Press Release

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Inspired from Nature and Optimized by A.I.
— Lighter, Stronger, Tougher Bio-inspired Structural Materials Innovation Research Made in Taiwan

Natural materials, which have risen from billions of years of evolution, have developed unique characteristics, such as hierarchical structures, multi-functionality, self-assembly at ambient temperature and pressure, capabilities of self-healing and environmental adaptation. Distinct from engineering materials, which are unable to perform both lightweight and high strength; high stiffness and high toughness, biological materials are often composites which possess remarkable mechanical properties, combining lightweight, high strength and high toughness owing to strengthening and toughening mechanisms from nano-, micro-, meso-, and macro-scales.

One intriguing example is the diabolical ironclad beetle armored with tough exoskeleton which can protect it from predators, being pinned by needles and even being run over by cars. Prof. Po-Yu Chen from Department of Materials Science and Engineering at National Tsing Hua University was invited to wrote a News & Views article for *Nature* [1], elucidating the strategies utilized by the ironclad beetles. The secrets lie in the layered, jigsaw-like joints between hardened forewings (elytra) and a series of functionally graded support structures connect the elytra and ventral cuticle. The findings inspire novel designs for armored vehicles, crush-resistant robots, and tougher, more reliable joints between different materials. Prof. Chen have studied a wide variety of natural materials, such as mollusk shells, crab exoskeletons, elk antlers, ram horns, toucan beaks, feathers, shark/piranha teeth, alligator/armadillo armors, snake/turtle shells, and published several highly cited journal articles and a textbook in this field. He pointed out that instead of materials selection, biological materials often achieve their superior performance and functionality through structural designs at varying hierarchical levels. However, the complex hierarchical structures of biological materials make them difficult to be fabricated and therefore limit the engineering applications. “A.I. plays a critical role

in finding out the key structural features and accelerating the development of novel bio-inspired materials."

Prof. Chen and collaborators from National Taiwan University and National Cheng Kung University further utilize multi-disciplinary approaches — integrating advanced structural characterization, mechanical testing, simulations, artificial intelligence, machine learning, and 3D printing — to further understand the structure-property-function relationships of a wide variety of natural materials and develop novel materials with superior mechanical performance. This research project titled "Design and Development of Novel Lightweight Structural Materials with Superior Mechanical Performance by Bio-inspiration and Materials Genome Initiative" is supported by Department of Engineering and Technologies, Ministry of Science and Technology.

Inspired from the brick-and-mortar microstructure of abalone nacre, we apply AI and machine learning to generate thousands of patterns made of hard and soft materials with a fixed ratio and select those exhibit tough mechanical performance for 3D-printing. Improved from the traditional brick-and-mortar structure, we find that the bow-tie structures with interlocking mechanism can significantly enhance both toughness and strength.[2] Learning from the lightweight yet strong *Liquidambar formosana* fruits, we design a series of porous materials with various hole arrangements and find that the bio-inspired Fibonacci structures possess superior mechanical properties than other regular structures.[3] Inspired from the exoskeleton of beetles, we fabricate helical/gradient structures which are impact resistant with high energy absorbent. Mimicking dragonfly wings, we utilize genetic algorithm approach to generate voronoi-like 2-D structures which are lightweight and flexible, in the meantime, exhibit improved toughness and strength.

Additionally, we are establishing database of structures and properties of natural materials, developing a prediction system of material properties based on given structures and a platform that can design optimized structures based on required mechanical properties. This technique titled "Generation of Bio-inspired Lightweight Structures by Integrating Artificial Intelligence and Materials Genome Initiative" received the MOST FutureTech Breakthrough Award and highlighted as one of the 11 word leading technologies. Two selected applications are bio-inspired/AI-modified shoe midsoles with multi-functionalities (elasticity, support, cushion) and customized designs and lightweight porous metals/alloys for artificial bones and discs. Inspiration from Nature, optimization by AI/Machine Learning, and realization by advanced manufacturing can accelerate the development of novel structural materials with superior mechanical performance and lead to wide

industrial applications, including bicycles, automobiles, aerospace, intelligent robots, biomedical materials and assistive devices.

References on International Publications:

1. P.-Y. Chen, “Diabolical ironclad beetles inspire tougher joints for engineering applications” *Nature* **586**, 502-504 (2020). doi: 10.1038/d41586-020-02840-1

   Link: https://www.nature.com/articles/d41586-020-02840-1

2. A, Ghimire, Y.-Y. Tsai, S.-W. Chang, P.-Y. Chen, “Tunable interface hardening: Designing tough bio-inspired composites through 3D printing, testing, and computational validation” *Composites Part B* (2021) in press.

3. Y. Chiang, C.-C. Tung, X.-D. Lin, P.-Y. Chen, C.-S. Chen, and S.-W. Chang, “Geometrically toughening mechanism of cellular composites inspired by Fibonacci lattice in Liquidambar formosana” *Composite Structures* **262**, 113349 (2020). doi:10.1016/j.compstruct.2020.113349

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