12-9-2021

Synthetic Hagfish Slime Mimetics: Mechanical Characterization

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Background

Hagfish are ancient animals that eject a slime when attacked by predators. The slime that the hagfish emit is almost entirely composed of water but protein strands within the slime cause the slime to have incredible strength. However, these protein strands will be formed synthetically for the purposes of our experiment.

To defend against foes, the Navy launches plastic ropes into the propellers of enemy warships in order to decrease the thrust of the motors. In a push to find a more biodegradable solution, the utilization of hagfish slime has shown great promise in stopping propellers.

While we know that the slime can stop propellers from functioning properly we hope to understand *how* this remarkable biomaterial withstands the impact of a sharp and quickly rotating propeller, while simultaneously reducing the thrust of the propeller. What specific mechanical properties allow for this phenomena? We know these protein threads strengthen in saltwater due to ionic crosslinking (Fig. 3). From this research we can maximize the capabilities of this incredible biomaterial.

The core application of this project is the eventual implementation of this synthetic hagfish slime into the Navy's arsenal. Beyond this, however, the protein threads may also be incorporated into medical materials and apparel.

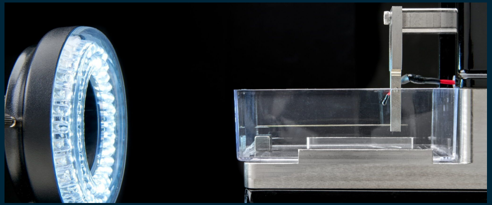

Fig.1 CellScale Microtester: Strand secured horizontally and beam slowly compresses the fiber

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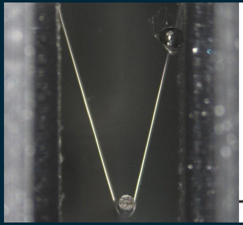


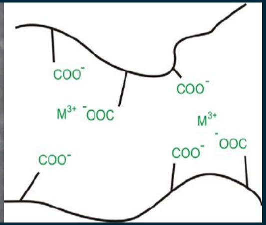


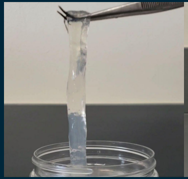
Fig. 2 Tension Test Example

Fig. 3 Ionic Crosslinking Example

Methods

0.45 mg of recombinantly produced thread protein is dissolved in 3 mL of formic acid. The mixture is centrifuged to remove impurities then transferred to a 26 gauge syringe. The syringe is immersed into either freshwater or a saltwater solution with NaCl, CaCl, $MgCl_2$ and other salts. The mixture is extruded into strands. These are referred to as FW and SW slimes, respectively.

The strands are then mechanically tested using the Microtester from CellScale (Fig. 1). FW and SW slimes are tested in a tank of freshwater and a tank of saltwater. Fibers are laid across a 3 mm gap between two small plastic towers. A thin beam that is perpendicular to the fiber slowly pushes down on the strand. A camera tracks the tip of this beam and compares this value to where the beam tip should theoretically be (Fig. 2). From this data, the Microtester calculates the force that the fiber is applying to the beam until the strand eventually breaks. The distance the beam compresses before breaking the strand is used to find the stretching capability of the sample.



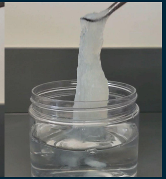


Fig.4 (left): FW slime example

Fig.5 (right): SW slime example

Results

Data indicates the presence of ionic crosslinkings has a dramatic impact on the stretching capability of the strands and potentially the force. An interesting finding was that when FW slime was in SW for an extended period (~30 minutes) it adopted these crosslinkings and had similar force and stretching as SW slimes. Conversely, when SW is in FW it loses these stretching characteristics relatively quickly and will break earlier. FW slimes tested in FW had an average stretch of 2.9x their original length, while SW slimes tested in FW had an average stretch of 3.8x. FW and SW slimes that were in tested in SW had an average stretch of 5x their original length, with a maximum stretch of nearly 6.75x. The stiffness of the SW slimes is roughly double that of the FW slimes. Thus far there is a wide deviation in toughness that have led to data that is not currently significant.

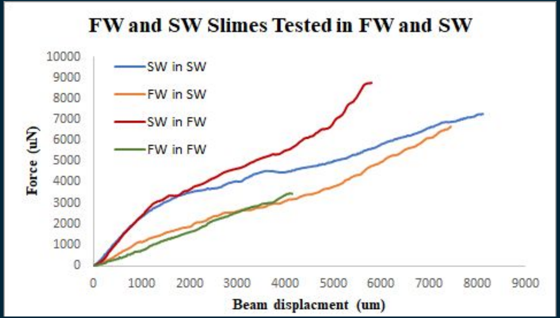


Fig. 6

Future Work

Replications of current methods will continue in order to verify or deny current findings regarding force and stretch differences between conditions. Beyond this, we will begin adjusting the composition of the saltwater to test if there is an optimal salt or concentration that is responsible for the strength of the slime. Additional experiments may include varying the strand width, mechanical testing of the entire network of strands, and using FTIR to analyze the slime on a molecular level. These procedures may help identify the conditions that maximize the strength of the slime.