Structure property relationships in beetle wing joints

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Abstract

Insect wings, particularly those of beetles, exhibit remarkable adaptations for flight and resilience, making them valuable for bioinspired engineering. This study investigates the fracture properties of wing joints in rhinoceros beetles (*Eupatorus gracilicornis*), highlighting the role of resilin, a flexible and elastic protein, under tensile and bending loads. Beetle wings are composed of a flexible membrane, veins, and joints, with the latter being critical in the folding process and mechanical performance of the wings. To evaluate joint strength and resilin contribution, mechanical tests were performed on hydrated and dried wings. Tensile tests using a micro-tensiometer and bending tests modelled as cantilever beams showed that dried wings fail at the resilin patch, which become brittle when dehydrated. This contrasts with the flexible and resilient properties of hydrated joints observed in nature. Fluorescence microscopy confirmed the presence of resilin at critical locations, leveraging its intrinsic self-fluorescent properties. Additionally, wing loading ratios for male and female beetles were calculated to relate joint strength to body mass. Results demonstrate a clear connection between resilin's hydration-dependent properties and joint durability, highlighting the adaptability of these structures under varying environmental conditions. The findings offer valuable insights into the design of bioinspired deployable wings for micro-robots, particularly in applications requiring lightweight, resilient composite structures capable of dynamic movement and folding. This research bridges biological understanding and engineering innovation, contributing to advancements in biomimetic technologies.

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