Humidity-sensitive mechanical properties of paper

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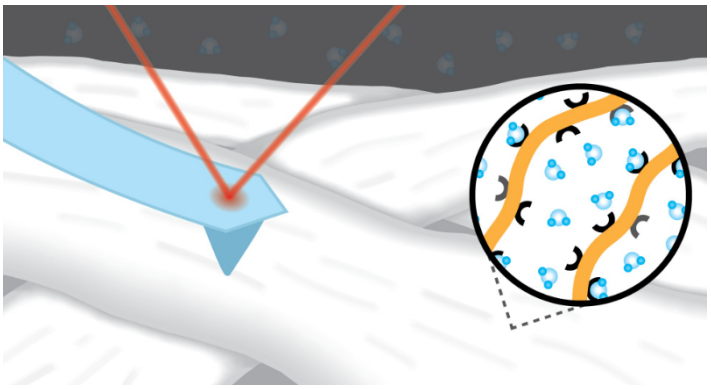
The effect of moisture on paper is of great relevance for numerous applications ranging from printing to packaging. The uptake of water in the polymer network of the paper fibers via the liquid or vapor phase of water results in hydro- or hygro-expansion of the paper, respectively. In our study, we use an atomic force microscope to measure the out-of-plane hygro-expansion of paper by probing the surface whilst varying the relative humidity. The high spatial resolution of the atomic force microscope enables measuring the out-of-plane hygro-expansion of paper fibers with subnanometer resolution. By locking the atomic force microscopy tip at a predefined location on a paper fiber, we monitor the expansion and shrinkage of paper with a temporal resolution in the millisecond range. We find a linear relation between the relative humidity and the out-of-plane expansion of the paper fibers. We also find a good fit between a sorption isotherm measurement and the Guggenheim-Anderson-de Boer model. The combination of these two measurements suggests that the vast increase in weight seen in the isotherm is due to water filling the pores between the fibers, where it does not result in additional out-of-plane expansion. The high temporal resolution enables studying the kinetics of the out-of-plane hygro-expansion. We find that the process is best described using a double exponential function comprised of two exponents with different time scales, which we attribute to two separate adsorption sites.[1] Additionally, the atomic force microscope is used to record force-distance curves whilst varying the relative humidity. The nanomechanical properties extracted from these curves are used to further study the impact of moisture on the fiber network.

Keywords:
Hygro-expansion, Adsorption, Paper, Cellulose fibers, Atomic Force Microscopy



The illustration shows a network of paper fibers in a humid environment. The surface of this paper substrate is probed using an atomic force microscope. It measures the out-of-plane hygro-expansion, which is due to water molecules adsorbing onto the polymer chains within the paper fibers.

References:

[1] Jantinus Wisman, Marjolein N. van der Linden, Thomas Anijs, E. Stefan Kooij, Detlef Lohse and Harold J.W. Zandvliet, *Langmuir* **2026** *42* (8), 6000-6006.