AUTOMATIC SYSTEM TO CONTROL THE ANISOTROPY OF NONWOVEN FELTED WEBS

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Abstract: *The webs produced using a card as former system generally keep the fiber orientation. This effect is not very important for a great number of applications. But if an even pore distribution is necessary or the mechanical properties are to be uniform in all directions, then this system doesn't work very well. Some years ago, it has been introduced a drafting operation of the web between the pre-needling and the final needling operations, as a solution. However, this alternative has a problem: there is no way to adapt it to variations in fiber orientation in the web. Taking into account these considerations, a new technological solution has been specifically devised to control the fibre orientation during the drafting operation in pre-needled felts. A prototype is used as drafting unit with the rolls driven by stepper motors and controlled by computer. Two video cameras collect images of the surface of the web, before and after the drafting operation, and process them in a computer. The values of the images textural descriptors, are calculated and compared. It is intended an increase in entropy which means that the web become less ordered and this is the situation we are aiming for. A computer program will adjust automatically the speed and pressure of the drafting cylinders so as to achieve the best possible situation in terms of the isotropy of the final product and, consequently, MD:CD ratio close to 1.*

Key words: *Nonwovens, Needlepunched, Drafting Control, Image Analysis, Texture Analysis, Anisotropy.*

1. INTRODUCTION

Although presently there are available several different methods for web formation, the use of a card, as a web former unit, is very common, mainly because it is a technology very well-known and accepted by the textile industry. For technical applications, the only problem present when the card is the former system is that a certain fiber orientation always occurs, which is acceptable in many cases because normally a cross lapper is used to increase the thickness of the web and to adjust the mass per unit of area. Although the mechanical properties of a product based on such a system may be similar in both principal directions, it must be considered that each layer keeps its particular fiber direction. Yet, for many applications, it is necessary that the distribution of fibers be as isotropic as possible in order to permit an even pore distribution as well as equal mechanical properties in all directions, particularly, along the MD and CD axis hence, requiring an MD:CD ratio close to 1. When the web consolidating system to be used is a needling process, a good solution consists in producing this needling operation in two steps: pre-needling and final needling [1,2]. During the pre-needling operation tufts of fibers are transported from their horizontal position to a vertical situation. If a drafting operation is introduced between these two steps, the fibers of the horizontal structure may rotate around the fibers of the vertical structure and reorient themselves. The critical point of this method is the control of the drafting operation. If it is not enough extended, then the web will keep some fiber orientation in a particular direction. On the other hand, if the drafting operation has been carried out too far, then a new kind of orientation will arise with all the inconveniences of the first one [3,4]

Characterization of web superficial properties with image analysis

Image analysis deals with images and can be summarized as a set of techniques that convert object images in numbers and prepares this data to be processed by computer methods. It is also known as digital image analysis [5]. Texture analysis, is an essential concept of image analysis that deals with primitives or elements called texels, and this mean a contiguous set of pixels with some regional property or pattern. A texture feature is a numerical value, extracted from an object image, that gives us some information about the variation of grey levels distribution and variation on an image. From a statistical point of view, image textures are complicated pictorial patterns that can be defined by statistical models, in way to characterize these same patterns.

According to the consulted bibliography, we found a prevalence of texture discrimination by the co-occurrence matrixes method in multiple researches works in many fields. This technique gives us a high dimensional texture description and puts in evidence the space relations between the grey levels. Thus, as the grey levels are a function of the mass per unit area, we have a direct characterization of the material structure [6]. The probability of spatial grey level co-occurrence is a second order density probability, which can be defined by a matrix of relative frequencies *f(i,j)* with witch two neighbouring pixels separated by a distance d on θ direction, occur on the image, one with grey level *i*, and the grey level *j*. Thus, for an image with N_G grey levels, the probability density functions can be written under the form of four squared matrices N_G X N_G for the 0º,45º,90º e 135º directions Haralick, Shanmungan and Dienstein [7] proposed 14 measures of textural features derived from the co-occurrence matrices, each one representing certain image properties. However, the textural descriptors used in this work were:

First order entropy $$H = -\sum_{i=0}^{G-1} p(i)\log_2\left[p(i)\right] \quad \textbf{(1)}$$

Second order entropy $$ENT = -\sum_{i=0}^{G-1}\sum_{j=0}^{G-1} P_{d,\theta}(i,j)\,Ln\left[P_{d,\theta}(i,j)\right] \quad \textbf{(2)}$$

2. MATERIALS AND METHODS

The experimental setup developed in this research work was comprised by the following elements:

1 – A Cosmatex nonwoven laboratorial line composed by a feeding/opener, card, cross-lapper and pre-needling/needling apparatus.

2 – An image analysis system composed by a Frame grabber DT3155 from Data Translation inc; 2 CCD_s Cohu model 2652-2000; Lenz system from Cosmicar – pentax; Monochromatic video monitor model TM923B from JVC and 1 PC for the drafting and pressure control and 1 PC for image acquisition and processing.

