Geometrical modeling of fibrous materials under compression

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Many fibrous materials such as nonwovens are consolidated via compaction rolls in a so-called calendering process. Hot rolls compress the fiber assembly and cause fiber-to-fiber bonding resulting in a strong yet porous structure. In this paper, we describe an algorithm for generating three dimensional virtual fiberwebs and simulating the geometrical changes that happen to the structure during the calendering process. Fibers are assumed to be continuous filaments with square cross sections lying randomly in the x or y direction. The fibers are assumed to be flexible to allow bending over one another during the compression process. Lateral displacement is not allowed during the compaction process. The algorithm also does not allow the fibers to interpenetrate or elongate and so the mass of the fibers is conserved. Bending of the fibers is modeled either by considering a constant "slope of bending" or constant "span of bending." The influence of the bending parameters on the propagation of compression through the material's thickness is discussed. In agreement with our experimental observations, it was found that the average solid volume fraction profile across the thickness becomes U shaped after the calendering. The application of these virtual structures in studying transport phenomena in fibrous materials is also demonstrated.
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I. INTRODUCTION

In manufacturing nonwovens, thermoplastic fibers are often bonded together by thermal calendering (see Fig. 1). In this process, the calender rolls slightly melt the surface of the fibers and cause them to fuse together at the crossovers. Hot calendering causes permanent changes in the structure and depending on the temperatures and pressures used in the process, various degrees of densification and fiber linkage can be achieved.

During the past years, there have been many pioneering works aimed at simulating the three dimensional (3D) structure of a fibrous material. Qi and Uesaka[1] generated 3D anisotropic virtual media made of interpenetrating fibers to model paper boards. With the same objective but in a different way, Koponen *et al.*[2] modeled 3D structures made up of short fibers based on a model developed by Niskanen and Alava.[3] Further investigations on 3D assembly of interpenetrating fibers have been conducted by Clague and Phillips[4] and Tomadakis and Robertson[5] who investigated the permeability of their fibrous media. In all the above studies, once a fibrous medium was generated, no further processing was performed on it. Thus, these studies have been limited to uncompressed assemblies of (discontinuous) fibers. Note that there are a few available published works dealing with compressing fibrous materials. These studies, however, are focused on stiffness and rigidity of fibrous materials (Kellomaki *et al.*,[6] Astrom *et al.*,[7] and Wu and Dzenis[8]). Our objective in this paper, however, is to simulate the structure of a nonwoven material before and after calendering. Since our fibers are continuous, these nonwovens would be similar to those produced by spun bonding. Spun bonding is a manufacturing technology which offers a one-step process for producing nonwovens from the raw materials (thermoplastic polymers) as the fiber and fabric productions are combined. Spun bonded fibers are continuous filaments that are quenched and drawn to form highly oriented crystalline fiber morphologies. Once collected in a web form, the fibers need to be bonded to form a fabric. Calendering is a common process used for thermally bonding spun bonded webs. In the current paper, we generate virtual spun bonded nonwovens and simulate the changes in their microstructural geometry

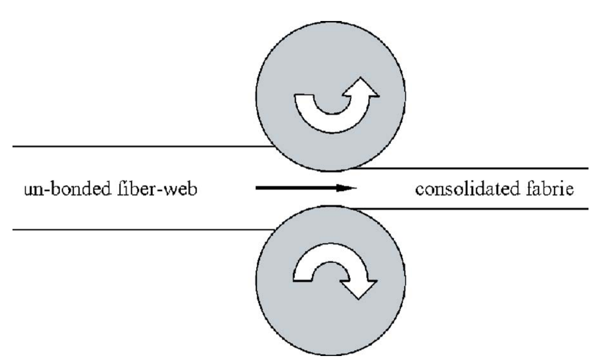

FIG. 1. (Color online) A schematic drawing of smooth calender bonding. Drawing is not to scale.

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