Tuning of glue viscoelasticity in spider glue to maximize adhesion

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Abstract

Adhesion in humid conditions is a fundamental challenge to both natural and synthetic adhesives. Yet, glue from most spider species becomes stickier as humidity increases. We find the adhesion of spider glue, from five diverse spider species, maximizes at very different humidities that matches their foraging habitats. By using high-speed imaging and spreading power law, we find that the glue viscosity varies over 5 orders of magnitude with humidity for each species, yet the viscosity at maximal adhesion for each species is nearly identical, 10-10 cP. Fourier transform infrared (FTIR) spectroscopy shows significant increase in protein hydration, specifically loosely bound water at high humidity. Further, we observe a reversible change in protein conformation such that the proteins become flexible at a molecular scale with an increase in humidity. However after washing the water soluble low molecular weight molecules (LMM) from the glue, the protein conformation is unresponsive to humidity. Many natural systems take advantage of viscoelasticity to improve functional response, but spider glue’s humidity responsiveness is a novel adaptation that makes the glue stickiest in each species’ preferred habitat. This tuning is achieved by a combination of proteins and hygroscopic LMM that determines water uptake in the glue. We therefore anticipate that manipulation of polymer-LMM interaction to control viscoleasticity can provide a simple mechanism to design humidity responsive smart adhesives.