3 – A specifically devised pre-needled drafting prototype, conceived with 4 drafting zones between 5 drafting sets of cylinders and equipped with two CCD_s, one at the beginning of the process and another one at the end.


Fig. 1*: Illustration of the developed prototype and control system.*

The pre-needled webs were produced using Lyocell fibres with 6,4 dtex and 60,5 mm. The needling density was kept constant and the webs mass per unit area were170 g/m^2. The drafting operation was conducted with constant pressure on each pair of rolls (2,4bar) and constant and equal pre-drafting length for all drafting zones. The variable parameters were the drafting ratio which assumed the following values: 0%; 6,7%; 13,3%; 20%; 26,7%; 33,3%; 40% and the used drafting zone (C1; C2; C3; C4). The pre-needled web´s images were acquired at the entry (IN) and at the exit (OUT) of the drafting operation. Their textural descriptors were extracted using the spatial grey level dependence method and compared in a fully automated and real time process.

3. RESULTS

3.1 - First order entropy

Table 1*: First order entropy results*

Drafting	Zone 1 (C1 IN)	Zone 1 (C1 OUT)	Zone 2 (C2 IN)	Zone 2 (C2 OUT)	Zone 3 (C3 IN)	Zone 3 (C3 OUT)	Zone 4 (C4 IN)	Zone 4 (C4 OUT)
0	6,02	6,215	6,098	6,152	6,033	6,249	6,071	6,397
6,7	5,955	6,458	6,107	6,233	6,073	6,208	6,028	6,304
13,3	6,069	6,505	6,058	6,283	6,068	6,277	5,877	6,488
20	6,092	6,481	6,127	6,467	6,092	6,331	5,994	6,540
26,7	6,062	6,470	6,067	6,453	6,041	6,323	5,918	6,526
33,3	5,946	6,440	6,193	6,391	6,095	6,300	5,872	6,450
40%	5,962	6,411	6,23	6,376	5,979	6,294	5,915	6,387

The observation of the evolution of the 1st order entropy when dependent of the increasing drafting ratio clearly shows that, for every drafting value considered and for all the drafting zones involved, the output entropy value is always higher than their comparative entry value. Additionally, our findings point that all the drafting zones analysed present a continued growth of the output entropy value until it reaches their maximum, which occurs in the drafting zone 4 and with a drafting ratio of 20%. When surpassing this value, with a continued increasing of the drafting ratio, all the drafting zones exhibit a slight but steady decrease of the first order entropy.

3.2 - Second order entropy

The analysis of the 2nd order entropy output, for all the different studied angular directions and for all the drafting zones, exhibits a similar behaviour. The collected data are shown in table 2.

Table 2*: Second order entropy results*

Drafting Rate	SIN 0°	SIN-45°	SIN 90°	SIN 135°	SOUT 0°	SOUT 45°	SOUT 90°	SOUT 135°	AVERAGE OUT
Zone 1									
0	10,400	10,770	10,481	10,773	10,448	10,836	11,062	10,866	10,803
6,7	10,454	10,776	10,441	10,785	10,955	11,305	10,973	11,318	11,138
13,3	10,514	10,849	10,520	10,858	10,981	11,318	10,556	11,350	11,051
20	10,550	10,979	10,673	10,986	10,932	11,383	11,156	11,397	11,217
26,7	10,496	10,865	10,564	10,870	10,942	11,341	11,095	11,331	11,177
33,3	10,355	10,701	10,397	10,712	10,912	11,318	11,079	11,338	11,162
40	10,318	10,707	10,418	10,716	10,871	11,245	11,046	11,265	11,107
Zone 2									
Drafting Rate	**SIN 0°**	**SIN-45°**	**SIN 90°**	**SIN 135°**	**SOUT 0°**	**SOUT 45°**	**SOUT 90°**	**SOUT 135°**	**AVERAGE OUT**
0	10,678	11,047	10,733	11,056	10,688	11,060	11,018	11,072	10,960
6,7	10,763	11,193	10,912	11,189	10,944	11,272	10,931	11,283	11,108
13,3	10,622	10,972	10,624	10,981	11,110	11,279	10,764	11,287	11,110
20	10,030	11,131	10,820	11,125	11,151	11,416	11,124	11,497	11,297
26,7	10,595	11,380	10,891	11,285	11,023	11,492	11,213	11,425	11,288
33,3	10,718	11,117	11,091	11,288	10,880	11,395	11,121	11,396	11,198
40	10,695	11,280	11,038	11,136	10,860	11,389	11,110	11,285	11,161
Zone 3									
Drafting Rate	**SIN 0°**	**SIN-45°**	**SIN 90°**	**SIN 135°**	**SOUT 0°**	**SOUT 45°**	**SOUT 90°**	**SOUT 135°**	**AVERAGE OUT**
0	10,577	10,982	10,664	10,990	10,880	11,285	11,425	11,336	11,232
6,7	10,744	11,191	10,956	11,196	10,850	11,335	11,351	11,273	11,202
13,3	10,715	11,226	10,968	11,232	10,981	11,534	10,991	11,382	11,222
20	10,805	11,211	10,914	11,216	11,194	11,630	11,089	11,631	11,386
26,7	10,565	11,229	11,057	11,235	11,220	11,617	11,275	11,625	11,434
33,3	10,790	11,189	10,858	11,195	11,102	11,526	11,239	11,540	11,352
40	10,593	11,100	10,888	11,106	11,081	11,380	11,226	11,532	11,305
Zone 4									
Drafting Rate	**SIN 0°**	**SIN-45°**	**SIN 90°**	**SIN 135°**	**SOUT 0°**	**SOUT 45°**	**SOUT 90°**	**SOUT 135°**	**AVERAGE OUT**
0	10,607	11,036	10,758	11,044	10,955	11,460	11,713	11,919	11,512
6,7	10,499	10,906	10,628	10,913	11,015	11,414	11,702	11,772	11,476
13,3	10,290	10,631	10,285	10,643	11,530	11,488	11,565	11,876	11,615
20	10,503	10,929	10,643	10,936	11,311	11,580	11,151	11,587	11,407
26,7	10,272	10,721	10,450	10,727	11,209	11,921	11,191	11,508	11,457
33,3	10,203	10,648	10,445	10,653	11,200	11,884	11,239	11,453	11,444
40	10,260	10,701	10,387	10,708	11,127	11,785	11,236	11,426	11,394

