MB 3 - Bioinspired turbine pier

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1. Motivation and bioinspiration

In designing our Velcro, we aimed to take inspiration from nature to create a strong and reliable method that performs well in submerged environments. Our base adhesion method was inspired by the Lentinula edodes (shiitake mushroom)[1]. The mushroom's cap (pileus) and stem (stipe) exhibit blunt edges and a robust structure, which were digitally modeled and optimized for 3D printing. By replicating these natural features, we used water-resistant materials to further enhance the design's effectiveness, ensuring that the adhesion remains reliable even when underwater conditions.

The lattice structure of our Velcro was inspired by the loofah sponge[2], known for its porous and interwoven fiber structure. This natural design was carefully studied and digitally modeled to maximize energy absorption and stress distribution. By imitating the loofah's network of fibers, our design may withstand significant impact and stress, providing both toughness and resilience. The interwoven fibers ensure that the structure is not only strong but also capable of spreading out the forces it encounters, which is crucial for maintaining integrity under pressure.

By combining these biomimetic elements, our final design will be able to achieve a balance of durability and performance that is particularly suited for underwater conditions. The shiitake mushroom's structural properties offer a solid and protective base, while the loofah sponge's lattice design ensures that the Velcro can absorb shocks and distribute stress effectively. This dual inspiration from nature allows our design to offer a smart and innovative solution to complex adhesion challenges, providing reliable performance and long-lasting durability.

2. Base adhesion design and preliminary testing

For the Velcro adhesive structure, we adapted a mushroom-like extrusion design tailored for a 100x100 surface area with final design extrusions featuring a 3mm base and a 4.45mm top, spaced 6.1mm apart center-to-center as shown in Figure 2. We faced challenges in achieving the right dimensions, which required iterative trial and error adjustments. Our design was inspired by a YouTube video on 3D printing Velcro, providing a foundation for our approach (link:youtube). In benchtop tests, we assessed performance by applying opposing forces to interconnected Velcro pieces; the design successfully withstood human-level 20 kg of force without detaching. Our Initial design we had faced the issue of fixing which is very hard to attach and remove with 6mm separation. For example, video is in the drive link, then we increased the distance between them by 6.1 mm and we found it as a perfect fit. This design efficiently handles both tangential and normal loads, meeting our testing objectives. This success led to a revised design with adjusted dimensions, enhancing the overall functionality of the Velcro system.

Onshape link

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[1] Filia Nauli Hapsari et al., "Velcro Product Design with Biomimicry Approaches," IOP Conference Series: Earth and Environmental Science, 2022 (PDF) Velcro Product Design with Biomimicry Approaches

[2] Gang He et al., "Lattice Structure Design Method Aimed at Energy Absorption Performance Based on Bionic Design," Machines, 2022 Lattice Structure Design Method Aimed at Energy Absorption Performance Based on Bionic Design

(https://cad.onshape.com/documents/38a13abe995013993c2278a6/w/63b7883d1b1a709cb60574d7/e/d2ef1028070175adfbc36248?renderMode=0&uiState=664e892bb68d873ab07e80fb)

3. Lattice structure design and preliminary testing

We designed this subsystem based on the Type 1 cell structure outlined in Figure 4 of Paper **2**. Our design was motivated by the lattice structure of a loofah sponge, which influenced our approach to creating a robust yet lightweight subsystem. The structure was specifically chosen for its ability to handle maximum tangential and normal loads without breaking, proving its suitability during testing. Under vertical load conditions, the loofah sponge lattice structure exhibited impressive load-bearing capacity, reaching a peak load of roughly 7000 N with a corresponding displacement of about 2 mm before yielding. It managed to support a significant load of 4000 N, resulting in a displacement of 10 mm. As the vertical load increased, several cells started to deform and buckle, causing a progressive failure of the structure. Initially, the graph displayed linear elastic behavior, indicating that the structure effectively withstood increasing vertical forces up to the maximum load of 7000 N. The primary mode of failure observed was localized buckling of the sponge cell structure, as shown in Fig. 6. A key challenge in our design process was maintaining a weight constraint under 50g and dimension constraint 50x50x100mm, while ensuring the structure was viable for printing and final test. Our model weighs 50.33gm to be exact.(Image uploaded in drive link.)
Onshape link
(https://cad.onshape.com/documents/b2404deea2e4099a46589a68/w/43189f93c29209041b76bfe1/e/984b363f516c6078e5248485?renderMode=0&uiState=664e8247e6713d3cf7b2bec8)

