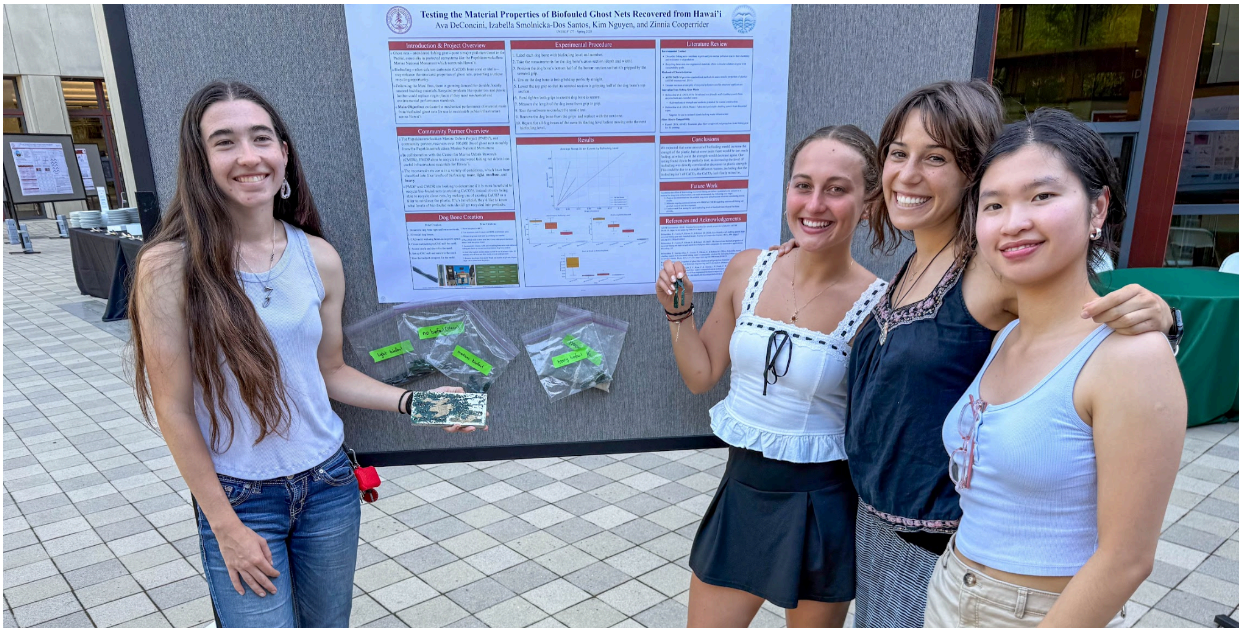
Ghost Net Investigation of Material Properties and Applications of Biofouled Fishing Net Debris



Ghost Net Busters

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Abstract

Every year, an estimated one million tons of fishing gear are abandoned in the ocean, posing a serious threat to marine ecosystems. In partnership with the Papahānaumokuākea Marine Debris Project (PMDP) and the Center for Marine Debris Research (CMDR), this project investigates a novel method of recycling high-density polyethylene (HDPE) ghost nets collected from Hawaiian waters. These nets often accumulate marine organisms—referred to as biofouling—some of which, like barnacles and shells, are rich in calcium carbonate ($CaCO_3$), a mineral additive known to improve plastic performance. Our team evaluated whether biofouling could enhance or degrade the tensile mechanical properties of recycled nets without the need for full removal of the biofoul. Using a custom aluminum mold and a heat press, we fabricated dog bone-shaped samples at four levels of biofouling, and conducted tensile tests using a precision mechanical test machine. However, contrary to initial hypotheses, results showed that increased biofouling correlated with lower tensile strength and strain at break, likely due to uneven mixing and weak HDPE–biofoul interfaces. We recommend future efforts incorporate pulverization and extrusion to achieve better material homogeneity and therefore garner more accurate results. Based on the observed performance, at the moment propose a tiered application system for the CMDR: fully cleaned nets for load-bearing parts, and increasingly biofouled nets for lower-stress or decorative uses. These findings support the potential of ghost net recycling in producing locally sourced, sustainable infrastructure materials for Hawaiʻi, particularly in post-disaster recovery contexts.

