Design and Optimization of Fuel Briquette with Bioinspired Structures for Properties Enhancement

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Introduction

More than 539 million tons of coal are consumed to generate energy each year. Incomplete combustion of coal produces a lot of poisonous carbon monoxide. Due to the fabrication limitation, there is little research on the relation of combustion efficiency and geometric shape of coal briquette.

Abstract

Nowadays, 3D printing enables the fabrication of objects with complex microstructures. This research is motivated to design **lightweight** 3D coal briquettes with bioinspired microstructures for good mechanical properties and high energy production. The Layered Depth Normal Imaging (**LDNI**) approach was used to design 3D coal briquette with bioinspired micro lattice structures. Thermal, fluid, and mechanical properties of the structures were simulated by using COMSOL Multiphysics. The morphology of briquettes was further optimized based on the simulation results.

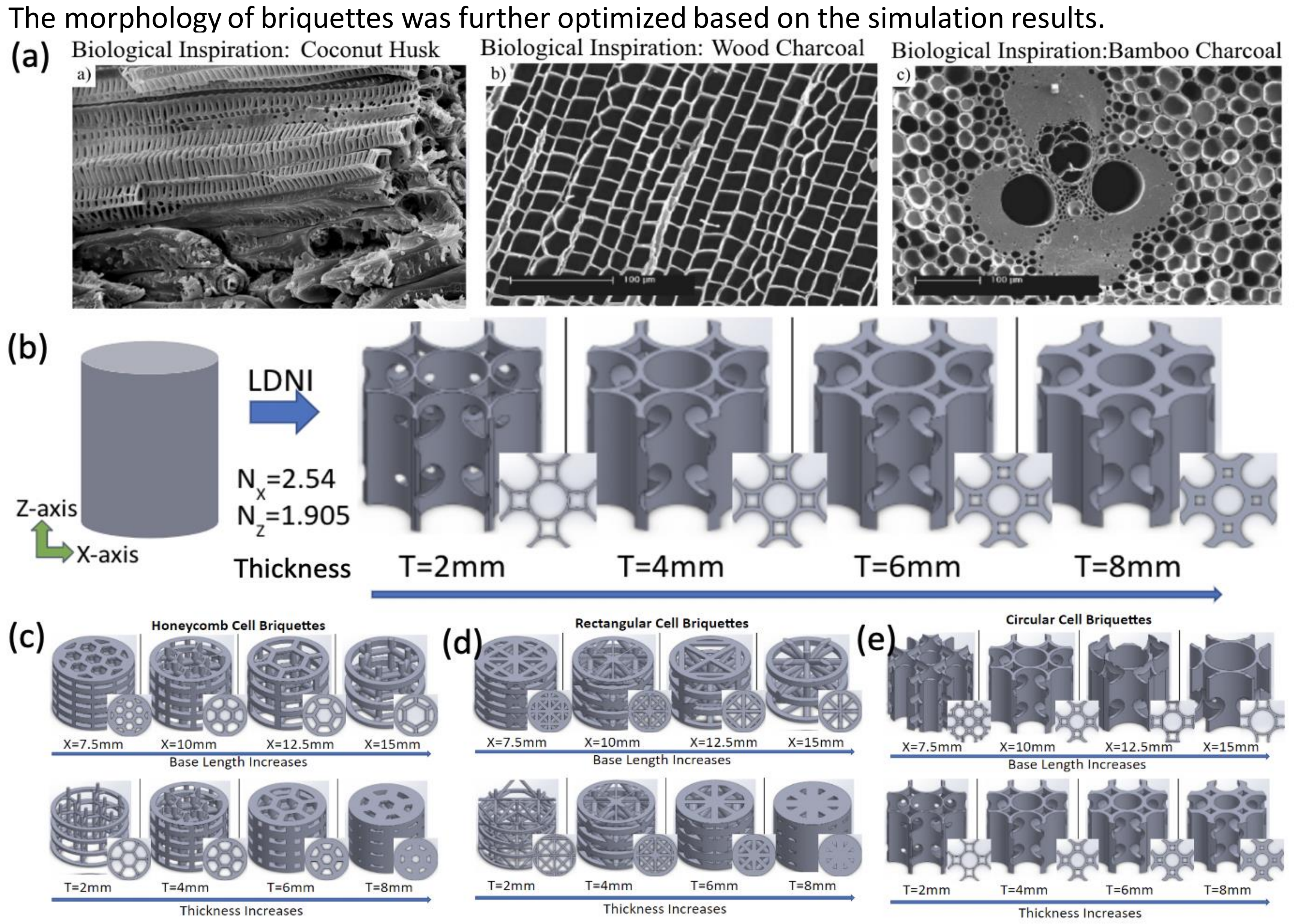


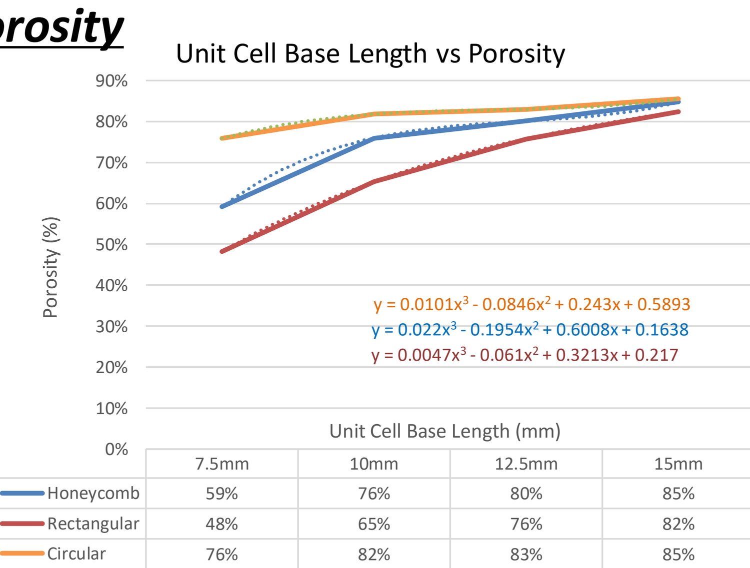