4. Pier performance testing

We conducted two types of performance tests on our design: a hydraulic press test and a load test. In the hydraulic press test, we measured the force applied and the deformation of the structure over time, recording the peak force that the structure could withstand. From the lateral/normal load test, we observed the maximum weight capacity of the total structure (Velcro and lattice), noting the point of failure at a 10-pound load limit, where the Velcro separated but the structure remained intact. The hydraulic load test demonstrated the mechanical response of a lattice-structured sample under compression, as depicted in the force-displacement curve. It starts with an initial linear region, indicating elastic deformation consistent with Hooke's law. The peak force applied reached approximately 7000 N at a displacement of 2 mm, indicating the initial resistance of the material. The force then decreased and stabilized around 4000 N as displacement continued to 12 mm, signifying material deformation. This information is critical for assessing the material's durability and structural integrity under pressure. Initially, an oscillation test was performed to verify the Velcros suitability for further evaluation. Following this, a load test setup involved one end of the Velcro attached to a stationary stand and the other to a structure with a progressively increasing weight from 2 pounds to 15 pounds on the left side. The Velcro maintained its integrity until reaching a 10-pound load, at which point it detached, and our structure separated. This outcome is essential for understanding the Velcro's maximum load capacity, providing valuable insights for its potential applications and limitations. Videos and additional recordings from these tests will be uploaded as supplementary files to further illustrate the findings and discuss the failure modes and mechanisms observed during the tests.

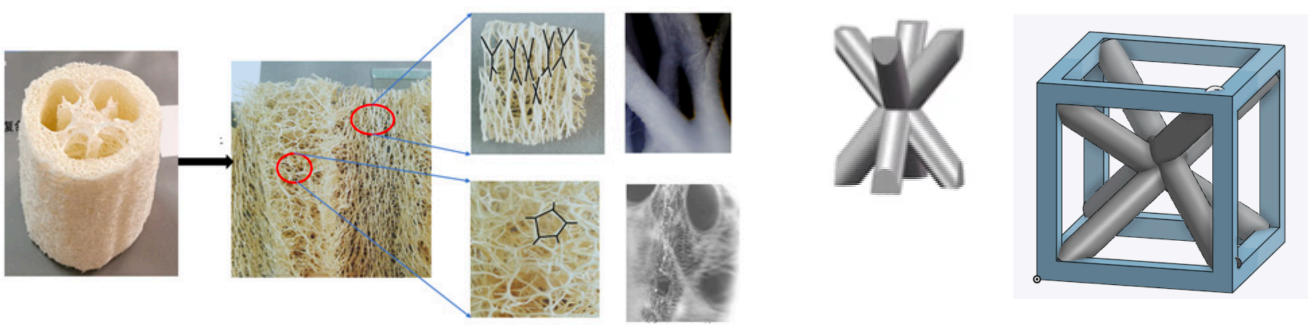
Drivelink:https://drive.google.com/drive/folders/1R8PSmJDnX4HS3cr4L_pQVtoFyVPHoWZC?usp=sharing

5. Conclusions and proposed design modifications

Overall, our design displayed moderate performance showing both strengths and weaknesses up to a limit in both the load and hydraulic tests. The load test indicated that the structure could only support a weight of up to 10 pounds, while in the hydraulic test, it withstood a normal force of up to 7KN. To improve performance, we plan to increase the spacing between the interlocking components of the Velcro to enhance connection strength and load capacity. Additionally, we intend to increase the thickness of the lattice structure to achieve greater strength and stability. These modifications are anticipated to significantly bolster both the connection strength and overall structural integrity, better fulfilling the requirements of our intended applications.

