열융착형 부직포의 역학특성 모델링

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Computational Modeling of Mechanical Performance in Thermally Point Bonded Nonwovens

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1. Introduction

Several theoretical models have been proposed in the past in an attempt to predict basic performance. The focus of these research efforts has been mainly directed towards the understanding of the mechanical behavior of the structures. Some of these efforts are summarized below.

Backer and Patterson pioneered a fiber web theory to accommodate the broad mechanical design requirements of nonwovens [1]. Hearle *et al*, extended the model to account for local fiber curvature [2]. It is interesting to note that Hearle *et al.*, measured fiber orientation by means of a projection microscope where the path of the fiber was manually traced on transparency. In the early of 1980's, Britton *et al.* [3-5] demonstrated the feasibility of computer simulation of the behavior of a network generated mathematically. The model is not based on any real fabric; rather it is designed for mathematical convenience in setting up the input data. Grindstaff and Hansen [6] on the other hand developed a computer simulation for stress-strain curve of point-bonded fabrics, but fabric strength mechanism and even fiber orientation distribution (ODF) were not included. Mi and Batra [7] recently proposed a model to predict the stress-strain behavior for certain point-bonded geometries. This model however, needs to be refined in terms of its underlying assumptions and developed further to make it applicable to various bond geometries.

2. Image Simulation

The new simulation scheme takes into account the bond details as well. A simulated image can be designed with the following variables: web density; fiber properties (fiber denier, crimp and thickness with allowed distribution); unit cell size; as well as various bond properties (bond size, shape and pattern). The most important component of the simulation is the way in which lines or curves are generated. For continuous fiber simulations, we use the procedure known as μ-randomness. μ-randomness is defined by the perpendicular distance from a fixed reference point (preferably located in the center of the image) and angular position of the perpendicular. Distance is sampled from random distribution and the slope is sampled from an appropriate distribution. Figure 1 shows one example of the input model. The images were generated with different number of lines, but basically following the same randomness with a specific bond pattern.

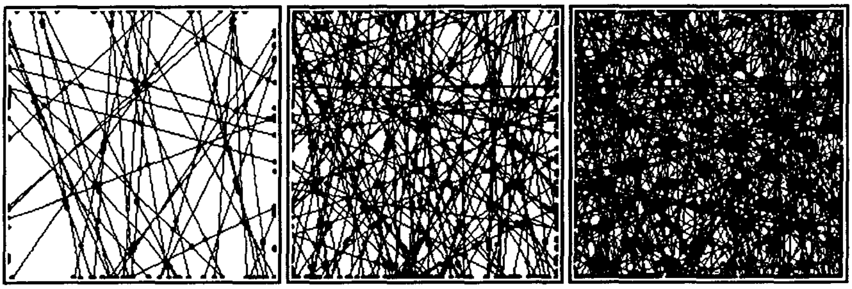

Figure 1 Image simulation and data acquisition; total number of simulated lines (left) 50, (middle) 150 and (right) 350

3. Theoretical Backround

When both ends of this fiber segment are anchored at two different bond sites, as the web is deformed the fiber segment is extended to a length (l_0+$d\ l$) such that

$$(l_0 + \Delta l)^2 = (y_0 + \Delta y)^2 + (x_0 + \Delta x + \tan \delta\gamma \cdot ((y_0 + \Delta y)))^2$$

where, Δl is the elongation of the fiber, Δx and Δy are the elongation components in machine direction (MD) and cross direction (CD), respectively, and $\delta\gamma$ is the shear strain of the web.

