Structure and mechanical behavior of self-organized fibrous materials

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Abstract

Fibrous networks with random structure are ubiquitous in our everyday lives. From biological structures, such as the cellular cytoskeleton and connective tissue, to man-made structures including rubber, paper and non-wovens, fibrous materials are the structural building block of many material systems. The reasons for this prevalence are: (a) networks are lightweight structures, (b) are non-continuum materials, (c) and exhibit large sensitivity to structural controllable parameters. Adhesion plays an important role in the mechanics of nanoscale fibres. This is due to the fact that adhesion, as well as other surface forces, such as capillary forces, organize the fibres in bundles and contribute to the energy balance of the ensemble of fibres.

In this work we study the effect of inter-fibre adhesion on the self-organization of the ensemble of filaments as well as the mechanical behaviour of the network. We study networks in which fibres are cross-linked and network in which the fibres are not cross-linked. In the first case, the connectivity of the network is preserved as the network organizes under the effect of adhesion. In the second case fibres form bundles which then organize in a network. The objective of this work is to define the dependence of the self-organized structure on network parameters and their effect on the mechanical behaviour of the adhesion-stabilized structures.

To study these systems, we develop a specialized computational technique able to represent cross-linked networks with adhesion. The method combines a finite element representation for the fibres with an adaptive scheme which accounts for fibre bundling. The degree of bundling evolves during network self-organization (at zero far field) and during the subsequent mechanical testing.

We observe that non-cross-linked networks may take one of three possible configurations: they may remain locked in the as-deposited state, may evolve under the action of inter-fibre adhesion to form a new type of network which we call “cellular network”, or may disintegrate as a result of excessive bundling. We produce a phase diagram which indicates what structure is favoured by a certain selection of network parameters (density, fibre bending and axial stiffness, strength of inter-fibre adhesion) [1,2].

Cross-linked networks also self-organize, but to a much smaller extent due to the topological constraints imposed by the cross-links. This leads to significant volume reduction. The mechanical behaviour of these networks is very different from that of the same network without adhesion. They exhibit both softening and stiffening under uniaxial stretch or shear. Once again, we establish the relation between network parameters and various aspects of the mechanical behaviour.

Keywords: **Stochastic materials, Fiber networks**

References

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