Microstructure-induced biomechanical responses of dragonfly wing veins

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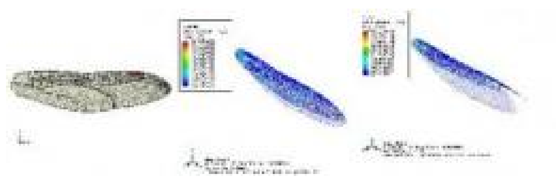

Simulation results of a dragonfly forewing. (a) model of the wing; (b) von Mises stress distribution during flapping; (c) dimensional changes during flight. Credit: © science china press

Wang's research team discovered the sandwich microstructure of dragonfly wing veins[1] and recently revealed the organic junction between these longitudinal veins and membranes of the dragonfly wing[2]. Based on observed microstructural model and previously reported model about the main longitudinal veins and membrane, in which the former is based on the tubular model with sandwich structure in thickness of tubular, and the latter is based on the sample tubular model with the same material in thickness of tubular, they were used to simulate and characterize the biomechanical responses of dragonfly wings under symmetrical loading.

The results indicated that the effect of different microstructural models on the flapping frequency, trajectories, and corrugated and torsional behaviors of the wing cannot be ignored. This is because the sandwich microstructure, consisting of soft matter with fibers in the protein layer and hierarchical structure in the chitin layer, of the longitudinal vein plays an important role in improving aerodynamic efficiency by creating self-adaptability in the flapping, torsion and camber variations of the wing as it twists. Understanding the complete structure of the wing, including the microstructural features and the organic junction between veins and membranes, provides new insight into the flight mechanism of the dragonfly and the wing's biomechanical responses, as shown by the study reported in issue 56 of the *Chinese Science Bulletin* and to be reported in the future.

Microstructure of the longitudinal vein and membrane. (a) sandwich structure; (b) hierarchical structure in nano- and meso- scales; (c) organic junction model of both the vein and membrane. Credit: ©science china press

Some of the results reported by this study are shown in Figures 1 and 2.

The organic junction with the hierarchical microstructure optimizes the dragonfly wing's biomechanics including to the strength, stiffness and toughness (see Figure 1). The organic junctions enable the corrugation of the total wing along the chord direction, which improves the warping rigidity, while the hierarchical microstructure at the nano scale in the thickness of chitin layer increases the flapping strength of the wing and lift coefficients, but not the torsional rigidity of wing. As the dragonfly wings twist during flapping process, the soft matter with fibers in the protein layer at the micro scale assists the turning performance and allows structural responses between the longitudinal veins and membranes that form the camber of the wing during the three dimensional changes. The camber and zigzag cross-section along the chord direction could enhance the aerodynamic efficiency of the wing [3] by creating more vortices under upstrokes and downstrokes, as shown in Figure 2. Moreover, the corrugated wing has an important effect on torsion deformation under sample aerodynamic loading, and it is more flexible than a wing without sandwich longitudinal veins. Thus, the organic junction between the vein and membrane contributes to the dragonfly wing's remarkable biomechanical behavior.

In addition, with the help of these two salient features, the wing can easily adjust the its chordwise length by changing the corrugated angle and allowing response to different flight environments. Although it is highly speculative, we believe that the wing possesses some self-adaptabilities to cope with the challenges of flight. From the view of energy, the authors suggest that this kind of self-adaptability helps the dragonfly reduce the amount of energy consumed during flight. Potentially, this research could inspire engineers to design self-adaptable and energy-saving flexible wings for micro aerial vehicles.

More information: 1. Wang et al. Compos Sci & Technol, 2008; 68: 186-192
2. Chen and Wang et al. Chinese Sci Bull, 2011; 56: 1658-1660
3. Ennos AR. J Exp Bio, 1988, 140: 137-160; Sane SP. J Exp Bio, 2003; 206: 4191-4208

Source: Science in China Press

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