In the case of very small increments of strain at each deformation step, the incremental strain, $\delta\varepsilon_\theta$, and the incremental specific stress, Δf_θ, in the bridging fiber are respectively as assuming the higher order terms of very small values equal zero,

$$\delta\varepsilon_\theta = \frac{l_x}{l_0}\delta\varepsilon_x \cos\theta + \frac{l_y}{l_0}\delta\varepsilon_y \sin\theta + \delta\gamma \sin\theta\cos\theta$$

and

$$\Delta f_\theta = E(\varepsilon)\left(\frac{l_x}{l_0}\delta\varepsilon_x \cos\theta + \frac{l_y}{l_0}\delta\varepsilon_y \sin\theta + \delta\gamma \sin\theta\cos\theta\right)$$

The global coordinates system (MD and CD direction) have been obtained from the local coordinate system (fiber direction) by a rotation angle of θ at which the fiber is oriented.

4. Application of the Model

In Figure 2, the nonwoven sample has a 0 degrees main orientation angle and ODF standard deviation of 50, the area web density is 60%, and the fiber type is continuous. For now, this will be considered the standard condition to avoid repeating the characterization details. The de-bonding force was changed from 0.005 N to 0.05 N. As the de-bonding force decreases, the maximum stress of web decreases because the web failure is due to the fiber-to-fiber interface failure when the de-bonding force is lower than the fiber strength. The de-bonding forces might depend on the amount of polymer fused and the structure of the bonded polymer.

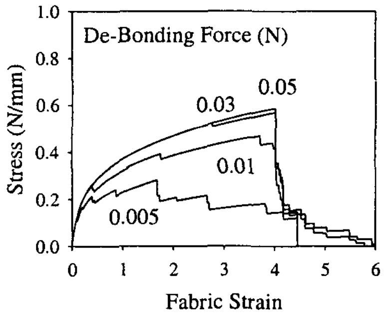

Figure 2 Web Stress-Strain curves as function of De-bonding Force.

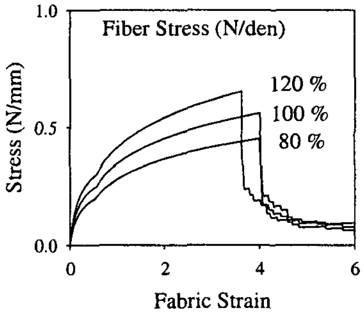

Figure 3 Web Stress-Strain curves as function of Fiber properties.

Figure 3 demonstrates the case for different fiber strengths. In this case, it is assumed that the all other conditions remain constant. When using stronger fiber, the web modulus and failure stress increase but the elongation at the maximum stress decreases. This propensity of the web directly reflects the property of constituent fibers.

5. Conclusions

We have developed a mechanics based model to help understand the behavior of point bonded nonwovens as a function of structural variables. This model appears to have considerable promise in eliminating much of the elaborate experimentation that is currently required in the development of new products or the improvement of current products and processes.

References

1. Backer, S., and Petterson, D., Some Principles of Nonwoven Fabrics , Textile Research Journal, 30, (1960), 704-711.
2. Hearle, J.W.S. and Stevenson, P.J., "Studies in Nonwoven Fabrics: Prediction of Tensile Properties", Textile Research Journal, 34, (1964), 181-191
3. Britton, P., N., and Sampson, A., J., " Computer simulation of the mechanical properties of nonwoven fabrics, Part1: the method", Textile Research Journal, 53 1.t, (1983), 363-368
4. Britton, P., N., and Sampson, A., J., " Computer simulation of the mechanical properties of nonwoven fabrics, Part1: Bond Breaking ", Textile Research Journal, 53, (1983), 1-5
5. Britton, P., N., and Sampson, A., J., " Computer simulation of the mechanical properties of nonwoven fabrics, Part III: Fabric Failure", Textile Research Journal, 54, (1984), 425-428
6. Grindstaff, T.H. and Hansen, S.H., " Computer Model for Predicting Point-Bonded Nonwoven Fabric Strength, Part I", Textile Research Journal, 56, (1986), 425-383-388
7. Mi, Z.X., Batra S. K. and T. F. Gilmore," Computational Model for the Mechanical Behavior of Thermally Point-Bonded Nonwovens, Part I: Theoretical Development", unpublished note.