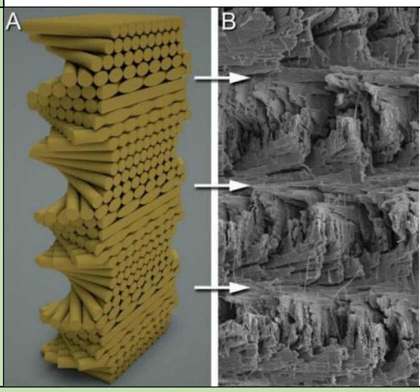
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	高衝擊力的附肢抵抗破裂 (High-impact Appendage Resists Cracking)
生物系統 LIVING SYSTEM	蟬形齒指蝦蛄 *Odontodactylus scyllarus* (Peacock mantis shrimp)
功能類別 FUNCTIONS	#防止破裂/斷裂 #Prevent Fracture/Rupture
作用機制標題	蝦的攻擊附肢分配衝擊力到纖維螺旋層 (Shrimp’s attack club distributes impact among spiraled layers of fibers)
生物系統/作用機制示意圖	

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

蟬形齒指蝦蛄 (peacock mantis shrimp)，是一種 5 英寸長的彩色甲殼類 (crustacean)，生活在關島 (Guam) 到東非的珊瑚礁中，會利用其棍棒狀附肢 (club-shaped appendage) 將堅硬的貝殼擊碎，從而捕食貝類。它的棍棒狀附肢能以超過 50 mph（80 kph）的速度移動，比 0.22 口徑手槍發射的子彈速度還要快，行進速度快到能導致在棍棒狀附肢尾流 (club’s wake) 中的海水沸騰。牠們強大的棍棒狀附肢使得在水族館飼養這種生物變成一種冒險，因為眾所周知牠們可以擊穿玻璃。

蟬形齒指蝦蛄的棍棒狀附肢由錯綜複雜地設計的材料製成，使其特別具有抗破裂性。棍棒狀附肢外部圍繞著鈣基 (calcium-based) 礦物。在這一層之下，棍棒狀附肢的設計是由礦化纖維 (mineralized fiber) 的方向所主導。

蟬形齒指蝦蛄使用碳水化合物長鏈，在周圍的海水中吸引、定向和固化 (solidify) 無機礦物質。所得的碳酸鈣 (calcium carbonate) 和磷酸鈣 (calcium phosphate) 纖維被生物礦化 (biomineralized) 成圓形層次，這在衝擊期間能抵抗橫向膨脹 (sideways expansion)，使棍棒狀附肢保持完整。

在這些圓形層次之間，幾丁質 (chitin) 和蛋白質纖維混合而成的薄片彼此疊放，每組纖維較下方的纖維排列稍微旋轉。這樣會在橫截面中形成螺旋狀結構，就像一疊扭轉的影印紙。蝦蛄棍棒狀附肢的螺旋區域幫助吸收每次打擊的衝擊力，就像彈簧一樣，並將

任何會在附肢周圍形成的裂痕引導到附肢材料中，減弱其作用力並防止筆直的裂紋形成和使附肢碎裂。

The peacock mantis shrimp, a multi-colored 5-inch crustacean that lives in coral reefs from Guam to East Africa, hunts shellfish by smashing through their hard shells using its club-shaped appendage. Its club travels faster than 50 mph (80 kph), exceeding the speed of a bullet from a .22 caliber gun, traveling so fast that the seawater literally boils in the club's wake. Their formidable club makes members of this species dicey to keep in an aquarium, because they've been known to punch through the glass.

The mantis shrimp's club is made of intricately designed material to make it especially crack-resistant. A strong calcium-based mineral surrounds the outside of the club. Below this layer, the club's design is dominated by the orientation of mineralized fibers.

The shrimp uses long chains of carbohydrates to attract, orient, and solidify inorganic minerals out of the surrounding seawater. The resulting fibers of calcium carbonate and calcium phosphate are biomineralized into circular layers, which resist sideways expansion during impact, keeping the club together.

Between these circular layers, sheets of blended (composite) materials made of chitin and protein are stacked one upon the other, each set of fibers rotated slightly from the fiber alignment below. This creates a spiraled structure in cross-section, like a twisted stack of printer paper. This spiraled region of the shrimp's club helps absorb the impact from each blow, much like a spring, and channels any cracks that do form in the club around within the club's material, weakening their force and preventing straight cracks from forming and splitting the club apart.

文獻引用 (REFERENCES)

「這種多區域結構 (multiregional structure) 內表皮 (endocuticle) 的特點是礦化纖維層呈螺旋狀排列 (helicoidal arrangement)，這種結構使抗衝擊性和能量吸收率提高。」(Grunenfelder et al. 2014: 1)

「透過實驗和計算方法，顯示了螺旋結構可減少複合板在衝擊期間全厚度損傷 (through-thickness damage) 的傳播，並使堅韌度提高。這些發現對航太工業、汽車和裝甲應用的複合材料零件設計產生了影響。」 (Grunenfelder et al. 2014: 1)

"The endocuticle of this multiregional structure is characterized by a helicoidal arrangement of mineralized fiber layers, an architecture which results in impact resistance and energy absorbance." (Grunenfelder et al. 2014: 1)

"Through experimental and computational methods, a helicoidal architecture is shown to reduce through-thickness damage propagation in a composite panel during an impact event and result in an increase in toughness. These findings have implications in the design of composite parts for aerospace, automotive and armor applications." (Grunenfelder et al. 2014: 1)

參考文獻清單與連結 (REFERENCE LIST)

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陳相元翻譯 (2021/04/04)；譚國鋈編修 (2021/06/23)；張勝凱 (2021/11/22)；陳柏宇編修 (2022/01/02)
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