Paper-like Characteristics of Degreased Pure Cotton Spunlace

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Abstract: Characteristics of a new type of Degreased pure Cotton Spunlace (DCS) were first investigated, compared with performances of Viscose Spunlace (VS) and the pure Natural Cotton Spunlace (NCS) before degreased. Bulk density of the VS is the greatest and that of NCS the smallest within the above three kinds of spunlaces. The pure cotton spunlace becomes thin after degreased, during which NCS is transferred into the DCS. The NCS is well gas-permeable, easily stretchable, poor in intensity, and just in opposite to the VS with the corresponding performances. However, all the features in the DCS described above are much closer to those within the VS. These characteristics of the pure cotton spunlace after degreased could be generally summarized as a paper-like phenomenon.

Introduction

Spunlacing technology, based on inserting fiber with water-injection needles for manufacture of nonwovens [1], doesn't hurt the fabrics, not lint and not produce environmental pollution. The nonwovens produced from it are absorbent and soft, and widely utilized as various skin-friendly health-care and disposable high-end textiles [2], such as facial mask [3], diapers, wipes, sanitary napkins, etc. As a new type of textile technology, this method was initially commercialized in the 1980s and then introduced into China in the 1990s. After several decades of rapid growth, its current annual output was estimated to be 50 million tons [4,5,6]. Raw materials of spunlacing are usually viscose [7] and polyester fibers, as well as a certain amount of natural cotton and wood pulp, where the natural cotton fiber is always used as one of the mixing components [8]. According to our knowledge, there are no pure NCS products in commercial market and even the pure DCS nonwovens are produced by a few of manufacturers [9,10], which only occupy a minimal market share. During production of the DCS, raw natural cotton fibers is firstly processed into degreased cotton [11] and then manufactured into the DCS nonwoven utilizing spunlacing technology. The current commercial route for the DCS is complicated and requires a much higher cost based on a complex technology. With advancement of consumer attitudes, production of pure cotton spunlace based on various simple and efficient approaches is significant in meeting people's pursuit for the natural products and the green environment.

In this paper, the mechanical characteristics of DCS originating from a new synthetic route were reported, where raw cotton fiber was firstly processed into the NCS by means of spunplacing technology and then further treated into DCS. A NCS sample with a consistent areal density to that of the DSC and a commercial VS sample with the same thickness as the NCS with substantially were chosen in our evaluation so as to establish a basic concept to this new type of DCS nonwoven.

Measurement procedure and materials

Spunlaced nonwovens evaluated in this paper were all manufactured and provided by a company. Thickness of the nonwoven sample was measured on a digital thickness meter (YG141N, Nantong Grand Experiment Instrument Co., Ltd.). Areal density was deduced from the mass of the nonwoven sample at a sample area of 10×10 cm^2. The bulk density was calculated according to the expression:

$r = s/h$. Wherein, the variable h represents the thickness of the spunlaced nonwoven and s the areal density.

The gas permeability of the nonwoven sample was measured on a digital gas permeability tester (YG461E, Wenzhou Fangyuan Instrument Co.) referring to GB/T5453-1997. During measurement, the diameter of the pore within the tester, which holds the sample and allows the gas flow through, was equal to 2.0 cm and the gas pressure difference between both sides of the sample was equal to 200 Pa. Compression test referring to FZ/T01051.2-1998 was carried out on a KES-FB3 type compression tester, where the contact area of the presser was 2.0 cm^{-2} and the lifting speed 0.05 $mm \cdot s^{-1}$. The measurement was implemented on a sample area of 10×10 cm^2 and the function between the thickness and pressure was obtained, while the thicknesses T_0 and T_M were acquired at a gentle pressure of 0.5 $cN \cdot cm^{-2}$ and a heavy pressure of 50 $cN \cdot cm^{-2}$, respectively.