Figure 1: A diagram of bioinspired design of 3D coal briquettes . a) Inspiration from nature; b) A model of the solid cylinder intersected with the unit cell once it goes through the LDNI process to make four models of varying thickness; c) Eight models of the circular cell briquettes inspired by bamboo charcoal structure; d) Eight models of the honeycomb cell briquettes inspired by coconut husk structure; and e) Eight models of the rectangular cell briquettes inspired by wood charcoal structure

Method

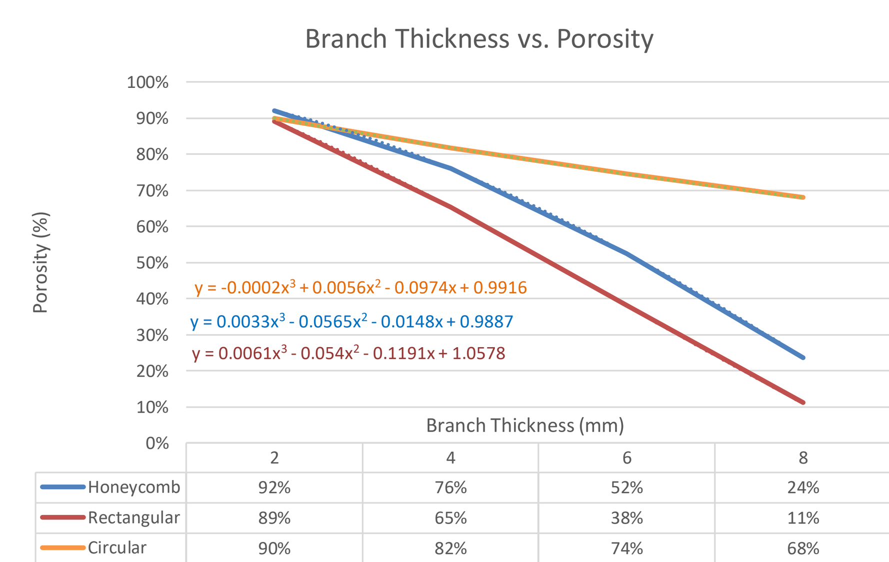
Layered Depth Normal Imaging (LDNI) is a geometric modeling approach that significantly decreases storage and increases speed when conduct geometric processing. LDNI projects an array of rays onto a specific 3D model and notes the intersecting points. The processing machine can perform a variety of Boolean operations on this layered point cloud model to create the desired object. In this project three different bioinspired unit cells were created, mirrored multiple times, and cut into the shape of a 1.5 inch tall and 2 inch diameter cylinder. The porosity of all 24 cylinders were calculated and used to set a standard between all three model types for mechanical, fluid and thermal testing in COMSOL Multiphysics.

