Elasto-capillary windlass : from spider webs to synthetic actuators

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Spiders' webs and gossamer threads are often paraded as paradigms for lightweight structures and outstanding polymers[1]. Probably the most intriguing of all spider silks is the araneid capture thread which is covered with tiny glycoprotein glue droplets[2]. Dedicated to catching prey insects and coping with being buffeted by wind, this fibre is particularly extensible. Even if compressed, the capture thread remains surprisingly taut, a property shared with pure liquid films, allowing both thread and web to be in a constant state of tension. Vollrath and Edmonds[3] proposed that the glue droplets act as small windlasses and are therefore responsible for the tension, but other explanations have also been suggested, involving for example the macromolecular properties of the flagelliform silk core filaments. Here we show that the nanolitre glue droplets of the capture thread composite induce buckling and coiling of the core filaments : microscopic observations reveal that the slack fibre is spooled into and within the droplets. We model the windlass activation as a structural phase transition, we identify the key parameters driving the process, and we show that fibre spooling results from the interplay between elasticity and capillarity. We further establish the material independence of the mechanism by developing an entirely synthetic version of the windlass system, composed of a polyurethane thread bearing a silicone oil droplet. Fibre size is the key in natural and artificial setups which both require micrometer-sized fibres to function. Our study demonstrates that the spools and coils inside the drops directly affect the mechanical response of the thread, adding to any effects that the protein conformations of the core filaments might have. Beside shedding light on araneid capture thread functionality, we assert that the properties of this biological system might provide novel insights for bioinspired synthetic actuators and kinetic energy absorption systems.

Références

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