Compression ratio is expressed as $EMC(\%)=[(T_M-T_0)/T_0]\times 100\%$ and compression power (or ratio power) as $WC=\int_{T0 \rightarrow TM} p dx$. Wherein, p represents the pressure and x does the compression displacement. When the p is replaced by the recovery pressure of the pressed sample, the above expression was further defined as compression recovery work (*WC'*). Thereby, compression recovery rate is expressed as $RC=(WC'/WC)\times 100\%$. Bending stiffness was measured on a KES-FB2 pure bending tester, expressed as $B=dM/dk$, where M is the bending moment based on the unit width of the sample ($cN \cdot cm^2 \cdot cm^{-1}$) and k the curvature (cm^{-1}) of the sample. Bending moment hysteresis *2HB* ($cN \cdot cm \cdot cm^{-1}$) was expressed using the bending stiffness at k=0.5 cm^{-1} from bending deformation/recovery curve. Prior to the measurement the sample was kept at 20±3 ^oC for 24 h in an environment with a relative humidity of 65±2% and the curvature was increased or decreased at a constant speed during an entire test cycle. Tension characteristics were determined on an electronic fabric strength tester (HD026N, Dongguan Fangyuan Instrument Co.), referring to GB/T3923.1-2013[12]. The width of the measured sample was equal to 5.0 cm, the distance between the ends of a pair of clips for holding the sample equal to 20.0 cm, and the test was conducted at 20 ^oC in an environment with a relative humidity of 65%. The stretching force vs different length, the tension and elongation vs the fracture of the spunlace sample were all recorded, the elongation at break was calculated and the tension fracture work integrated until fracture of the sample.

Experimental results and discussion

Density and densification shrinking

Table 1. Thickness, areal density and bulk density of the three kinds of spunlaces

Sample	***Thickness*** [mm]	***Areal density*** [$g \cdot m^{-2}$]	***Bulk density*** [$kg \cdot m^{-3}$]
VS	0.647±0.03	61.8±0.4	95.5
NCS	0.697±0.06	40.9±1.0	58.7
DCS	0.502±0.04	43.4±3.8	86.5

Thickness, areal density and bulk density of the three kinds of spunlaces were listed in table 1. Each datum originated from the average of three parallel detections. The thickness (0.647 mm) of VS was approximately closed to that (0.697 mm) of NCS and the areal density (40.8 $g \cdot m^{-2}$) of NCS was roughly as same as that (43.4 $g \cdot m^{-2}$) of DCS as considered with their deviation ranges. The bulk density was calculated with the thickness and areal density by the expression $r = s/h$. Herein, the bulk density of VS was the largest (95.5 $kg \cdot m^{-3}$) and that of the NCS the smallest (58.7 $kg \cdot m^{-3}$) in the three samples. Herein, the bulk density of the DCS (86.5 $kg \cdot m^{-3}$) was enlarged by 47% more than that of NCS and much more closed to that of VS (95.5 $kg \cdot m^{-3}$). Furthermore, the thickness of DCS (0.502 mm) was reduced by 22% less than that of NCS (0.697 mm), based on the same areal density. It is thus an important conclusion that the degreasing process makes the pure cotton spunlace shrinking and thinning.

Gas Permeability and the Permeability Deterioration

Table 2. Air permeability of the three kinds of spunlaces [mm·s^{-1}]

VS	*NCS*	*DCS*
1993±62.3	2792±283.6	2425±247.1

Gas permeability of the three kinds of spunlaces is list in table 2. Although having the same thickness, the NCS and VS possessed the largest (2792 mm·s^{-1}) and the smallest (1993 mm·s^{-1}) values of gas permeability, respectively. The degreasing process enabled the gas permeability of pure cotton spunlace to reduce from 2792 mm·s^{-1} (NCS) down to 2425 mm·s^{-1} (DCS) under a further thickness-reduced condition as shown in table 1. Therefore, the degreasing process enables pure cotton spunlace to somewhat deteriorate in gas permeability.