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1. Introduction

The Papahānaumokuākea Marine National Monument is “the largest contiguous fully protected conservation area under the U.S. flag, and one of the largest marine conservation areas in the world” [1]. It includes many islands and atolls in the Northwestern Hawaiian Islands, and is home to a diverse range of marine life. Unfortunately, it is also currently home to a significant amount of ghost nets–fishing nets that have been lost, abandoned, or discarded in the ocean. Along with other marine debris, these can entangle and kill the vibrant marine life. These fishing nets are not all necessarily from Hawaiian fishermen. These ghost nets can come from a variety of places in the Pacific Ocean, transported around by ocean currents, and deposited at the Hawaiian atolls and islands. Many of these nets have been entangled in the reefs for up to several decades, often after drifting across the Pacific Ocean for months or even years before washing ashore or snagging on coral. Once trapped, they tend to remain in place due to their weight and structure. Despite constant exposure to saltwater, sunlight, and wave action, they don’t easily degrade because they’re made of durable synthetic materials like nylon or polyethylene, which are specifically engineered to resist environmental breakdown. As the nets sit underwater for long periods of time, they’re exposed to a variety of biofouling and UV degradation [8]. Biofouling is an accumulation of organic material that grows on ghost nets, including algae, microorganisms, and plants [8].

Our community partner, the Papahānaumokuākea Marine Debris Project (PMDP) is based in Honolulu, O’ahu, and goes on cleanup trips to the Northwestern islands to recover hundreds and thousands of pounds of mostly ghost nets and other marine plastic debris. Most of the recovered marine debris is currently incinerated, with a small portion being diverted for research and development. They aim to change the current end-of-life use of their process, hoping to divert as many ghost nets as possible from getting burned and, instead, to get recycled. They are currently partnered with a local research center, the Center for Marine Debris Research (CMDR) at Hawaii Pacific University, also based in Honolulu. CMDR is working on developing a recycling process to turn biofouled nets into pellets that can be used to make long-life infrastructure products in the local Hawaiian economy. The biofouling found on the nets is composed of calcium carbonate, which also happens to be a filler added into recycled plastic to reinforce the plastic and enhance its material properties. We will help the CMDR investigate if recycling biofouled nets, having the calcium carbonate with the plastic from the beginning, would be beneficial or what complications can come along with it.

We hope to make a more circular economy in Hawaii, limiting the need for importing plastics while tapping into the plastic and calcium carbonate resources they currently have.

Figure 1: Biofouled fishing nets recovered from the Papahānaumokuākea Marine National Monument

Our goal is to come in and do research into the end life of the ocean plastics and come up with better alternatives that will reduce the associated greenhouse gas emissions, instead of coming up with a new framework for their entire process. To understand which types of biofouled nets should be used for what, CMDR has a number of tests they want to run but neither they or their local universities have the machines to perform those tests.. As Stanford students, our team can and will utilize the machines and resources that Stanford has to assist CMDR's research and development process, which in turn supports PMDP's goal of reducing net combustion.

We hope to close the recovery + production loop by transforming recovered nets into valuable infrastructure materials, creating a circular, self-sustaining system that reinvests waste into Hawaiian communities. By aligning with local stakeholders like CMDR and PMDP, we seek to turn marine pollution into an opportunity—reducing plastic waste at scale while driving economic and environmental resilience. Because this report contains a lot of potentially unfamiliar jargon, we have compiled a full GhostNetBusters dictionary located in Table 3 of the Appendix section. High-density polyethylene (HDPE) is a durable thermoplastic valued for its strength-to-density ratio, moisture resistance, and low melting point. These properties make it suitable for both packaging and long-life infrastructure applications. However, when HDPE becomes biofouled — coated with marine organisms — its mechanical and thermal properties may degrade or become inconsistent, complicating reuse. While recycled HDPE is already used in a variety of applications, there is limited data on how biofouling impacts its performance once reprocessed. This knowledge gap limits the ability of organizations like the Center for Marine Debris Research (CMDR) and the Papahānaumokuākea Marine Debris Project (PMDP) to confidently integrate ghost nets into recycled material streams.

2. Background

Our project aims to characterize how biofouling affects the mechanical performance of HDPE across a range of contamination levels. By testing tensile strength, flexural modulus, and melt flow index, we hope to identify contamination thresholds, assess whether pre-washing improves material quality, and determine feasible end uses for biofouled plastics in durable infrastructure.

Ethical considerations have shaped this project from the outset. Recycling ghost nets helps reduce reliance on virgin plastic and mitigates the harm abandoned gear causes to marine ecosystems and Indigenous coastal communities. Our collaboration with CMDR and PMDP — organizations rooted in local stewardship — reflects a commitment to co-developing solutions rather than extracting data. By exploring how to transform waste into viable building materials, we aim to support circularity, environmental justice, and access to affordable, sustainable construction resources in Hawai‘i and beyond.

