Research Experiences for Teachers

Shear Stress Evaluation in 3D Printed Mechanically Interlocking Surface Features Inspired by Euplectella aspergillum and Nacre

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Introduction and Background

Ceramics have long been used as a building material because they demonstrate hardness, wear resistance, biocompatibility, and they are easily acquired. The main drawback of Ceramics is brittleness and ad tendency to catastrophically fail when put under strain. Inspiration for addressing this limitation can be found in nature.

Euplectella aspergillum is a marine sponge made of brittle materials consisting of concentric cylindrical layers of silicate spicules separated by organic interlayers. The combination exhibits high strength and toughness despite being lightweight.

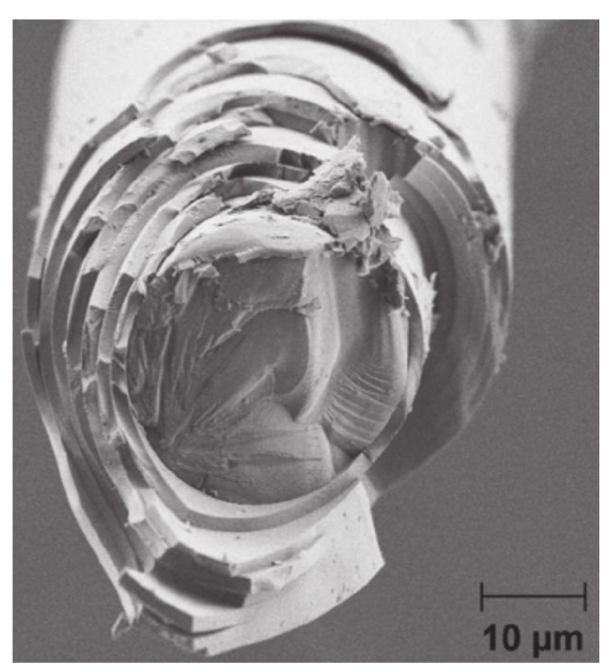
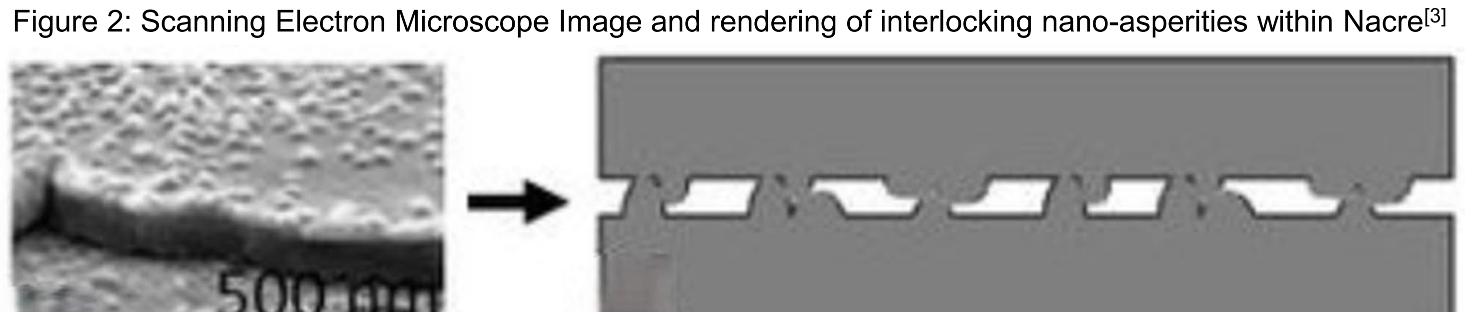


Figure 1: Scanning Electron Microscope Image of *Euplectella aspergillum* Spicules[1]

The organic interlayer between each spicule can be replicated by adhesives[4]. But, in previous studies it was found that adhesives paired with Interlocking surface structures provide a stronger, tougher, method of connection[5]. A natural structure that demonstrates interlocking surface features can be found in a Natural Composite, Nacre, which makes up the shells of certain Mollusks. The interfaces between the plates within Nacre exhibit interlocking teeth like nano-asperities that increase resistance to shear and tensile forces. To mimic this structural interface and determine how much benefit interlocking surface features can provide between concentric cylindrical layers, samples with interlocking teeth were 3D printed and mechanically tested to evaluate shear behavior and strength.

Figure 2: Scanning Electron Microscope Image and rendering of interlocking nano-asperities within Nacre[3]



Significance

Increased mechanical performance and a lesser likelihood of catastrophic failure in brittle materials will make them more effective and prevalent in biomedical and structural applications.

Materials and Methods

All samples were created using a Formlabs Form 3+ SLA (Stereolithography) 3D printer using Rigid 10K resin. The printer solidifies the resin layer by layer using a UV laser allowing for fine details to be printed. Post-Print each sample needed to be washed and cured using the Form Wash and Form Cure from Formlabs.