6. Contribution statement

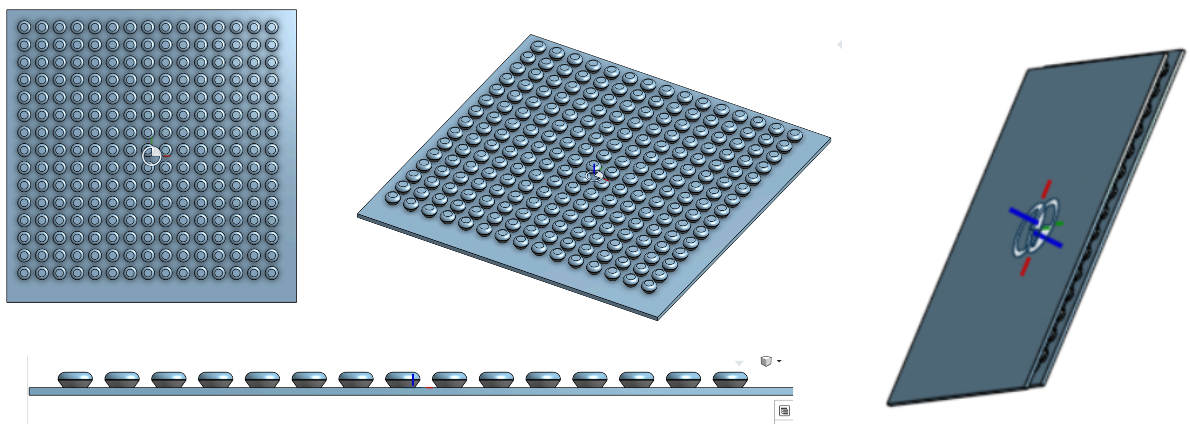
"Ananth" - Focused primarily on gathering essential data during the research phases. He also assisted in writing sections of the report on Motivation and Bioinspiration, as well as the Conclusion.
"Prathyush" - Played a crucial role in proposing initial designs inspired by biological models, tailored to specific constraints. He assisted in writing sections of the report on Lattice Structure Design, Preliminary Testing, and Pier Performance Testing.
"Sujith" - Made significant contributions to the analysis of data, which enhanced overall project insights and aided in finalizing the design. He assisted in writing sections of the report on Base Adhesion Design, Preliminary Testing, and Figures and Plots.



1. Loofah Sponge Structure, these shapes of cell structure are inspired and modeled

<u>*2. Velcro* adhesion design, the shape of mushroom was inspired and modelled in cad for best surface adhesion.</u>

<u>FIGURE 1 - Inspired Designs lattice (1) and Velcro (2)</u>

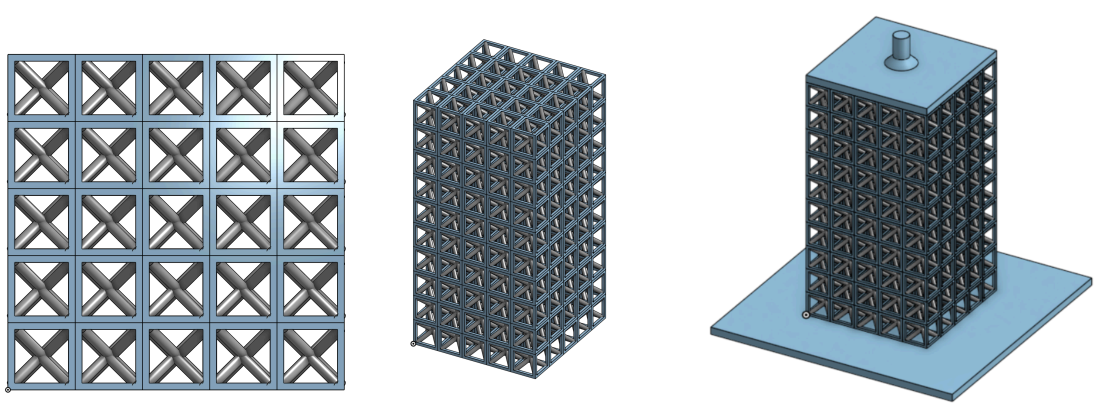


<u>Assembled Velcro</u>

<u>Top , ISO and side views</u>

<u>Note:</u> We assemble both plates top to bottom for a good grip between materials which ensures the good surface adhesion. Structure dimensions (100x100x3mm). Both plates attach between the spaces of other surface.

