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Investigating Impact Tolerance of Sea Urchin Shell Structure for Aerospace Applications

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Abstract

Biomimicry takes inspiration from nature to create more resilient and innovative sustainable solutions to complex human problems. The structure of sea urchins can be used as a biological model to create lightweight, impact-resistant material that can be adapted to develop more structurally sound architecture in infrastructure. This report focuses on Echinocyamus pusillus since it primarily relies on its skeletal construction because it lacks collagen fibers within its sutures [1]. Since these bioinspired structures can be used to tolerate harsh environments where impact protection is essential, they can be utilized for many applications like high pressure structures in deep sea exploration and landing gears for space exploration purposes. The purpose of this project is to examine the unique shell structure of the sea urchin through experimental testing and Finite Element Analysis.

Project Objectives

This study focuses on two specific characteristics: the overall dome shape and its internal supports (the radial buttress system and the longitudinal ribs) (**Figure 1**). The objectives are to investigate the impact tolerance of the shell of a sea urchin by studying the effect of different thickness (2 mm or 3 mm), different numbers of buttress (0, 4, or 8), and different spacing of buttresses (even or uneven spacing) through experimental testing and Finite Element Analysis (FEA) using Abaqus.

Methodology Used

The specimens are 3D modeled using SolidWorks and then 3D printed using the Stratasys Objet260 Connex3. The material used is TangoPlus FLX930 because a sea urchin is not completely rigid, but slightly flexible. It has a tensile strength of 0.8-1.5 MPa and elongation at break of 170-220%. It is hard to 3D print a part that is hollow inside, so the part is cut in half in the horizontal direction, so two individual parts are printed where the two parts are inserted into each other to form the elliptical shape. Instron CEAST 9350 drop tower is used to impact the specimens at room temperature (**Figure 2a**). The impactor is a cylindrical in shape with a diameter of 16 mm. The specimens are tested at various impact energy levels of 5 J, 10 J, 20 J, and 40 J. Instron 5582 Universal Testing Machine with a load cell of 10kN is used for compression tests (**Figure 2b**) with a load sensitivity of 50% and a displacement rate of 5 mm/min. The specimens are placed between two parallel load platens, representing a fixed-fixed end condition. Furthermore, Abaqus FEA software is used to simulate a simple compression of 40 mm. For the material property, Mooney-Rivlin is used to model the hyperelastic material [2]. Experimental data from uniaxial and biaxial testing are used for the C10 and C01 values [2].

Results Obtained

Impact and compression graphs are analyzed to understand the effect of different thicknesses, number of buttresses, and buttress spacing. Stiffness against number of buttresses graph are presented in **Figure 3**. The stiffness are obtained through experimental compression testing and a simple compression simulation using Abaqus FEA. Representative energy against time curves for all the ten specimens impacted with 40 J of impact energy at room temperature are presented in **Figure 4**.

Significance and Interpretation of Results

The experimental and FEA data are both in agreement that adding buttresses increases the stiffness. FEA data shows that uneven spacing has a higher stiffness for the 8 buttresses, but even spacing has a higher stiffness for the 4 buttresses. For the 40 J impact test, the 4 and 8 buttresses have no rebound, which indicate that the structure absorbs all the energy during impact.

Figures/Charts

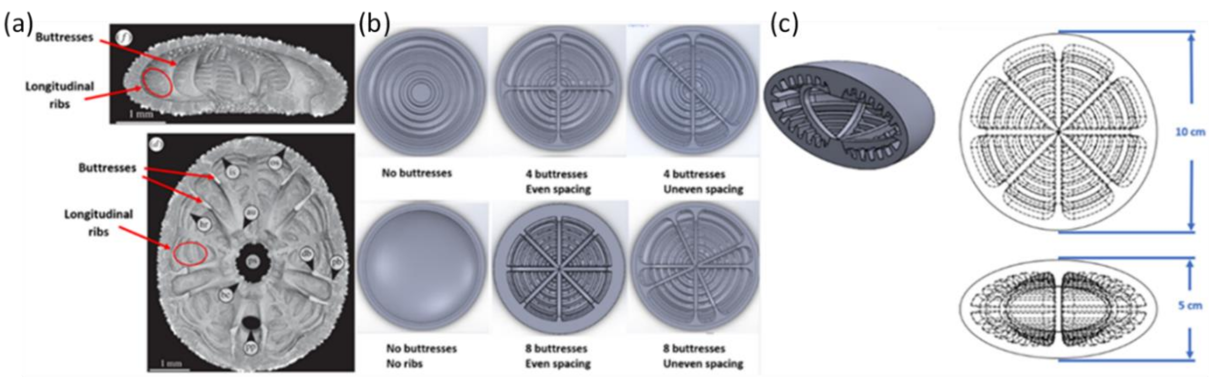

Figure 1. Design: (a) internal support [1]; (b) cross-section cut; (c) overall dimensions