Results

Porosity



	7.5mm	10mm	12.5mm	15mm
Honeycomb	59%	76%	80%	85%
Rectangular	48%	65%	76%	82%
Circular	76%	82%	83%	85%

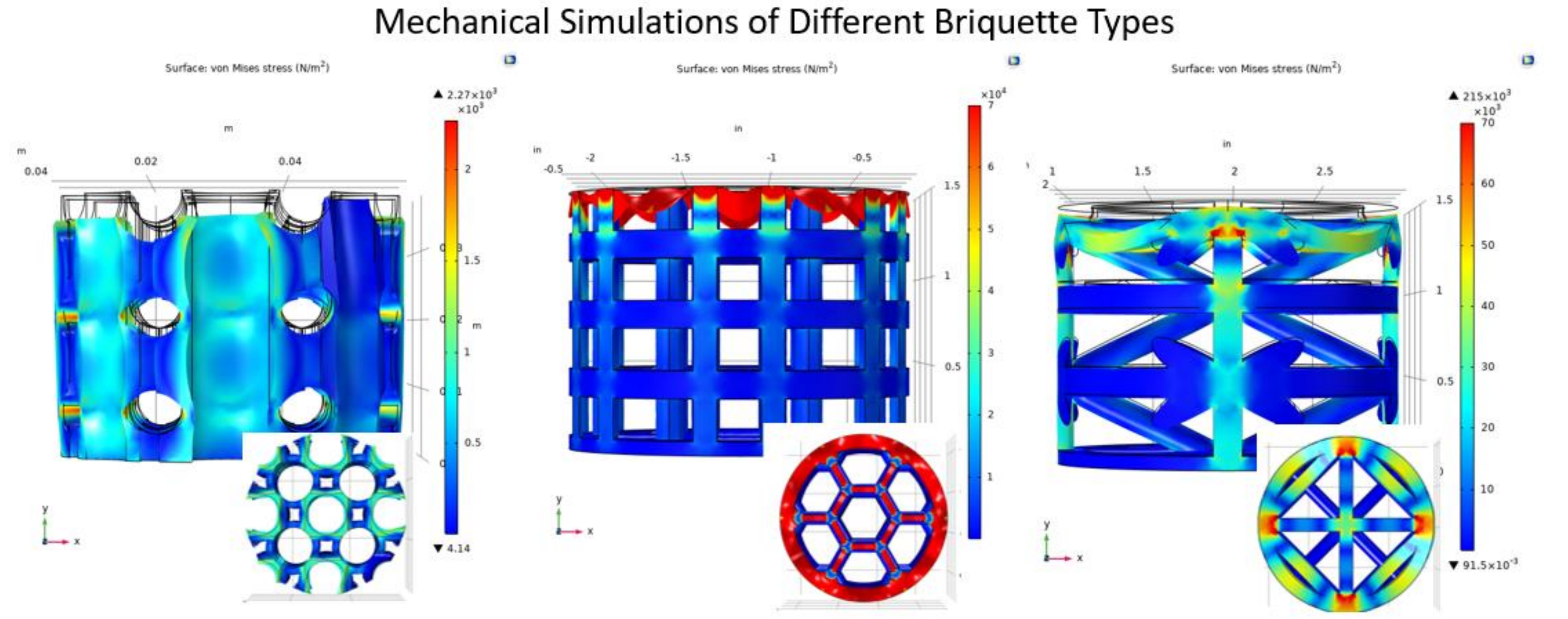


	2	4	6	8
Honeycomb	92%	76%	52%	24%
Rectangular	89%	65%	38%	11%
Circular	90%	82%	74%	68%

