.

**3.1 Compressional Behaviour of Spunlace Nonwoven Fabric**

Compressional properties of textile structures have direct relevance to the bulk and handle of fabric. Compressional behaviour is important parameter to understand the aesthetic properties as well as dimensional stability of textiles used for apparel application. It is observed from Table 2 that for 100% PET and 100% viscose spunlace nonwoven compression parameter decreases while recovery parameter increases whereas for P/V blended fabric both parameters decrease with increase in fabric density.

From Table 2, it is observed that the compressional parameter ( $\alpha$ ) decreases with increase in mass per unit area of fabric. The compression characteristics of a fabric generally depend on the mechanical and surface characteristics of the constituent fibres, the degree of

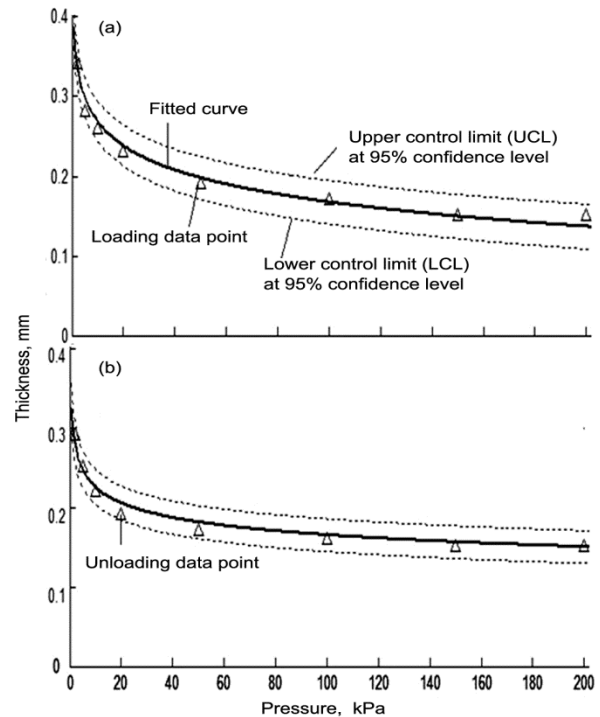


Fig. 2 — Best fitted curve of  $S_1$  with experimental points at 95% confidence limit (a) loading and (b) unloading

Table 2 — Compression and recovery characteristics of spunlace nonwovens

Sample code	Initial thickness ( $T_0$ ) mm	( $\alpha$ )	( $\beta$ )	$E_1$	$E_2$	Energy loss ( $E_L$ ) %	Observed recovered thickness ( $T_r$ ), mm	Thickness loss ( $T_L$ ) %
S <sub>1</sub>	0.3521	0.1341	0.1303	36.16	34.43	4.78	0.2811	20.16
S <sub>2</sub>	0.5514	0.1263	0.1485	59.81	53.93	9.84	0.4612	16.36
S <sub>3</sub>	0.3806	0.1140	0.1019	44.77	43.00	3.95	0.3305	13.16
S <sub>4</sub>	0.5020	0.0661	0.0698	76.18	68.82	9.66	0.4315	14.04
S <sub>5</sub>	0.3489	0.0921	0.0789	46.76	44.40	5.05	0.2891	17.14
S <sub>6</sub>	0.454	0.0872	0.0979	59.28	53.21	10.24	0.3733	17.78

$\alpha$ -Compression parameter,  $\beta$ -Recovery parameter,  $E_1$ - potential energy stored during loading,  $E_2$  - potential energy recovered during unloading.

entanglement of the fibres influencing the available inter-fibre spaces and number of fibres in the cross-section.

A structure with high degree of entanglement is expected to result less inter fibre spaces. When the number of fibre in the cross-section increases the degree of entanglement is also expected to be more. However, the bending characteristics of the fibres may play a role in deciding the entanglement. Higher entanglement may reduce the liberty of the bending behaviour of the fibre and increase the inter-fibre cohesion thereby influencing the compression property of the fabric. A decrease in compressional parameter with an increase in mass per unit area may be due to the increased compactness of fabric with more entanglement between fibres, thereby restricting its movement. This trend is observed for all fabrics, irrespective of fibre types/blends.

It is observed from Table 3 that the fabrics (S<sub>1</sub> and S<sub>5</sub>) with same weight per unit area and approximate same thickness show higher compressibility with lower recovery and vice versa. But the fabric S<sub>2</sub> shows higher compressibility with higher recovery compared to S<sub>6</sub> due to higher thickness value. Further the compressional and recovery parameters take care of individual data during compression and recovery, whereas the compressibility % and recovery % are calculated based on the end points. Hence, the compressional and recovery parameters are more important for nonwoven structure compared to compressibility % and recovery %.