Calcium carbonate is often used as an additive for recycled plastics to strengthen the plastic quality, but PMDP/CMDR will already have calcium carbonate from the biofouling on the nets. CMDR wants to figure out if we can recycle the biofouled nets as is and skip the additive filler step. They want to know how much bio-foul the nets can have that would still produce adequate quality for different intended end-of-life uses. We will do testing with Stanford equipment on nets that are in a wide range of conditions sorted into four categories by the CMDR (clean, light biofoul, medium biofoul, and heavy biofoul) to figure out their chemical, physical, and thermal properties. They want to test the tensile (to measure how a material behaves when stretched and looks at the strength, modulus, and strain at break), flexural (to measure how a material behaves when it's bent and looks at the strength and modulus), and melt flow index (to measure how easily a material melts and flows under heat and pressure). Our plan of operation was to tackle the tensile test first, then flexural and melt flow index testing if time allowed.

To conduct the tensile tests, the nets would have to be in the shape of dog bones. While waiting for the CMDR to send us shredded nets, we worked on developing a process to create the units for testing. We must pelletize the material to test melt flow, extrude or heat press the material into thin rectangular prisms for the flexural tests, and create dog bones to perform the tensile tests. We hoped to use an extruder to create the specimen shapes that are compatible with the respective instruments, but the computer hooked up to the extruder wasn’t functional, so we ended up using only the heat press.

The CMDR sent us unwashed shredded nets, and they wanted us to wash these nets as well so that we would have eight different categories of nets to test (the same four levels of biofouling but each level will be washed or unwashed as well). They also wanted to know if washing was necessary (if it would help strengthen the plastic by removing salinity/impurities or if it would correlate with weaker properties). However, we didn’t have the time to wash or do testing on washed nets, so we set aside some nets that can be washed and tested in the future.

CMDR hopes to eventually use the recycled plastics in long-life infrastructure projects for Hawaii, including spider ties, composite panels, and recycled plastic lumber. What the products can be will partly depend on the quality and properties of the tests [10]. With plastic lumber, they do not need as high of a quality of recycled plastics [10]. However with other plastic products, it will be hard to compete with virgin or non-biofouled recycled plastics’ quality. CMDR is not trying to make the products themselves, but instead create a supply of recycled plastic resources that entrepreneurs and other organizations can use to create long lasting products.

Recycling biofouled plastics is tricky and not a lot of other organizations want to do that because virgin plastic is much more consistent and cheaper [12]. We do not expect the properties to be on par with virgin polymers, so our goal is to better understand and quantify its variability. By providing CMDR with insight into how ghost net plastic properties differ across a range of conditions, we hope it will make it more feasible for them to develop a recycling process.

3. Design

In collaboration with our project partners, CMDR and PMDP, we determined that tensile testing biofouled material would be the most useful and actionable way for us to help. Originally, we hoped to do melt flow index and flexural testing as well, but that ended up being outside of the scope of our abilities for this class. The plastic needed to be in a shape that we could use for tensile testing, and we wanted it to be structurally more like the end products that might be utilized in infrastructure projects. As such, we determined that we needed to create dog bones out of each biofouling level in order to conduct the tests. Then we could test each set of bones and analyze them to determine how the tensile integrity was affected by the biofouling, and make recommendations based on the results. We also hypothesized what was likely to happen as compared to the control for each set of biofouling. Our hypothesis and results are discussed more in depth in the next section.

Our biggest challenge for this project turned out to be creating the dog bones in order to test the nets we received. We started by testing various molds and melting techniques on clean nets we received from the Ocean Voyages Institute. We considered two different ways to create the dog bones: melting the plastic into flat sheets and cutting out the shape we needed, or using molds that would shape the material as we melted it. Either process would utilize the heat press in the Yang & Yamazaki Environment & Energy Building, also known as Y2E2, basement lab (room B33).

We discussed several approaches to both the mold and the sheet techniques. We originally attempted to use the molds, but couldn't make it work. We then moved on to trying to make plastic sheets we could cut the bones from. That proved to be difficult, especially because the dog bones would have to be precise in order to not affect our results and the height was a nonstandard size (.13 inches). We attempted sheets while brainstorming other ideas to make the molds work, and eventually determined a different way to make use of the molds.

For creating the plastic sheets, our original attempt produced a wafer thin sheet of plastic. From this we realized that there would need to be a stopper at the thickness that we would want our sheet to be, otherwise the press would spread the material out continuously.