<u>Figure 2 - CAD design views and Assembled velcro</u>



<u>Top and ISO views</u> ***<u>Final Lattice Strucutre Design</u>***

Note: Structure dimensions include (50x50x100mm) and total weight <50g. Final design Shows the structure attached to a base which is attached to a velcro and at top point in figure shows the load applied.

FIGURE 3 - CAD design views and Final lattice strucutre

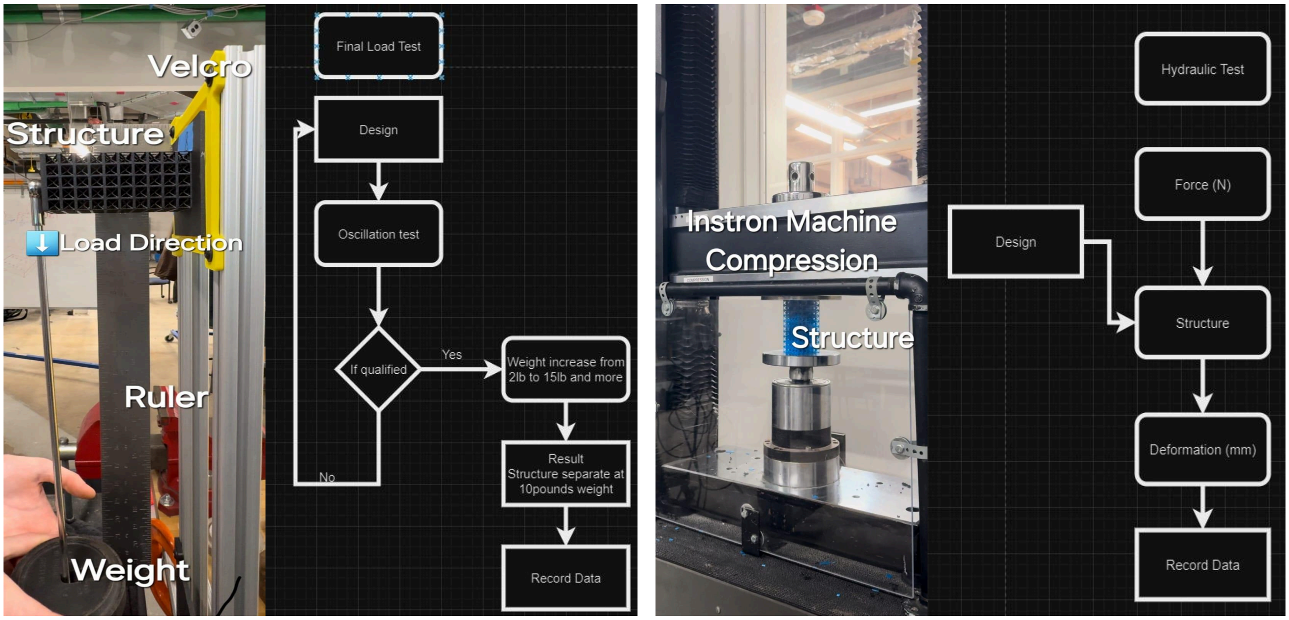


FIGURE 4 - Load test Setup and (Flow chart) && Hydraulic Test Setup and (Flow chart)

