Water-responsive materials for evaporation energy harvesting

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Abstract: Water-responsive (WR) materials hold great promise as evaporation energy harvesting actuators, opening the doors to a novel category of green energy production. As is often the case, the bio-derived materials present best in the class performance, with unprecedented water-responsive energy densities. However, a lack of understanding of fundamental mechanisms involved in WR actuation has limited the engineering and upscaling of these materials thus far. We studied regenerated silk fibroin (RSF) free films, derived from *Bombyx mori* silkworm cocoons with various post-treatments, which change the secondary structure of the bio-polymer along with its WR properties. To study the H-bonding networks in our samples, we use a humidity-controlled transmission FTIR to probe the water in the RSF films during the low-high-low humidity cycles. We identified the presence of bulk-like mobile and ice-like bound water populations in the material and more importantly, we find that there is a common threshold of bound-to-mobile water ratio above which the material becomes water responsive and is able to induce tensile stress during dehydration. Furthermore, the three samples with significantly differing secondary structures and WR performance, were shown to exhibit a common value for the threshold bound-to-mobile water ratio at which the material becomes water-responsive. This insight into the fundamental working of WR actuation is an important step towards engineering RSF as an actuator material for evaporation energy harvesting. Moreover, we also fabricate composite RSF material, by the addition of *Bacillus subtilis* spores, which show high energy density and fast response times, but have the disadvantage of not functioning as a macroscopic material on its own. By doing so we can increase the power density of the RSF and tackle the scaling-up issue of spore-based WR materials and make the composite applicable for evaporation energy harvesting.