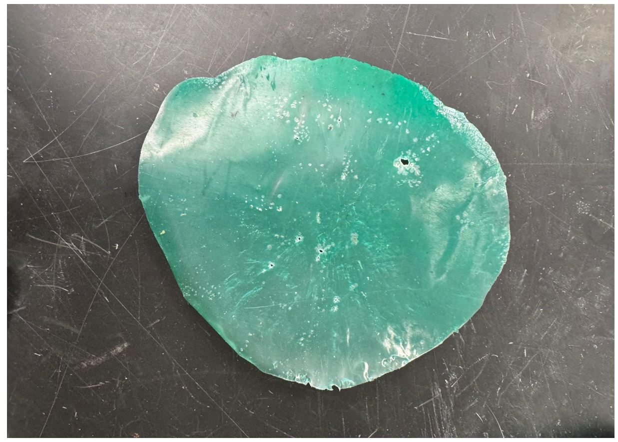

Figure 2. Plastic dog bones used for tensile testing **Figure 3.** First attempt at a plastic sheet

We then tried to use pieces of 3/16 in aluminum sheet for the stopper , but the plastic shreds failed to melt as well as they had previously. For the next attempt, we added enough net shreds to the point where the material could not fully flatten as it had before. This strategy mostly worked, though the resulting "puck" of plastic contained several pockets. We then later used this technique to premelt and compact material for mold use.

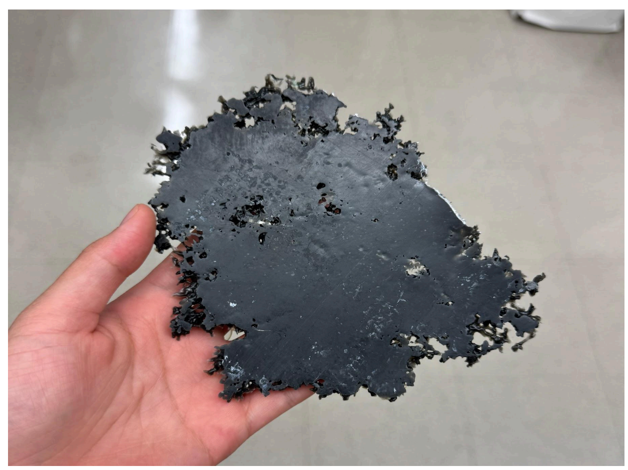

Figure 4. First attempt at a plastic sheet. **Figure 5.** "Puck" of plastic, iteration on first attempt

Figure 6. Material shrinkage when filling the mold

We believed that the molds would be a more efficient and better solution, but we had some trouble figuring out the best way to actually make it work. Originally, we tried to fill the mold from the top, and compress the material down into it. Unfortunately, we were unable to fill the mold with enough material to make a solid dog bone, as the plastic shrinks dramatically when melted.

Eventually we realized that we could pile the shredded plastic below the mold and allow the excess material to overflow out of the sprue channel and the sides of the mold once pressure and heat were fully applied. To combat the material shrinkage, we premelted some of the material before pressing it into the mold. Generally the upside down mold method worked well, the exception being with the heavily biofouled material.

Figure 7. Dogbone and material overflow

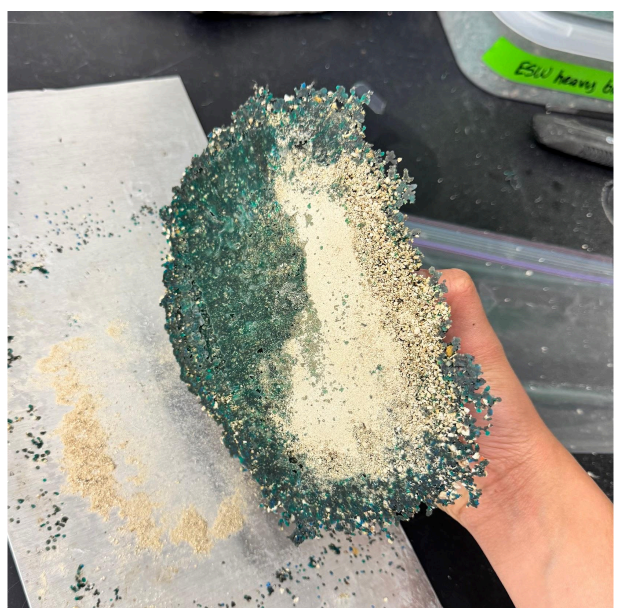

Figure 8. Biofouled material stuck in the mold

For both the mold and the sheet options, we needed a prototype to test on, and then preferably an easy way to make a lot more in that same method. We only were able to add repeatability for the mold option, and therefore decided to make a larger mold with more cavities for bones to be made – eight dog bones to the original one.

