Deciphering the Exoskeleton of Beetle with Nanomechanics

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Northwestern Engineering's Horacio D. Espinosa and his team are working to comprehend the underlying design principles and mechanical properties that lead to structures with such ideal and unique properties. This work could ultimately disclose information that could guide the manufacturing and design of novel and enhanced artificial substances by emulating these time-tested natural patterns, a procedure known as bio-mimicry.

Postdoctoral fellow Ruiguo Yang and Wei Gao and graduate student Alireza Zaheri, all members of Espinosa's lab, were the co-first authors of the paper. Cheryl Hayashi, lecturer of biology at the University of California, Riverside, was also a co-author.

Though there are more than a million species of beetles, the group is first studying exoskeleton of the Cotinis Mutabilis, a field crop pest beetle native to the western United States. Like all crustaceans and insects, its exoskeleton is made of twisted plywood structures, called as Bouligand structures that help protect against predators.

Fibres in this Bouligand structure are bundles of chiting polymer chains wrapped with proteins. In such chain structure, each fibre has a greater density along the length than along the transverse. “It is highly challenging to characterize the properties of such fibres given that they are directionally dependent and have a tiny diameter of just 20 nanometers,” says Espinosa, the James N. and Nancy J. Farley Lecturer in Entrepreneurship and Manufacturing at Northwestern's McCormick School of Engineering.

“We had to introduce a new characterization technique by taking advantage of the spatial distribution of fibres in the Bouligand structure.” To meet this limitation, Espinosa and his group employed an innovative method to identify the material properties and geometry of the fibres that comprise the exoskeleton. They cut the Bouligand structure along the plane, resulting in a surface composed of closely linked cross-sections of fibres with varying orientations. They were then able to analyse the mechanics of the fibres.

“With almost more than a million of species, which exceedingly vary from each other in terms of taxonomic relatedness, ecology, and size, the beetle is the biggest group of insects,” says Hayashi. “What makes this study more interesting is that the techniques applied to the Cotinis mutabilis beetle exoskeleton can be extended to the other beetle species.”

By linking the mechanical properties with the geometries of exoskeleton from varying beetle species, Espinosa and his group plan to gain insights...
into natural selection and better comprehend structure, function, and other property relationships.