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Spontaneous imbibition dynamics in yarns and knit stitches by fast X-ray tomography and free energy analysis

Monday, 31 May 2021 16:10 (15 minutes)

Moisture management in textiles is not only of importance for functional clothing, but also for medical fabrics. Understanding or even predicting the dynamics of spontaneous imbibition in textiles is challenging due to the heterogeneity of textile structures and thus the complexity of the fiber/water/air interfaces. The physics on the pore scale determine the macroscopic water transport. Contrary to some classes of porous media, e.g. sedimentary rock, step-wise uptake/imbibition dynamics have been observed for textiles and models in the style of Darcy's or Washburn's laws cannot always be applied. We employ time-resolved X-ray tomographic microscopy (XTM) to study pore-scale filling processes and their impact on the overall imbibition dynamics.
Textiles are multiscale materials. Yarns are processed into fabrics, e.g. by weaving or knitting. The yarns are twisted bundles of fibers. The fibers can be porous themselves, but we focus in this study on dense fibers of polyethylene terephthalate (PET, not swelling) with uniform wettability and contact angle 48°. 32 continuous PET fibers with circular cross section and a diameter of 55 µm are manually spun to yarns with 200 twists per meter and mounted at given tension (2.5, 10 and 30 mN/tex) in a sample holder attached to a reservoir. The setup is placed on the rotating sample stage of the TOMCAT beamline for synchrotron XTM at the SLS, Paul Scherrer Institut, Villigen PSI, Switzerland. By remotely filling the reservoir, we image the full spontaneous water imbibition process in a 5 mm yarn segment from an unlimited reservoir in 4D with 2.75 µm voxel size and up to one tomographic scan per second. In a second experiment, equally prepared yarns are mounted in a configuration mimicking the contact of two yarns in the wale direction of a knit stitch. This configuration forces the water to pass the yarn contact to reach the top of the field of view.
XTM reveals the inter-fiber pore system and the dynamic evolution of the water configuration with its corresponding change in free energy. The imbibition process displays two very distinct time scales. While pores are filled in quick bursts, there are long periods of almost flow stagnation at pore transitions. It is found that these periods correspond to quasi-equilibria of the water configuration with almost vanishing free energy gradient. The water reconfigures slowly until it reaches again a state with high free energy gradient that allows higher fluxes. Such high fluxes are supported by the longitudinal aspect ratio of the pores. Since these low-energy-gradient periods can last up to minutes, the overall water uptake in yarns is not dominated by the wetting speed, but by the periods when water is (almost) not flowing. Since the fiber configuration at the yarn contact prevents the formation of continuous cross-yarn pores, this yarn contact is the locus of many such slow water reconfigurations. Consequently, water uptake in both studied systems, namely single yarns and stitches, is characterized by two-scale step-wise dynamics with slowdowns at pore-to-pore and yarn-to-yarn transitions, a crucial information for potential modeling approaches of textiles.

Time Block Preference

Time Block A (09:00-12:00 CET)

References

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