Figure 9. Single test mold and the larger production mold for the dogbones

While we tested dog bone making processes, we were in talks with CMDR to get samples of their nets to test on. They were kind enough to send us shredded samples of each fouling level: none (clean), light, medium, and heavy.

Then, once we could make the dogbones and had received the shredded nets from CMDR, we made several of each biofouling level to test on, using the top-down mold method. We tested various combinations of temperature, pressure, mold configuration, and duration, and arrived at (after spraying the mold with mold release spray), setting both the top and bottom layers of the heat press to 400ºF, at 10 tons of pressure, for 10 minutes, then turning off the heat press to let it cool under pressure. We would remove the dog bones the next day.

Figure 10. Clean dog bone specimens

To validate the design, we conducted tensile tests using the MTS Criterion 43 universal testing system in the Blume Structural Engineering Center. Each dog bone was clamped upright between serrated grips, as shown below in Figure 11.

Figure 11. Dog bone specimen after failure in testing mechanical testing instrument

The instrument was set at 1mm/s using a 5 kN load cell, meaning once calibrated with the specimen loaded, the instrument would pull upwards at a rate of 1mm/s, with data acquisition at 10 Hz. This test setup allowed us to measure ultimate tensile strength, elastic modulus, and strain at break across the different biofouling conditions, which were the desired characterization methods requested by Mafalda. Each of these data points are gathered simultaneously as the piece stretches until failure.

We conducted tensile testing to quantify how biofouling affects the mechanical integrity of recycled HDPE fishing net material. Specifically, this test setup allowed us to measure ultimate tensile strength, elastic modulus, and strain at break across the four different levels of biofouling (clean, light, medium, heavy). These parameters provide a foundational understanding of how the material performs under load and whether it retains sufficient structural properties for reuse in infrastructure applications.

These mechanical properties were specifically requested by Mafalda to support the broader goals of the project, which include evaluating the feasibility of using ghost net material in construction components such as spider ties and plastic lumber. By characterizing strength, stiffness, and ductility, we could provide actionable insights to CMDR and PMDP about the viability and limitations of using biofouled material without extensive preprocessing. Tensile testing was selected over other characterization methods (such as melt flow index or flexural testing) due to equipment constraints and because it directly evaluates the load-bearing capacity of the material, which is most relevant for structural reuse.

4. Results and Discussion

We aimed to evaluate whether biofouled HDPE retains sufficient tensile mechanical integrity for reuse in structural applications without preprocessing. Understanding how biofouling affects the tensile properties of recycled marine plastics is crucial for determining their suitability in load-bearing infrastructure. All referenced tables and figures can be found in Appendix F.

Understanding how biofouling affects the tensile mechanical properties of recycled marine plastics is crucial for determining their suitability in structural applications. Our tensile testing of HDPE ghost nets at varying levels of biofouling (clean, light, medium, and heavy) revealed clear trends in material performance degradation, particularly in peak stress, modulus, and strain at break. In contrast to prior research, such as the tensile testing of new and used fishing ropes by Belmokhtar et al. in *Polyolefin-Based Cladding Panels from Discarded Fishing Ropes*, where the modulus of elasticity remained statistically unchanged across conditions, our data show a marked decline in both stiffness and strength as biofouling increased. This discrepancy may arise from differences in processing—Belmokhtar's work involved processed ropes likely free of residual organics, while ours deliberately preserved the fouled state to evaluate unprocessed feedstock viability. Overall, the results highlight the limitations of directly recycling heavily biofouled material without preprocessing, and suggest that while biofouled HDPE may retain some potential for reuse, its tensile mechanical integrity is strongly compromised in the as-received state.

Experimental Setup

We performed tensile testing on 25 dogbone specimens produced from shredded HDPE ghost nets at four biofouling levels: clean (no fouling), light (Level 1), medium (Level 2), and heavy (Level 3). Nets were not washed or preprocessed to preserve as-received conditions. Specimens were pressed into ASTM D638 Type V shapes using a heat press and CNC-machined mold. Tensile tests were conducted using an MTS Criterion load frame, collecting peak load, peak stress, elastic modulus, and strain at break.

Dimensional and specimen-level results are presented in Table 1, which includes dogbone measurements, calculated cross-sectional areas, and mechanical properties for each test. As biofouling increased, we observed greater mass and dimensional variability, likely due to organic and mineral buildup on the plastic surface. This affected both sample consistency and stress calculations, given the reliance on cross-sectional area for normalizing mechanical results.

