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Mechanical Properties of Hagfish Protein Hydrogels

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Background

Hagfish are ancient animals that eject a strong slime when attacked by predators. This slime is composed of intermediate filaments that contribute to its incredible strength (Fig. 1 & Fig. 2).
To defend against foes, the Navy launches plastic ropes into the propellers of enemy warships in order to decrease the thrust of motors. In an effort to find a more biodegradable solution, the utilization of hagfish slime has shown great promise in stopping propellers (Fig. 3).
We hope to understand how the slime withstands the impact of a quickly rotating propeller, while simultaneously reducing the propeller's thrust. What specific mechanical properties allow for this phenomena? From this research we can maximize the capabilities of this novel and versatile biomaterial.

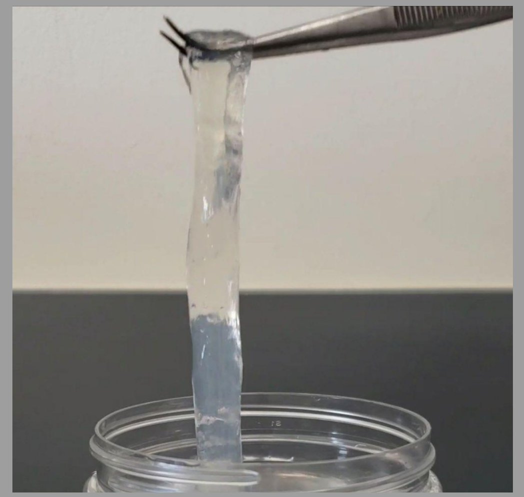


Fig. 1 (left): Recombinantly produced FW slime
Fig. 2 (right): Recombinantly produced SW slime

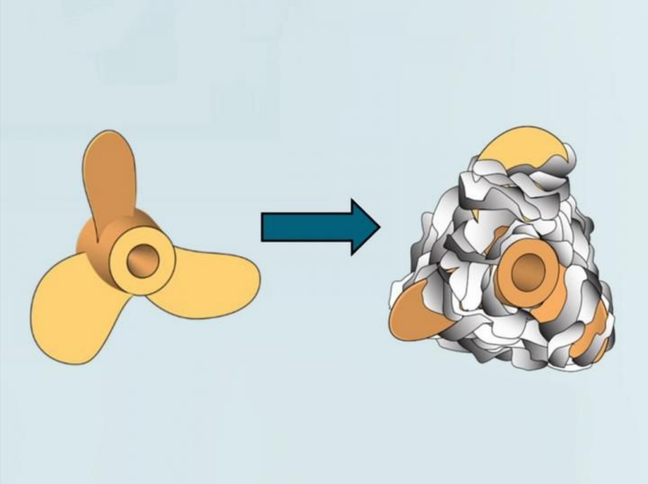

Fig. 3: Hagfish slime affecting a propeller

Methods

- Recombinantly produced alpha protein, gamma protein, or an equal mixture of the two are dissolved in formic acid at certain protein concentrations (10%, 15%, 20%, 25%)
- After 24 hrs, centrifuged and transferred to a syringe
- Extruded into strands in freshwater (FW) or a saltwater solution (SW)
- FW and SW slimes are tested in a tank of freshwater or saltwater
- Mechanically tested using the MicroTester from CellScale (Fig. 4 & Fig. 5) for force and elongation
- Analysis standardized by fiber diameter (n≥10)

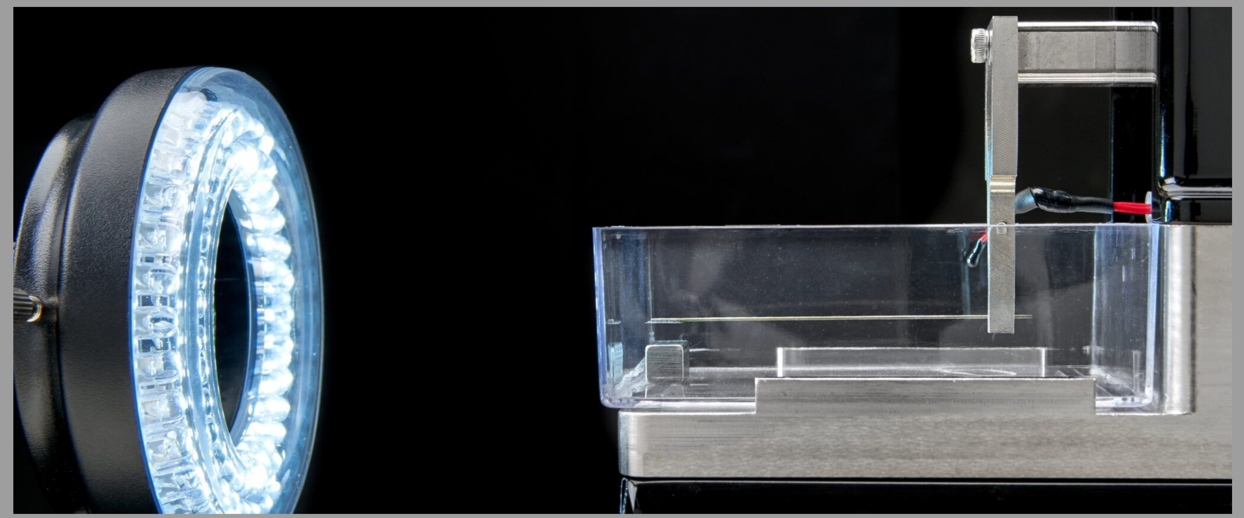

Fig. 4 CellScale MicroTester: Strand secured horizontally and beam slowly compresses the fiber