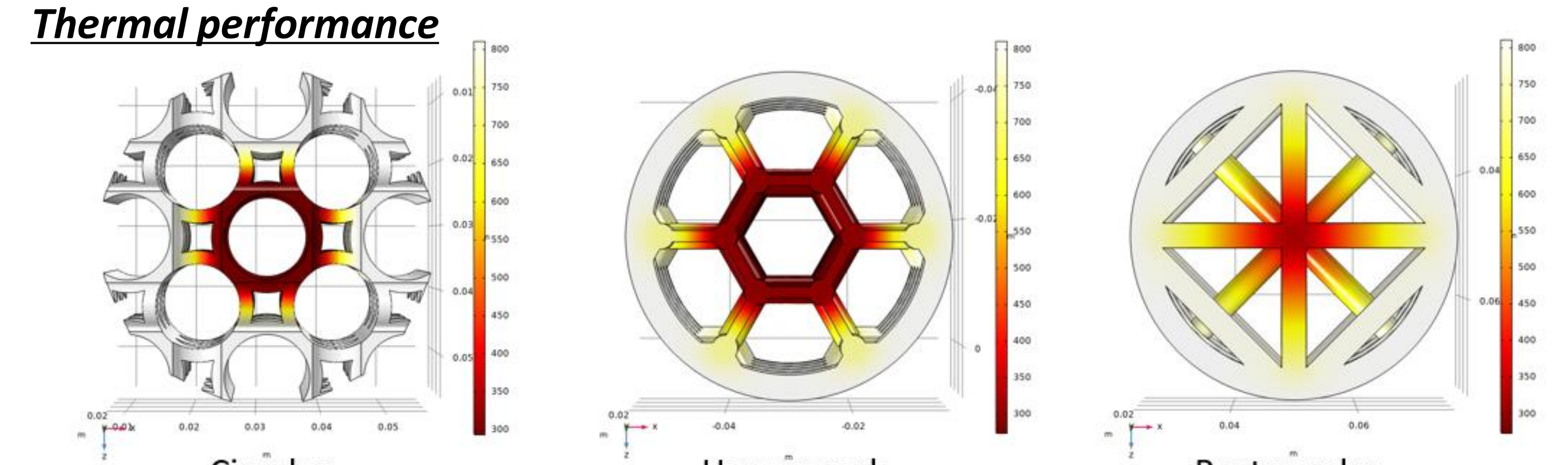
The simulations in COMSOL were split into two testing phases: unit cell testing and optimization of the unit cell structure. Phase I focused on analyzing the mechanical, fluid and thermal properties of the three briquette types to determine which geometry performed the best among the three areas. In order to provide standardized results across all three geometries, the three briquettes chosen had porosities within a 0.1% difference. As pictured, it was chosen that the honeycomb unit cell structure was the most optimal throughout all the tests, mainly due to a low amount of buckling in the mechanical simulations and high airflow velocity in the fluid simulation.

Mechanical performance

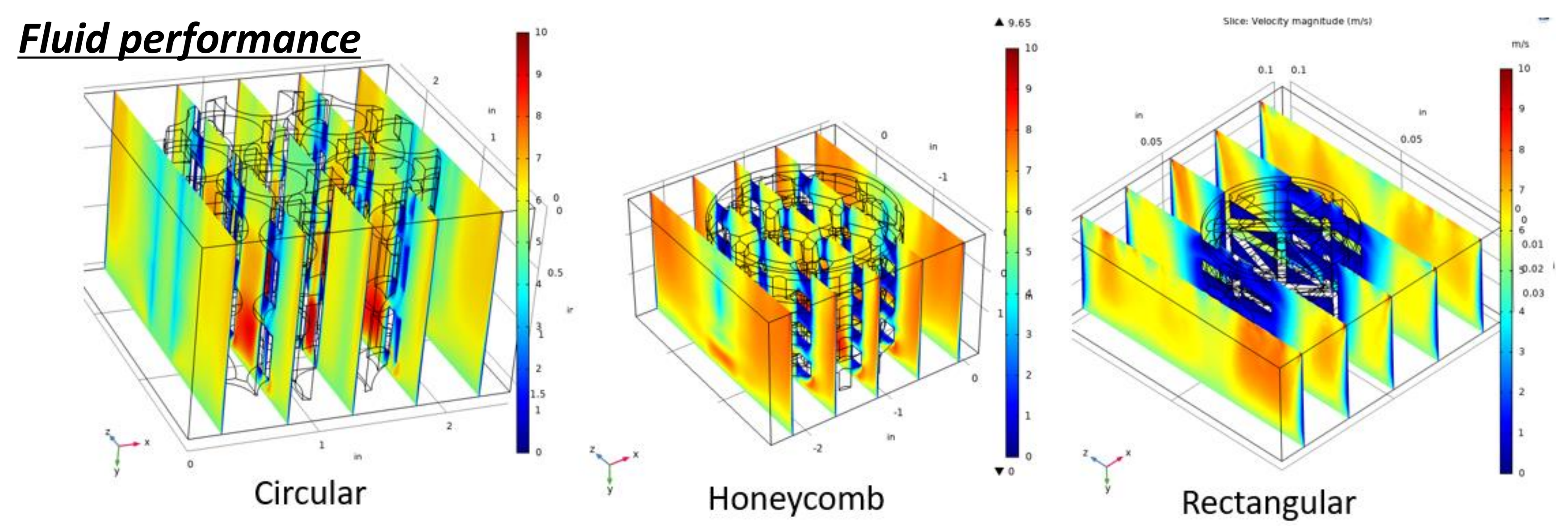
Mechanical Simulations of Different Briquette Types