Compression and Compression Rate Decline

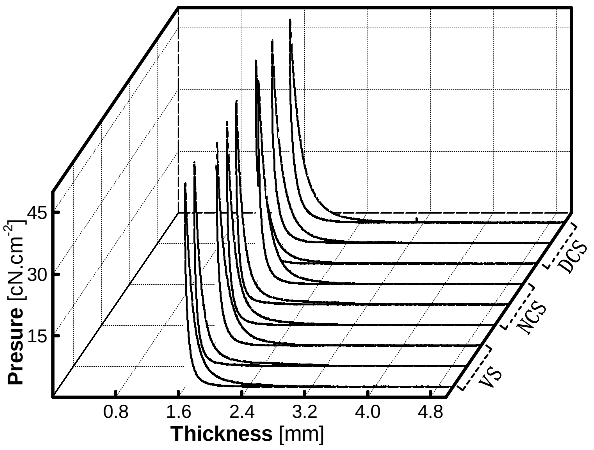

Figure 1. Compression-recovery cycle curves of the three kinds of spunlaces

Table 3. Thickness, compression work and compression recovery rate of the three kinds of spunlaces

Property	*VS*	*NCS*	*DCS*
T_0 [mm]	2.74±0.210	2.49±0.14	2.13±0.047
T_M [mm]	1.59±0.055	1.46±0.04	1.47±0.017
Compression Rate [%]	41.8±0.1	41.3±0.0	30.9±0.1
Compression Work [cN·cm^2·cm^{-1}]	0.64±0.04	0.75±0.08	0.56±0.05
Compression Recovery Rate [%]	41.4±1.1	45.2±1.0	48.5±4.4

Compression-recovery cycle curves of three spunlaces are shown in Fig. 1. The thickness, compression rate, compression work as well as compression recovery rate of all the three kinds of spunlaces were summarized and listed in table 3, based on processing of the above cycle curves. The compression rates of VS (41.8%) and NCS (41.3%) were exactly the same, but the compression rate of DCS (30.9%) was only two-thirds the rate of the pure cotton spunlace before degreased (i.e. the rate of NCS). The compression work of NCS was 0.75 cN·cm^2·cm^{-1}, which was greater than that of VS (0.64 cN·cm^2·cm^{-1}) at the same thickness. However, the compression work of DCS (0.56 cN·cm^2·cm^{-1}) was the smallest in all the three spunlaces. It is thus obvious that the degreasing process enables the compression extent and the compression work of the pure cotton spunlace to decrease.

Stretching and Strength Enhancement

Tension-elongation curve of the three kinds of spunlaces are shown in Fig. 2. The VS sample had the maximum strength and the minimum fracture elongation and, however, these properties in the NCS were just the opposite. The fracture strength was improved and the fracture elongation decreased in the pure cotton spunlace after degreased, closed to that the VS performed.

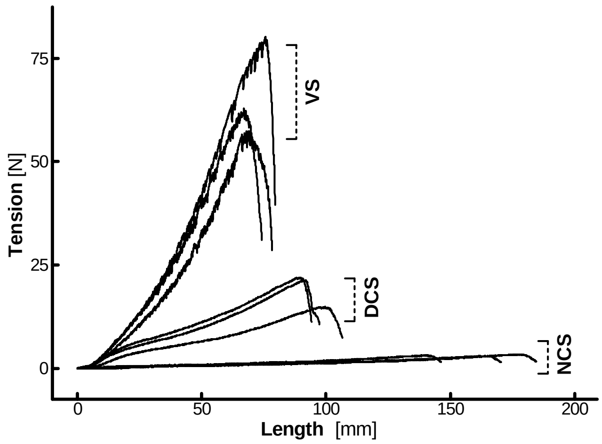

Figure 2. Tension-elongation curves of the three kinds of spunlaces

Table 4. Tension characteristics of the three kinds of spunlaces

Property	***NCS***	***DCS***	***VS***
Fracture Strength [N]	3.2±0.2	19.4±3.9	53.4±12.0
Fracture Elongation [mm]	158.9±19.5	93.1±5.8	61.03±11.3
Fracture Elongation Rate [%]	79.5±9.7	46.5±2.9	30.5±5.6
Fracture Work [10^{-3}·J]	184.8	831.6±124.9	1511.6