The values of compression parameter and compressibility are more for polyester spunlace nonwoven fabric as compared to viscose spunlace nonwoven fabric for same weight per unit area. Polyester fibre is bulkier with less flexural rigidity as

compared to viscose fibre. The bulk and resilience of polyester fibre may not facilitate compaction, while low flexural rigidity facilitates entanglement. So, the low flexural rigidity is expected to allow more compression of the structure on load application. When two fibres of different generic nature are blended, the differential surface and cross-sectional characteristics may influence the arrangement of fibres in the structure. The general tendency of viscose for coherence leads to a compacted structure but its difference in bulk and cross-sectional shape with the polyester fibre may disturb compaction. The resultant of the two effects shows the compression parameter at a value between that obtained for structure with polyester and/ or viscose only. Therefore, in P/V blended spunlace nonwoven fabric, compression parameter as well as compressibility (Table 3) decreases with increase in weight per unit area due to increase in fabric density.

The compressional parameter for P/V fabric (S<sub>4</sub>) is found to be less as compared to viscose fabric (S<sub>6</sub>) due to the dissimilar nature of fibres, restricting the compression of structure which becomes more prominent with higher entanglement at higher weight per unit area. Hence, the compressional parameter is lesser for P/V fabric as compared to viscose fabric at higher weight per unit area.

### 3.2 Recovery Behaviour of Spunlace Nonwoven Fabric

Recovery behaviour of textile structure is important for its application in apparel application. A fabric is considered to be the best for apparel application when it recovers completely from deformation on removal of deformation force. Recovery behaviour of a textile material is directly related to its dimensional stability.

It is observed from the Table 2 that recovery parameter ( $\beta$ ) increases for both 100% polyester

Table 3 — Value of compression and recovery parameters for studied spunlace nonwoven

Sample code	Compressibility %	Recovery %	Compression resilience, %	Fabric density g/cc
S <sub>1</sub>	57.14	80.00	96.54	0.1286
S <sub>2</sub>	58.18	83.64	90.22	0.1455
S <sub>3</sub>	52.63	86.84	96.05	0.1184
S <sub>4</sub>	36.0	86.00	90.33	0.1600
S <sub>5</sub>	42.86	82.86	94.95	0.1286
S <sub>6</sub>	46.67	82.22	89.75	0.1778

nonwoven and 100% viscose nonwoven with increase in weight per unit area of fabric. The surface property and the elastic behaviour of fibre are expected to influence the cohesive nature of the structure, thereby influencing the recovery behaviour.

A fabric with higher mass per unit area offers more inter-fibre entanglement and accordingly applied pressure on such fabric results in higher stress development due to increased fibre-to-fibre entanglement/friction. This leads to a decrease in compressibility and also helps in improvement in recovery parameter.

The value of recovery % (Table 3) is less for polyester spunlace nonwoven fabric as compared to that for viscose spunlace nonwoven fabric for same weight per unit area despite having lower energy loss %. This may be due the higher coherence nature of viscose fibre. Hence, viscose spunlace nonwoven exhibits lower compression resilience as compared to polyester and its blend with polyester. Further the energy loss % is calculated from Eq. (3). The values of  $E_1$  and  $E_2$  are obtained by area under the respective cycle using MATLAB. The recovery % is calculated based on the end points. Hence, it can be observed that the value of energy loss% follows similar trend as that of recovery parameter as both are obtained through curve fitting in MATLAB.

The recovery parameter for P/V fabric (S<sub>4</sub>) is found to be less as compared to viscose fabric (S<sub>6</sub>) due to the dissimilar nature of fibres, restricting the recovery of structure which becomes more prominent with higher entanglement at higher weight per unit area. Hence, the recovery parameter is lesser for P/V fabric as compared to that for viscose fabric at higher weight per unit area. Polyester/viscose (50/50) blended spunlace nonwoven shows decrease in recovery parameter as well as recovery % with increase in mass per unit area due to lower inter-fibre friction of polyester and viscose in the blend.

### 3.3 Thickness Loss

Table 2 shows that thickness loss is more for 100% polyester fabric compared to that for 100% viscose

fabric for approximately same initial thickness (0.35 mm) and weight per unit area (45 gsm). This is due to the fact that polyester spunlace nonwoven has less recovery% as compared to the viscose fabric. Further, it can also be explained that polyester based spunlace nonwoven is more compressible and less recoverable, which results in higher thickness loss.

It is observed that the thickness loss% for 80 gsm viscose nonwoven fabric is slightly more than that of polyester spunlace nonwoven despite having higher fabric density and less compressible fibre. It is due to less number of fibres per unit area in viscose spunlace nonwoven which leads to mobility and partial depth-wise alignment of fibres. It is also observed that the loss in thickness decreases for polyester fibre with increase in mass per unit area of the fabric. This is due to the compact structure at higher fabric weight as manifested by the increase in fabric density. The thickness loss for P/V blend and viscose fibre based nonwoven, however, increases with weight per unit area despite increase in fabric density. This may be due to lesser recovery % and better coherence nature of viscose fibre.

### 3.4 Energy Loss

Table 2 shows that energy loss% is less for polyester nonwoven fabric compared to that for viscose fabric for the same weight per unit area (45 gsm) and approximately the same thickness (0.35 mm). The inability of a structure to recover is manifested as the loss in energy. Polyester fibre structure offers more compression resilience than a structure of viscose fibre which is believed to be the primary reason for the less energy loss in case of polyester fabric. It is also observed from the table that the energy loss % increases with increase in mass per unit area of fabric, irrespective of its composition. The compactness of the structure at higher fabric weight as indicated by the increase in fabric density might have caused decrease in compression resilience (Table 3).