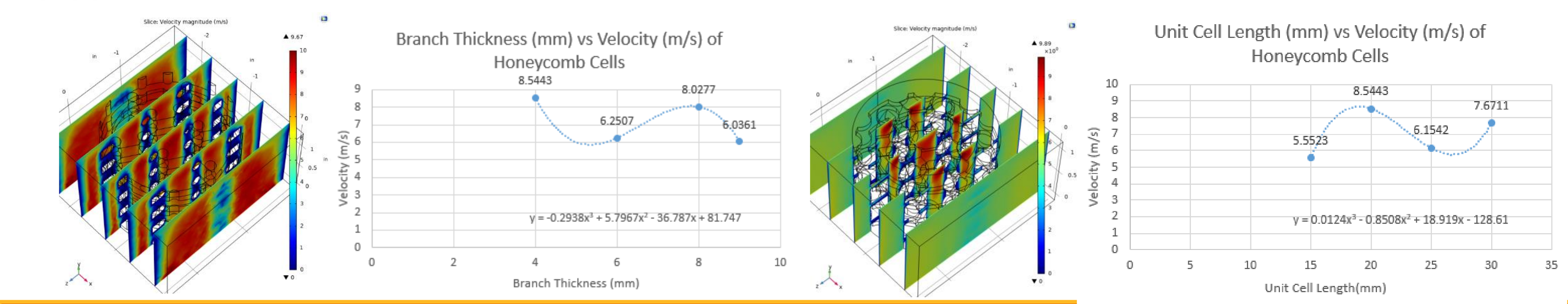
Thermal performance



Fluid performance

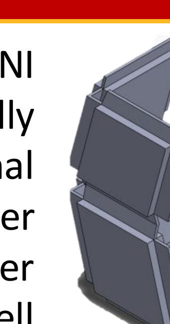


Phase II focused on the fluid simulation of the chosen honeycomb structure. By simulating an airflow of 5m/s through the top of the model the velocity at the center was measured to try and find how branch thickness and unit cell geometry affect airflow. The results dictated that the optimal **honeycomb briquette has a branch thickness of 4mm and a unit cell length of 19.062mm**.



Summary and Outlook

3D briquettes with bioinspired micro lattice structures have been developed using LDNI based geometric modeling. The next step of this project is to build these models physically using a direct ink writing (DIW) 3D printer, and to verify the mechanical, fluid, and thermal results that have been simulated. Direct Ink Writing also allows us to explore other advantages that 3D printing uniquely provides, such as an opportunity to explore further applications by designing flexible solid fuel with origami cells for more efficient fuel cell



Acknowledgements

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Reference:

EurekAlertAAAS. (2016, July 05). Coconuts could inspire new designs for earth-quake proof buildings. Retrieved August 08, 2020, from https://www.eurekalert.org/pub_releases/2016-07/sfeb-cci070116.php
Zeng, L., Lai, L. M. L., Qi, D., Lai, Y. H., & Yuen, M. M. F. (2011). Efficient slicing procedure based on adaptive layer depth normal image. *Computer-Aided Design*, *43*(12), 1577-1586.
Zhao, Z., Kuang, X., Wu, J., Zhang, Q., Paulino, G. H., Qi, H. J., & Fang, D. (2018). 3D printing of complex origami assemblages for reconfigurable structures. Soft matter, 14(39), 8051-8059.
(n.d.). Retrieved August 08, 2020, from http://ldnibasedsolidmodeling.sourceforge.net/

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