Qualitative Results

During the molding process, we observed a clear pattern of increasing difficulty in demolding specimens as the level of biofouling increased. The clean specimens slid easily out of the mold with precise geometry and smooth edges, requiring no additional tools or post-processing. However, for the light, medium, and especially heavy biofouled specimens, the dog bones became progressively more difficult to remove. In several cases, we had to pry them out using tools, which occasionally resulted in minor damage or deformation.

We suspect this is due to the fact that Ease Release 200 mold release spray is formulated specifically for HDPE, and may not prevent adhesion of non-HDPE contaminants like barnacles, algae, or salt residues. These contaminants appear to bake into the mold cavity, creating a mechanical and chemical bond that resists clean release.

These issues extended into the mechanical testing phase. Many of the biofouled dog bones failed at or near the location of visible biofoul or at hollow points within the specimen—voids likely caused by poor compaction or uneven melting during fabrication. These defects compromised the uniformity and structural continuity of the test specimens.

As a result, we began to question whether our testing results accurately reflect the true mechanical performance of the recycled HDPE. It is likely that specimen fabrication inconsistencies, especially in the heavily fouled samples, introduced artifacts that weakened the material at unintended points and skewed our data. These findings suggest a need to reconsider our dog bone creation strategy, particularly when working with highly biofouled material, to ensure that testing outcomes are both reliable and representative.

Weight and Geometry Effects

Figure 1 shows the average weight by biofouling level. Clean specimens weighed the least, with weight increasing significantly at each fouling level. Level 3 (heavily fouled) samples weighed nearly twice as much as clean specimens, reflecting the accumulation of barnacles, sand, salt, and biological matter.

This surface buildup also influenced the cross-sectional area. Table 2 compares average areas to the nominal ASTM Type V dimensions (12.7 mm^2). Clean samples closely matched nominal values, while fouled specimens—especially at Levels 2 and 3—showed enlarged, irregular areas. These differences likely stem from cutting imprecision and embedded debris. Because stress values are normalized by area, such variation contributes to scatter in mechanical results.

To further explore whether cross-sectional area influenced performance, Figure 4 shows correlations between area and both peak load and peak stress. A positive correlation exists between area and peak load (as expected), but the relationship weakens for peak stress, which is area-normalized. This suggests that increases in area due to fouling do not fully explain the observed degradation in material strength—reinforcing that fouling acts more as a contaminant than a reinforcing phase.

Mechanical Performance Trends

Mechanical results by fouling level are summarized in Table 3, and visualized in Figure 2, which plots average values with standard deviation error bars. Clean specimens had the highest peak stress (~23.8 MPa), modulus (~2358 MPa), and strain at break (~0.13 mm/mm). With each increase in biofouling, all three metrics declined, with Level 3 samples averaging only ~3.8 MPa in strength and ~0.03 mm/mm in strain—an ~84% and ~77% reduction, respectively, from the clean baseline. These changes are reinforced by Figure 5, which presents the percent decrease in each property from clean to each fouling level for intuitive comparison.

Representative stress–strain curves in Figure 3 further illustrate the trend. Clean samples exhibited classic ductile behavior with substantial elongation before failure. Light and moderate fouling reduced elongation and increased brittleness, while heavily fouled samples failed abruptly with minimal deformation.

Quantitatively, Table 4 summarizes the percent reductions in peak load, peak stress, modulus, and strain at break. Even light fouling led to a ~29% reduction in strength and ~77% reduction in ductility. By Level 3, peak stress declined by ~84%, and modulus and strain by ~57% and ~77%, respectively. These findings underscore the severity of mechanical degradation due to biofouling.

Interpretation of Results

These results align with Belmokhtar et al. (2022), who found reduced strength in recycled marine ropes due to mineral and biological contamination. However, their materials were eventually pelletized and reprocessed, which improved uniformity and performance—something we did not attempt here. Our findings thus isolate the impact of raw, unwashed biofouling on tensile performance, highlighting that preprocessing (e.g., washing, pelletizing) may be critical to restoring mechanical integrity.

Sources of Error and Limitations

Several factors likely contributed to variability in our results:

- **No Preprocessing:** Specimens were not rinsed prior to testing, and likely contained entrapped seawater, detritus, algae, and dirt—all of which reduced interfacial adhesion.
- **Shredding Only:** Shredding (vs. pulverizing or extrusion) produced a coarse, heterogeneous feedstock that was difficult to mold uniformly.
- **Dog Bone Size:** Our Type V dog bones were small relative to the average size of biofouled inclusions, increasing the chance of defect-induced failure.
- **Weak Interface:** In some tests, fractures occurred not from material yielding but from localized defects—likely at the HDPE/biofoul interface (Figure 2).