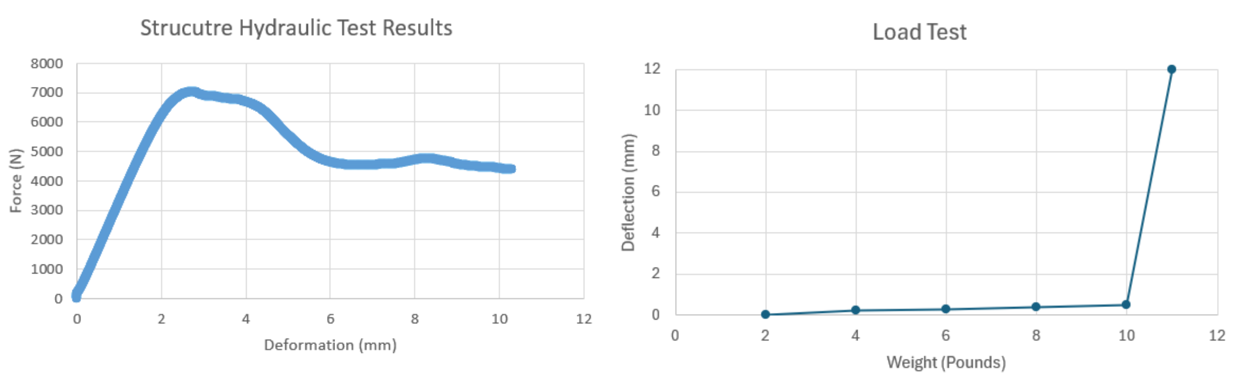
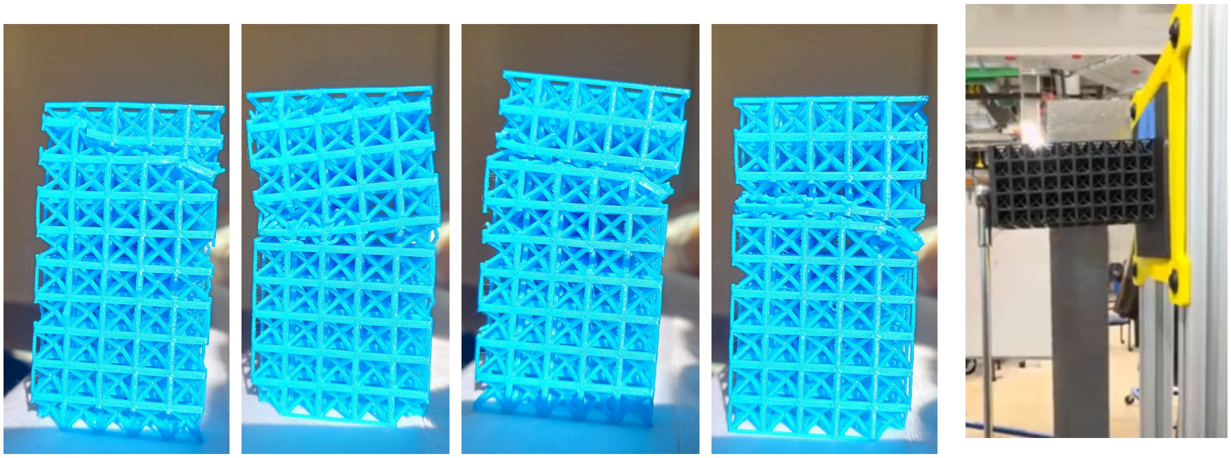
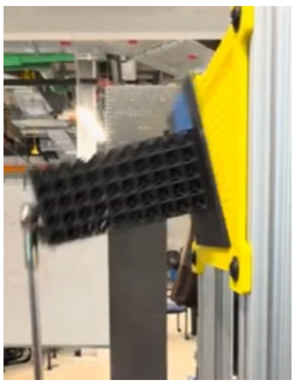


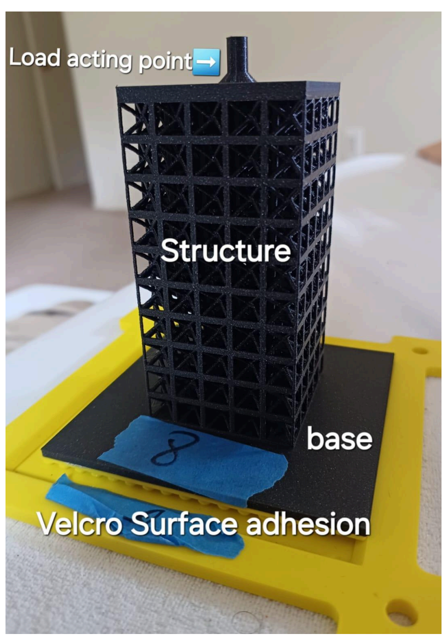
FIGURE 5 - Hydraulic Test Result (pier turbine) and Load test Result (Deflection vs Load)





Note: First 4 images of Blue Lattice Structure show result of all Four sides views (Front, Left, Right, Back) of Hydraulic Test. Next 2 images show the result of Load test Where at 10 pounds load the velcro got separated with no observable damage to structure.

FIGURE 6 - Failure Models of both tests.



Final Model