Table 4 lists the tension characteristics of three kinds of spunlaces, summarized from the tension-elongation curves in Figure 2. The fracture strength of the NCS sample was only just one-eighth the strength of VS, but its fracture elongation was more than twice the elongation of the VS. Every above characteristic of DCS was located between the corresponding value of the NCS and the value of the VS. Sufficient strength is the basis of a variety of application of spunlaced nonwovens and it is evident that a simple post-degreasing process improves the strength of the pure cotton spunlace and ensures its application in possibility.

2.5 Bending Stiffness and Stiffening

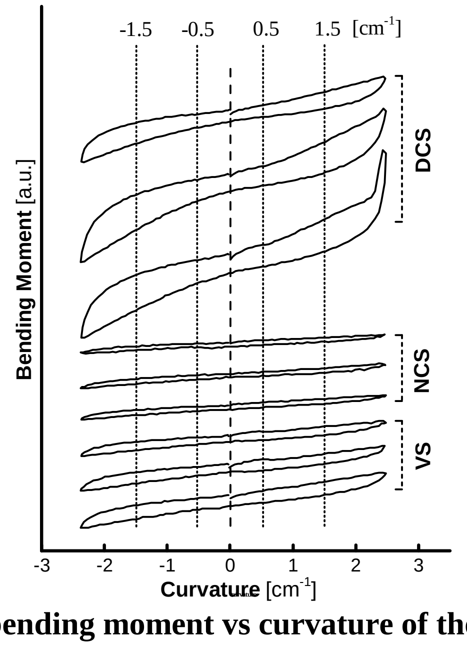

Figure 3 Cycle curves of bending moment vs curvature of the three kinds of spunlaces

The cycle curves of bending moment vs curvature of the three kinds of spunlaces are shown in Fig. 3. The curves of the NCS sample were similar to those of VS, which of positive and negative branches were closer to each other. However, the cycle curves of DCS were significantly enlarged as shown in Fig. 3, indicating an obviously difference between its positive and negative bending moments.

Table 5. Bending stiffness of the three kinds of spunlaces

Property	*VS*	*NCS*	*DCS*
Bending Stiffness [cN.cm^2.cm^{-1}]	0.0137±0.0038	0.0070±0.0013	0.0436±0.0120
Bending Hysteresis [cN.cm.cm^{-1}]	0.0173±0.0033	0.0078±0.0009	0.0333±0.0089

The bending stiffness and hysteresis of the three spunlaces are summarized and shown in Table 5. Both the bending stiffness and hysteresis of NCS were significantly less than these of VS at the same thickness. After the degreasing process, the bending stiffness of DCS was, however, 62 times that of NCS, and 3 times that of VS, though NCS and VS obviously possessed much more thicknesses than the DCS. This is to say the degreasing process enables cotton spunlace stiffening, the shape of the cotton spunlace difficult to recover, and these features of the pure cotton spunlace after degreased could be summarized as a mild paper-like phenomenon.

Conclusions

Degreasing process enables the pure cotton spunlace shrinking significantly, during which its bulk density increases closely to the value of viscose spunlace. Although deteriorated somewhat, the gas permeability of the pure cotton spunlace after degreased is still higher than that of viscose spunlace. The degreasing process makes the pure cotton spunlace shrinking and its compressible extent declining simultaneously. The fracture strength of the pure cotton spunlace after degreased increases substantially and its fracture elongation decreases sharply. Meanwhile, it is difficult for this degreased cotton spunlace to be bended and more difficult for it to restore to its original shape if it is bended. Degreasing process enables the mechanical characteristics of the pure cotton spunlace closer to those characteristics of viscose spunlace, which presents a certain degree of stiffening, shows mild paper-like features. These results are significant for the new development of the pure cotton spunlace and for its application as commercial products.

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