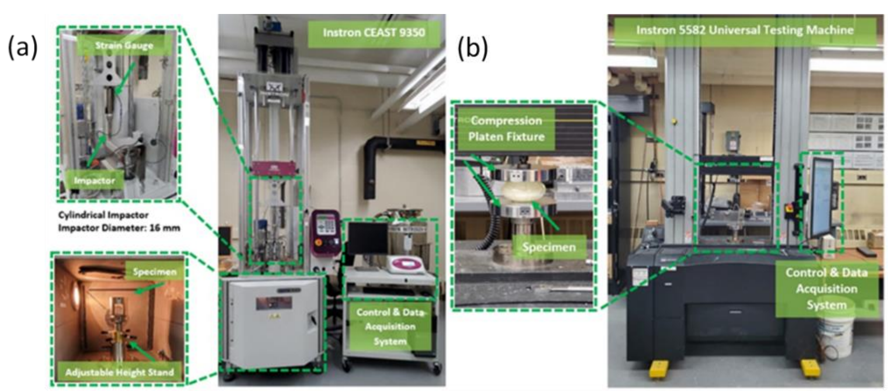

Figure 2. Experimental setup: (a) impact test; (b) static compression test

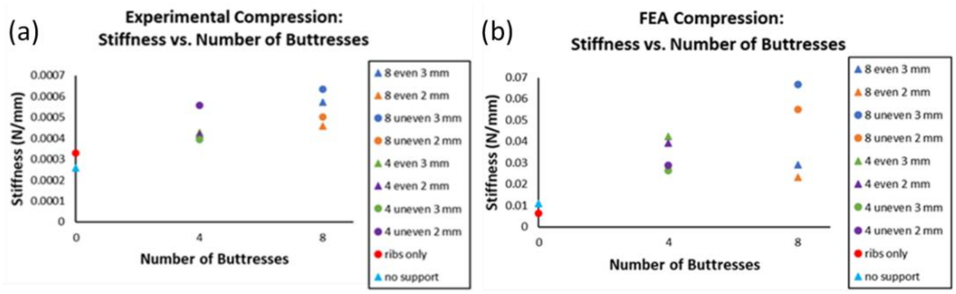

Figure 3. Compression Test: (a) experimental; (b) Finite Element Analysis

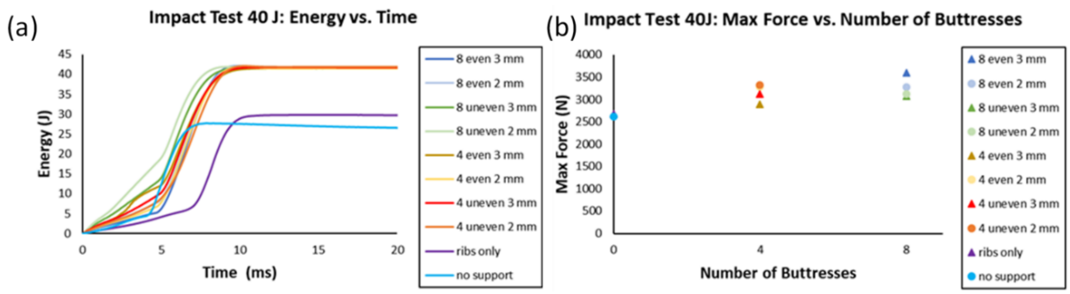

Figure 4. Impact Test of 40 J: (a) Energy vs. Time; (b) Max Force vs. Number of Buttresses

Acknowledgments

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References

[1] Grun TB, Nebelsick JH. Structural design of the minute clypeasteroid echinoid *Echinocyamus pusillus*. Royal Society Open Science. Year 2018, Volume 5, Issue 5, Page 171323.

[2] Morris K et al. Uniaxial and biaxial testing of 3D printed hyperelastic photopolymers. Journal of Applied Polymer Science. Year 2020, Volume 137, Issue 8, Page 48400.