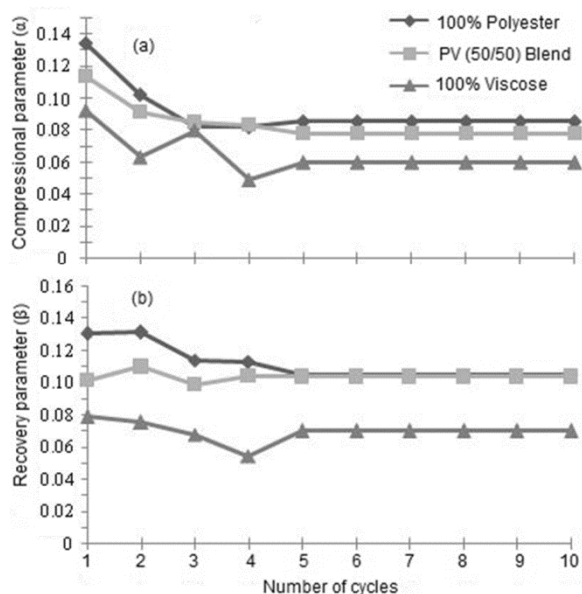


Fig. 3 — Effect of type of fibre/ blend and number of cycles on the (a) compressional parameter, and (b) recovery parameter

### 3.5 Effect of Cyclic Loading on Compression and Recovery Behaviour

Figure 3 shows the effect of cyclic loading on compression and recovery behaviour of the fabrics. It is observed that as the number of cycle increases, the fabric becomes more and more compact due to fibre-to-fibre slippage at each stage, which results in decrease in value of compressional and recovery parameters. The possibility of readjustment of fibre arrangement during loading and unloading actions is likely to make the structure compact. Fibre slippage and readjustment after five loading cycles appear to be reduced drastically, leading both the parameters ( $\alpha$  and  $\beta$ ) to remain constant.

### 4 Conclusion

The compression and recovery behaviour of spunlace nonwoven fabric can also be described with the help of two parameters  $\alpha$ ,  $\beta$  and the initial thickness with pressure change in logarithm form. Compressibility and recovery behaviour depends on the characteristics of constituent fibres and mass per

unit area. The compression and recovery behaviour of spunlace nonwoven, in general, significantly improve with increase in mass per unit area. Cyclic loading also have significant effect on compressional behaviour as compressibility decreases very rapidly and then becomes stable. Good compressional and recovery behavior, good compressional resilience with acceptable thickness loss % and energy loss % for polyester/viscose blended spunlace nonwoven can conveniently be used for apparel application and specifically in interlining fabric.

### References

- 1 Dutton K C, *Consumer Acceptance of Nonwoven Fabrics for Apparel and Accessory End-Uses*, PhD thesis, North Carolina State University, Textile Technology Management, 2009.
- 2 Saleh S S D, *Low Stress Mechanical Properties of Hydroentangled Fabrics*, PhD thesis, The University of Leeds, School of Textiles and Design, 2003.
- 3 Batra S K, Thompson M & Wadsworth L, *Nonwoven Glossary*. INDA (Association of the Nonwovens Fabrics Industry) 2002.
- 4 Berkalp O, *Fibers Text East Eur*, 14 (2006) 81.
- 5 Sliva, E, *Evolution on the Use of Nonwovens in Apparel Short Review* (North Carolina State University) 2010.
- 6 Dhange V, Webster L & Govekar A, *Int J Fiber Text Res*, 2 (2) (2012) 12.
- 7 Yao Bao-Guo, Yan Li-xia, Wang Jian-chao & Hong Shui-yuan, *Telkomanika*, 11(2) (2013) 674.
- 8 Mitsuo M, *J Text Eng*, 52(1) (2006)1.
- 9 Kawabata S & Niwa M, *Int J Cloth Sci Technol*, 3(1)(1991)7.
- 10 Hari P K, Types and properties of fibres and yarns used in weaving, *Woven Textiles: Principles, Technologies and Applications*, edited by K Gandhi (Wood head Publishing), 2012, 29.
- 11 Dunlop J I, *J Text Inst*, 74 (1983) 92.
- 12 Batra S K & Mohamed M H, *International Seminar on Nonwovens* (The Bombay Textile Research Association, Mumbai, India), 1990.
- 13 Van Wyk C M, *J Text Inst*, 37(1946) T285.
- 14 Kothari V K & Das A, *Geotext Geomembranes*, 11 (1992) 235.
- 15 Kothari V K & Das A, *Geotext Geomembranes*, 12(2) (1993) 179.
- 16 Kothari V K & Das A, *Geotext Geomembranes*, 13(1994)55.
- 17 Das A, *Compressional Properties of Nonwoven Fabrics*, PhD thesis, Indian Institute of Technology, Delhi, 1994.