Mechanical behavior of cross-linked random fiber networks with inter-fiber adhesion

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Abstract

We study the effect of inter-fiber adhesion on the mechanical behavior of cross-linked random fiber networks in two dimensions. To this end, we consider networks with connectivity number, z, below, at, and above the isostaticity limit of the structure without adhesion, z_c. Fibers store energy in the axial and bending deformation mode and the cross-links are of freely rotating type. Adhesive forces lead to fiber bundling and to a reduction of the total volume of the network. The degree of shrinkage is determined as a function of the strength of adhesion and network parameters. The mechanical response of these structures is further studied in uniaxial tension and compression. The stress-strain curves of networks without inter-fiber adhesion exhibit an initial linear regime, followed by strain stiffening in tension and strain softening and strain localization in compression. In presence of adhesion, the response becomes more complex. The initial linear regime persists, with the effective modulus decreasing and increasing with increasing adhesion in cases with $z > z_c$ and $z < z_c$, respectively. The strain range of the linear regime increases significantly with increasing adhesion. Networks with $z > z_c$ subjected to tension strain-stiffen at rates that depend on the adhesion strength, but eventually enter a large strain/stress regime in which the response is independent of this parameter. Networks with $z < z_c$ are stabilized by adhesion in the unloaded state. Beyond the initial linear regime their tangent modulus gradually decreases, only to increases again at large strains. Adhesive interactions lead to similar effects in compression. Specifically, in the $z > z_c$ case, increasing the adhesion strength reduces the linear elastic modulus and significantly increases the range of the linear regime, delaying strain localization. This first investigation of the mechanics of cross-linked random networks with inter-fiber adhesion opens the door to the design of soft materials with novel properties.

Keywords: random fiber networks, adhesive interactions, mechanical behavior.