Studies on the Fiber Orientation Distribution Function and Mechanical Anisotropy of Thermally Point-Bonded

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Abstract

Current efforts to establish links between geometrical features and mechanical performance of nonwoven fabrics in general, and of point-bonded (spot-bonded) nonwovens in particular, would be served significantly by the measurements of Fiber Orientation Distribution Function (ODF) and tensile modulus which occurs during controlled-deformation experiments. Image analysis technique (using the Fast Furier Transform) is used to quantify the fiber orientation distribution. The results suggest that, within a typical window of processing conditions, ODF has a significant influence on the mechanical anisotropy. The data also suggest that mechanical anisotropy of thermally point-bonded nonwovens is likely to be governed by different stress mode according to the applied macroscopic tensile direction.

Introduction

The high rate of growth in nonwovens has led to a substantial increase in research aimed at establishing links between structure and mechanical properties [1, 2] of these materials. Image analysis techniques [3-6] have been used to obtain an insight into how these structures respond to applied macroscopic deformations. The indirect methods for the nonwoven structures were based on light scattering, flow-field analysis and the Fast Fourier Transform (FFT) of the image as well as the Hough Transform [7]. It was found that as an indirect method, the utility of the Fourier method was unquestionable especially in dealing with noisy images [5, 6].
However, since most of these attempts do not allow sufficient insight into the mechanisms responsible for the deformation characteristics of these nonwovens. This study will examine the issues regarding the relationship of the ODF and tensile modulus at different azimuthal angles from the preferred fiber orientation direction in nonwovens. A direct comparison is made between the results obtained by Fast Fourier Transform and those obtained by tensile testing.

Experimental

Materials

Thermally point-bonded nonwoven fabrics were produced at two different bond areas, 15 % and 40 % from the same unbonded precursor web. The precursor fabric was a unidirectional, carded fabric of poly(propylene) fibers, with a staple length of 1.5 inch (5.08 cm) produced by sequentially combining the webs from two cards. The final fabrics had a weight of 20 g/yd^2 (21.9 g/m^2). Nonwoven fabrics produced at a constant calendar roll pattern, temperature (160 ^{o}C) and pressure (40 psi). In the point-bonded nonwoven fabric of the present study, these directions allow easy identification of the repeating unit of the bond pattern.

Tensile Texting

Each nonwoven tensile-test sample measured 15 x 2.5 cm. The samples were tested on an Instron tensile testing machine at an extension rate of 100 %/min. The clamps used were 5 cm wide and 2.54 cm high. The gage length used was 10 cm. The properties of most nonwoven fabrics, especially those produced from carded webs, are anisotropic, i.e., they vary according to the direction in which the fabric is tested. Testing was carried out on samples cut at ten-degree azimuthal intervals. The secant modulus at 10% elongation was obtained from the load-elongation data. The data represent the averages and the standard deviations obtained from five measurements in each case.

Fiber Orientation Distribution Function (ODF)

The fiber orientation distribution function (ODF) was determined by using the Fourier method. An image of a nonwoven structure is composed of spatial details in the form of brightness transitions cycling from light to dark and from dark to light. Spatial frequencies in a nonwoven image are related to the orientation of the fibers; fibers are

shown in black on a white background (or vice versa).
If the fibers are predominantly oriented in a given direction in a nonwoven fabric, the rate of change in frequencies in that direction will be low and the rate of change in frequencies in the perpendicular direction will be high. We use this property of the Fourier Transform to obtain information on the fiber orientation distribution in a nonwoven fabric.

Results

A nonwoven sample that has completely random ODF and over all bond may show the identical angular mechanical performance and frequency of ODF at all azimuthal directions. From this aspect, this study has been focused on the relationship between ODF and angular mechanical performance of the targeted nonwoevns. The simulated tensile modulus was compared with the simulated ODF in Fig. 1. For the purpose of easy comparison, the maximum and minimum values for each case are set at the same levels respectively. It should be noted that there exist some difference at the comparison, especially, in the non-principal (far from 0^{o} or 90^{o}) directions.

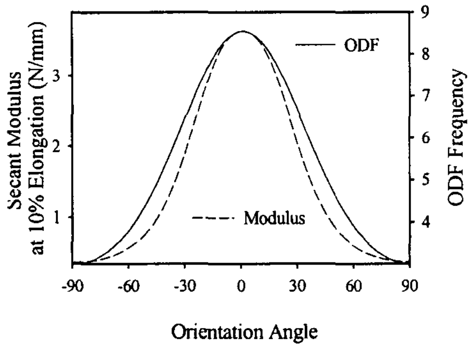

Figure 1. Comparison of simulated ODF and tensile modulus.

From the failed results of the nonwovens, it is manifested that application of a macroscopic tensile strain produces a significant shear stress concentration along the initially preferred direction in fiber ODF, except when the two directions are either parallel or normal to each other. An important consequence of this effect is in the failure process, which shows a propensity for its propagation along the dominant fiber orientation direction, unless the macroscopic tensile stress is applied along, or close to, 0^{o} or 90^{o}. The latter cases lead to failure in the relatively uniform tensile mode. Therefore, one of the reasons responsible for the mechanism of the difference shown in Fig. 1 can be found in the different stress transform mode. The preferred fiber orientation induced un-symmetrical structure results in shear stress concentration, that leads to a substantially higher degree of compliance, when the macroscopic tensile stress is applied to non-principal direction.

Conclusions

It is generally believed that the fiber orientation distribution function is found to be rapid, simple and quite suitable for predicting the mechanical performance of nonwovens. However it should be noted that there exist different stress transform modes when the macroscopic tensile stress is applied to the nonwovens at various directions. It is manifested that application of a macroscopic tensile strain produces a significant shear stress concentration that leads to a substantially higher degree of compliance of nonwovens, except when the stress is applied along, or close to, 0^{o} or 90^{o}. An important inference from this work is the recognition of the difference between the ODF and mechanical anisotropy along the azimuthal angles.

References

1. H.S. Kim, B. Pourdeyhimi, A.S. Abhiraman, and P. Desai, Textile Research Journal, *Textile Res. J.*, **71**, (2002) 965.
2. S.M. Lee and A. S. Argon, *J. Textile Inst.*, **1**, (1983) 1.
3. B. Pourdeyhimi and B. Xu, *Int'l Nonwovens Journal*, **6**, (1994) 26.
4. B. Pourdeyhimi, R. Ramanathan and R. Dent, *Textile Res. J.*, **66**, (1996) 747.
5. B. Pourdeyhimi, R. Dent, and H. Davis, Measuring Fiber Orientation in Nonwovens, *Textile Res. J.*, **67**, (1997) 143.
6. B. Pourdeyhimi, R. Dent, A. Jerbi, S. Tanaka and A. Deshpande, *Textile Res. J.*, **69**, (1999) 185.
7. B. Pourdeyhimi and H.S. Kim, *Textile Res. J.*, 72, (2002) 803