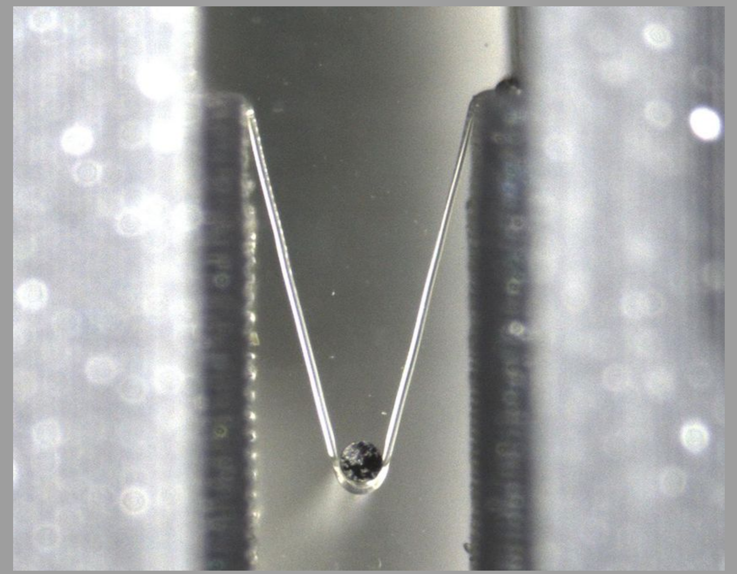

Fig. 5: Tension Test Example

Property	Concentration (w/v)	Alpha				1:1 Alpha:Gamma				Gamma				
		FW-FW	FW-SW	SW-FW	SW-SW	FW-FW	FW-SW	SW-FW	SW-SW	FW-FW	FW-SW	SW-FW	SW-SW	
Diameter (µm)	10%	120.1	130.3	128.7	135.9	114.2			136.1	124.3	114.7	134.2	146.3	142.48
	15%	145.1	133	136.3	130	131.8	123.7	139.1	159	135.4	133.5	147.2	141.3	
	20%					137.6			145	147.2	145.2	167.3	139.7	
	25%					143.1			153.3	181.8	186.7	178.1	179.2	
Stress (MPa)	10%	0.34	0.18	0.38	0.36	0.53			0.46	0.29	0.18	0.18	0.12	0.83
	15%	0.78	0.78	1.96	1.64	0.99	0.65	1.05	0.84	0.66	0.42	0.59	0.66	
	20%					1.06			1.38	0.9	0.67	1.11	1.33	
	25%					1.6			2.24	0.85	0.63	1.19	1.18	
Strain (mm/mm)	10%	2.99	3.36	4.6	4.92	2.41			4.15	2.96	3.39	2.84	4.1	3.74
	15%	2.57	4.64	4.03	4.83	2.55	4.39	4.05	5.79	2.48	4.54	3.3	3.92	
	20%					2.28			4.42	2.48	6	3.04	4.73	
	25%					2.47			4.97	2.74	3.7	3.47	4.05	
Toughness (MJ/m^3)	10%	0.48	0.35	1.02	1.02	0.57			1.06	0.45	0.36	0.33	0.32	1.72
	15%	0.92	2.15	3.84	4.09	1.2	1.77	2.28	2.84	0.84	1.14	1.12	1.45	
	20%					1.24			3.35	1.11	2.54	1.83	3.28	
	25%					2.01			6.2	1.21	1.3	2.26	2.54	
Elastic Modulus (kPa)	10%	152	124	252	207	204			225	165	142	193	115	395
	15%	275	303	840	611	405	263	440	271	318	212	366	357	
	20%					803			590	557	314	609	503	
	25%					1041			971	383	266	531	426	

Fig. 6: Results indicate alpha protein and higher protein concentration slime fibers outperform other fibers

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Results

Initial results are indicated in Fig. 6. Key findings:

- FWFW samples consistently performed the lowest for strain and toughness
- Diameters of fibers were fairly consistent across all conditions
- Higher protein concentration is positively correlated with higher stress, toughness and modulus, but had no apparent effect on strain
- Alpha fibers considerably outperform gamma fibers in terms toughness and stress
- Alpha fibers performed similarly, and occasionally outperform, mixed protein fibers- potential for lowered production costs

Future Work

Beyond replications using current methods, we hope to complete applied testing of well-performing fibers on propellers. Additionally, due to the known cytocompatibility, tunability, and mechanical characteristics of the fibers, which closely mimic native tissues, biomedical uses in tissue scaffolds are a viable research direction.