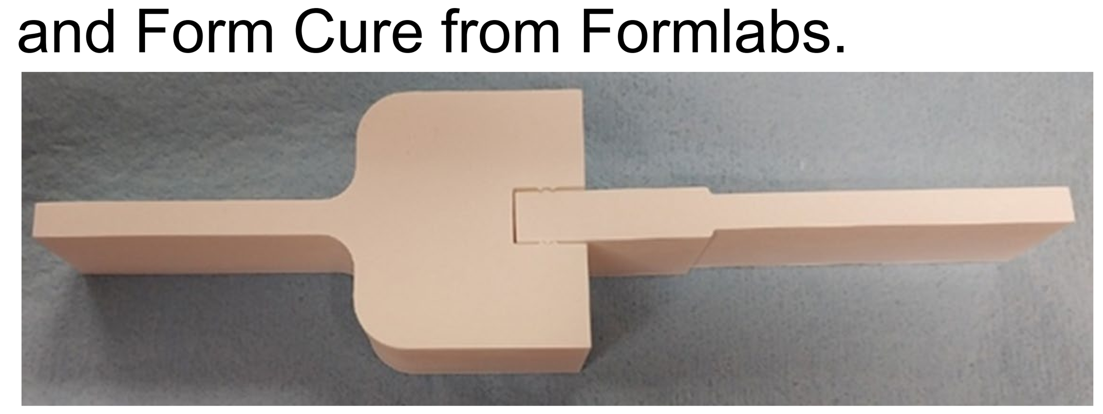


Figure 3: 3D Printed Sample with Interlocking Surface Features

Mechanical Testing was conducted using a Servohydraulic Testing System manufactured by MTS. This testing was undergone at 1 mm/min displacement rate following ASTM D3528 standards.

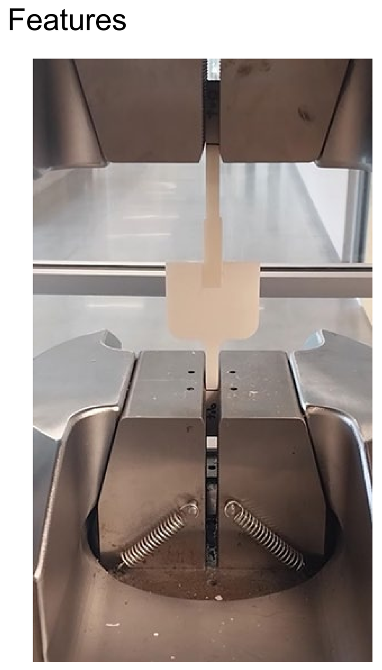


Figure 4: Servohydraulic Testing Machine Setup

In the testing process shear stress was induced and the behavior of the structure was analyzed. Finite Element Analysis was performed using the MOOSE Framework. These simulations provided the basis for SolidWorks designs of experimental samples.

Results

Ten Interlocking Designs were printed with different resolutions (size of teeth) and tolerances (separation between teeth). This was done to ensure print accuracy and to accurately assess the structural integrity interlocking surface structures provided. Changes were made to initial designs because the initial number of 5 teeth proved to be too strong, resisting strain enough such that other parts of the structure would break before shear would occur. To address this issue, the number of teeth were reduced to a singular 250μm resolution, 50μm tolerance dot-shaped interlock. When tested, the design accepted a load of over 500 Newtons and sheared along the plane of the interlock.

Figure 5: Structural Failure outside the Interlocking Surface Features

Figure 6: Shear Fracture along surface features in a successful test

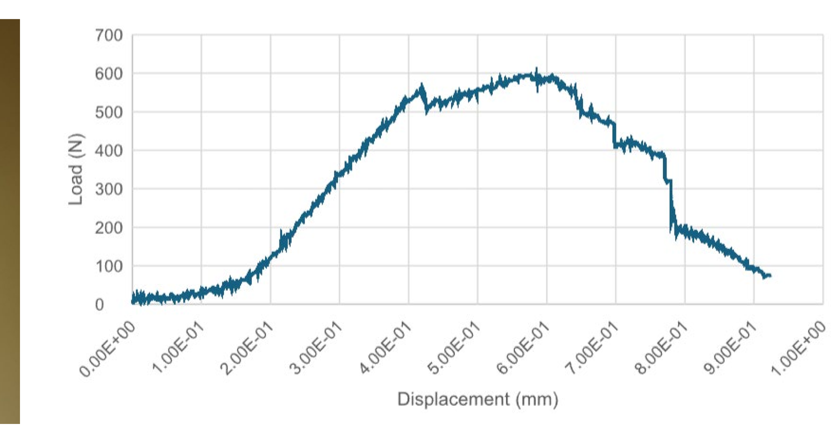


Figure 7: Load and Displacement Curve of a successful shear Fracture 250μm x 50μm sample

Conclusion and Next Steps

Mechanically interlocking surface features demonstrate properties that will enhance structural stability and decrease the likelihood of catastrophic fracture in brittle building materials. Future work includes 3D printing additional samples to validate data and to train a simulation regarding optimal orientation and sizes of Interlocking surface features.

Acknowledgements

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Citations

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