The 2nd order entropy for the 0º direction, thus for CD direction, presents a continued growth up to maximum value, which is nearly 20% of the drafting ratio. After this peek, a decrease of their values occur until it reaches a minimum value, approximately stable and slightly higher than the value of the initial entropy. The 2nd order entropy for the 45° direction shows a slight decrease in the initial phase, which may be caused by a minor increase in the fibrous structure orientation in this direction. However, posteriorly it increases their value to a maximum which is achieved with higher drafting rates revolving around 20% to 30%, hence compensating the initial disorientation loss. Starting from this point is possible to see yet another entropy decreasing until reaching values slightly higher than the initial input values. The 2nd order entropy for the 90º direction, commonly known as CD direction, denotes an initial diminishment for the early stages of the pre-needled web drafting process to a value close to 13,3% which produces a new reorientation of the fibrous structure along this direction and thus compensating the entropy gain obtained by the fibrous disorganization within the CD direction. Since this value, the entropy rises until reaching a maximum attained with a drafting ratio ranging between 20% and 26,7%. Afterward, we assist to an entropy decay tending to a limit value in which the output entropy is slightly higher than the initial one for all the analysed drafting zones. The 2nd order entropy evolution for the 135º direction is marked by their continuous increment along with the increasing in the drafting rate, up to is peak, which is close to 20%. After this maximum, it starts a steady but slight decrease with a tendency to stabilize. The overall behaviour for all the drafting zones exhibits only minor changes, apart from the initial stage of the drafting zone 4. As expected, the average 2nd order entropy, in all the different drafting zones, display a variation pattern analogous to their individual behaviour for all the diverse angular directions considered. It should be noted that the mean values of the 2nd order entropy demonstrate an increasing output evolution with lower values achieved with the drafting zone 1 and maximum values reached with the drafting zone 4.

4. CONCLUSIONS

The analysis of the variation of the studied textural descriptors - first and second order entropy – as a function of the variation of the drafting ratio permits the following conclusions:

The evolution of the first order entropy along with the drafting ratio increasing, evidence a continuous growth until a maximum peak followed by a slowly, but steady, diminishment with the continued increase of the drafting rate. The behaviour of this variable is in accordance with the theoretical assumption, in which the fibrous disorganization induced by the rotation movement of the fibres (web horizontal structure) around the tufts (web vertical structure) is caused by a drafting rate limited to a set of optimal values. Higher drafting rate values will produce a new reordering of fibres, but in the opposite direction from the initial one and, consequently, the decrease of the entropy of exit of 1st order entropy. The analysis of the variation of 2nd order entropy along with the increasing drafting ratio, for all the different angular directions studied, also favours some interpretations consistent with the behaviour demonstrated by the 1st order entropy. The comparison of the behaviour of the 2nd order entropy variation, when a function of the drafting ratio increasing, for the concrete case of this experimental setup, allows to infer that the optimum drafting value to carry out the correction of the MD:CD ratio to values close to the intended unit value, revolves around, approximately, 20% a value from which a new reordering of the web fibres occurs in the opposite direction to the initial situation and induces a similar mechanical behaviour, but with an opposite value.

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