Implications for CMDR

Our results underscore the importance of preprocessing in marine plastic recycling. While raw biofouled HDPE has insufficient mechanical properties for structural applications, the degradation is not necessarily irreversible. With improved fabrication (washing, pelletizing, extrusion), these materials may still meet minimum strength thresholds for infrastructure-grade composites.

This informs ongoing work with the Papahānaumokuākea Marine Debris Project (PMDP) and the Center for Marine Debris Research (CMDR), which aims to recycle ghost nets into useful infrastructure. Based on our preliminary findings, at this point in time, we recommend that:

- **Clean HDPE nets** are prioritized for high-strength applications (e.g., spider ties).
- **Lightly fouled nets** may suit lower-load uses (e.g., plastic lumber, signage).
- **Medium and heavy fouled nets** should either be preprocessed or downcycled into non-load-bearing products (e.g., cladding or park benches).

5. Conclusion

Contrary to our hypothesis, raw biofouling significantly reduced the tensile performance of recycled HDPE from ghost nets. While we anticipated calcium carbonate from marine encrustations to act as a reinforcing filler, the untreated inclusions introduced defects and brittleness due to poor dispersion and weak interfacial bonding. These findings are consistent with existing literature and emphasize the importance of preprocessing in any viable recycling strategy for marine plastics.

A major accomplishment of this project was the development of a consistent method to process and mold highly contaminated fishing nets into standardized tensile specimens. Our use of a CNC-milled mold, heat press, and unwashed input material allowed us to isolate the effect of biofouling and evaluate its impact on mechanical properties. The study also identified key design improvements, such as the need for scaled-up molds to better accommodate fouled inclusions and a distributed fabrication workflow to increase throughput and consistency.

These results carry important implications for marine debris recycling and infrastructure applications. While raw biofouled nets are not immediately suitable for structural use, our findings suggest that effective preprocessing—particularly washing, pelletizing, and extrusion—could recover material performance and enable reuse in coastal infrastructure. By partnering with CMDR and PMDP, future efforts can apply these insights to turn ocean waste into valuable, durable components for a circular economy.

6. Future Work

To advance this work, future efforts should focus on improving preprocessing, expanding property characterization, and pursuing scalable implementation.

Preprocessing should be standardized and streamlined. CMDR could provide pre-washed, dried, and pulverized ghost nets, then extrude them into uniform pellets to improve moldability and reduce heterogeneity. Larger mold designs are needed to accommodate coarse inclusions and produce more representative test specimens. Fabrication could be outsourced to partner labs (e.g., Chico State) to ensure consistency and free up time for characterization.

Characterization should move beyond tensile testing to include FTIR, DSC, GPC, XRD, MFR, flexural strength, and impact resistance, following the Belmokhtar et al. study. Broader testing will clarify how biofouling impacts thermal, chemical, and mechanical behavior. Increasing replicates and applying statistical methods like Welch's t-test will improve the robustness of comparisons.

Scaling and impact should be pursued through pilot trials with HDPE product manufacturers to validate a tiered-use framework (e.g., load-bearing vs. decorative). Engaging local communities, especially Indigenous groups in Hawaiʻi, will help co-design relevant products. At the systems level, partnerships with policymakers and waste managers could align supply chains and incentives around circular reuse models like extended producer responsibility.

To carry this work forward, we recommend next year's team include a Materials Science student for testing and a Mechanical Engineering student for mold optimization and CNC workflows.

