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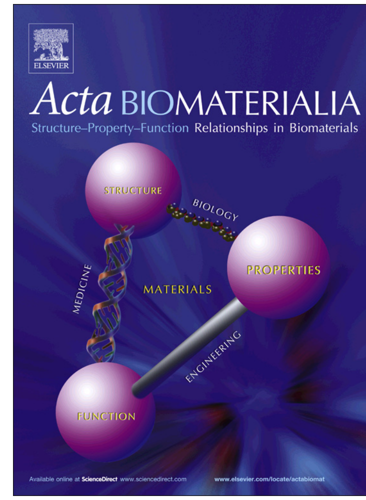

Structural, tribological, and mechanical properties of the hind leg joint of a jumping insect: Using katydids to inform bioinspired lubrication systems

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Structural, tribological, and mechanical properties of the hind leg joint of a jumping insect: Using katydids to inform bioinspired lubrication systems

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Abstract

This study investigates the structural properties of the hind leg femur-tibia joint in adult katydids (Orthoptera: Tettigoniidae), including its tribological and mechanical properties. It is of particular interest because the orthopteran (e.g., grasshoppers, crickets, and katydids) hind leg is highly specialized for jumping. We show that the katydid hind leg femur-tibia joint had unique surfaces and textures, with a friction coefficient (μ) at its coupling surface of 0.053 ± 0.001. Importantly, the sheared surfaces at this joint showed no sign of wear or damage, even though it had undergone thousands of external shearing cycles. We attribute its resiliency to a synergistic interaction between the hierarchical surface texture/pattern on the femoral surfaces, a nanograded internal nanostructure of articulating joints, and the presence of lubricating lipids on the surface at the joint interface. The micro/nanopatterned surface of the katydid hind leg femur-tibia joint enables a reduction in the total contact area, and this significantly reduces the adhesive forces between the coupling surfaces. In our katydids, the femur and tibia joint surfaces had a maximum effective elastic modulus (E_{eff}) value of 2.6 GPa and 3.9 GPa, respectively. Presumably, the decreased adhesion through the reduction of van der Waals forces prevented adhesive wear, while the contact between the softer textured surface and harder smooth surface avoided abrasive wear. The results from our bioinspired study offer valuable insights that can inform the development of innovative coatings and lubrication systems that are both energy efficient and durable.

Statement of Significance

Relative to body length, insects can outjump most animals. They also accelerate their bodies at a much faster rate. Orthopterans (e.g., grasshoppers, crickets, and katydids) have hind legs that are specialized for jumping. Over an individual's lifetime, the hind leg joint endures repeated cycles of flexing and extending, including jumping, and its efficiency and durability easily surpass that of most mechanical devices. Although the efficient functioning of insect joints has long been recognized, the mechanism by which insect joints experience friction/adhesion/wear, and operate efficiently/reliably is still largely unknown. Our study on the structural, tribological, and mechanical properties of the orthopteran hind leg joints reveals the potential of katydid bioinspired research leading to more effective coatings and lubrication systems.

Keywords: Insect joint, Katydid, Biotribology, Biolubricant, Nanoindentation