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8. Appendix

Appendix A – Full List of User Requirements

Category (Performance/Features, Operating Conditions, Reliability, Conformance)	Requirement Number (e.g., UR 1-1)	Priority	User Requirement	Justification	Source	Requirement Number (e.g., ER 1-1a)	Engineering Requirements	Measurement Method	Justification
Operating Conditions	UR 1-1	1	User shall not burn fishing nets after their collection from waterways.	Efforts to reduce contribution of greenhouse gases. Align with their sustainability mission and values.	Community partner	ER 1-1a	Develop a method or process to clean the nets, remove debris, and separate them from other materials.	N/A	Contaminants (e.g., organic matter, plastics, non-nylon components, salt, oils, marine organisms) make recycling opportunities difficult.
						ER 1-1b	Identify the specific polymers (e.g., nylon, polypropylene).	categorization	Knowing the material ensures compatibility with the intended end use.
						ER 1-1c	Supply an existing recycling initiative (company, organization, project, etc.) with nets obtained by PMDP	Mechanical or chemical processes to separate nets into necessary components for repurposing.	Create partnerships! Don't reinvent the wheel, if there is a method out there already that works
Logistics	UR 1-2	2	User does not have to excessively sort collected fishing nets for recycling and processing.	PMDP's manual collection process means there's little control of the debris type they collect and it's all mangled together.	Community partner	ER 1-2a	Determine the volume of nets collected and whether your solution can scale with the supply.	cubic feet, cubic meters	PMDP has their own method of collecting nets, which doesn't include sorting them.
						ER 1-2b	Consider ease of transport from collection sites to processing or manufacturing facilities.	hours, days, week; gallons of gas	Minimize energy-intensive processes to align with sustainability goals.
						ER 1-2c	Evaluate storage needs, especially for mangled or bulky nets that may require compacting or baling.	cubic feet, cubic meters, pounds	Determine if current infrastructure is sufficient or if additional is necessary.
Conformance	UR 1-3	3	Improved system provides social, environmental, and economic benefits.	PMDP's current linear model efficiently addresses problems of accumulating marine debris in their community by removing it and sending it away, but it	Student team	ER 1-3a	Look for opportunities to engage the local community in processing or manufacturing.	community engagement	Reciprocity, empathy!!
						ER 1-3b	Ensure the project aligns with local Hawaiian values and practices regarding sustainability and ocean stewardship.	community engagement	Reciprocity, empathy, humility!
						ER 1-3c	Consider the environmental footprint of the new end use.	CO2 emissions	Ensure minimal by-products or waste are generated during repurposing.

Appendix B – Project Expense Summary

Project Expense Summary		
Remaining Budget	Expense	Purpose
$200	—	—
$191.28	-$8.72	Mold Release Spray
$141.28	-$50	Hawaii → CA Nets Shipment

Appendix C – Ghost Net Busters Blog

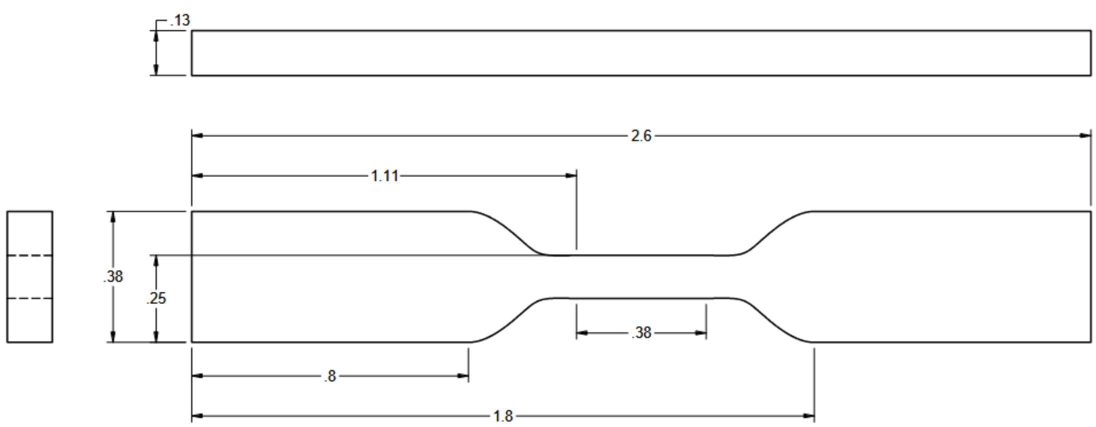
Appendix D – Project Summary

Each year, over one million tons of fishing gear are lost at sea, contributing to widespread ecological damage. In partnership with the Papahānaumokuākea Marine Debris Project (PMDP) and the Center for Marine Debris Research (CMDR), our team investigated the mechanical viability of recycling ghost nets—specifically high-density polyethylene (HDPE) nets fouled with marine organisms—for use in Hawaiian infrastructure. We tested HDPE samples at four levels of biofouling to assess how residual organic matter affects tensile strength. Results showed a clear decline in performance with increased fouling, due to poor bonding and material inconsistency. Contrary to our hypothesis, biofouled material did not behave like a reinforced composite.

Despite the challenges, this project demonstrated that, with proper preprocessing (e.g. washing, pelletizing, extrusion), recycled ghost nets may still serve as a valuable material stream. We recommend a tiered-use strategy: clean nets for load-bearing applications and fouled ones for lower-stress or decorative uses. This work supports PMDP and CMDR's long-term vision of creating a circular plastics economy in Hawaiʻi while reducing ocean waste and promoting sustainable, locally sourced building materials.

Appendix E – Dog Bone CAD File Specifications

Figure 1. Dimensions for dog bones, in inches



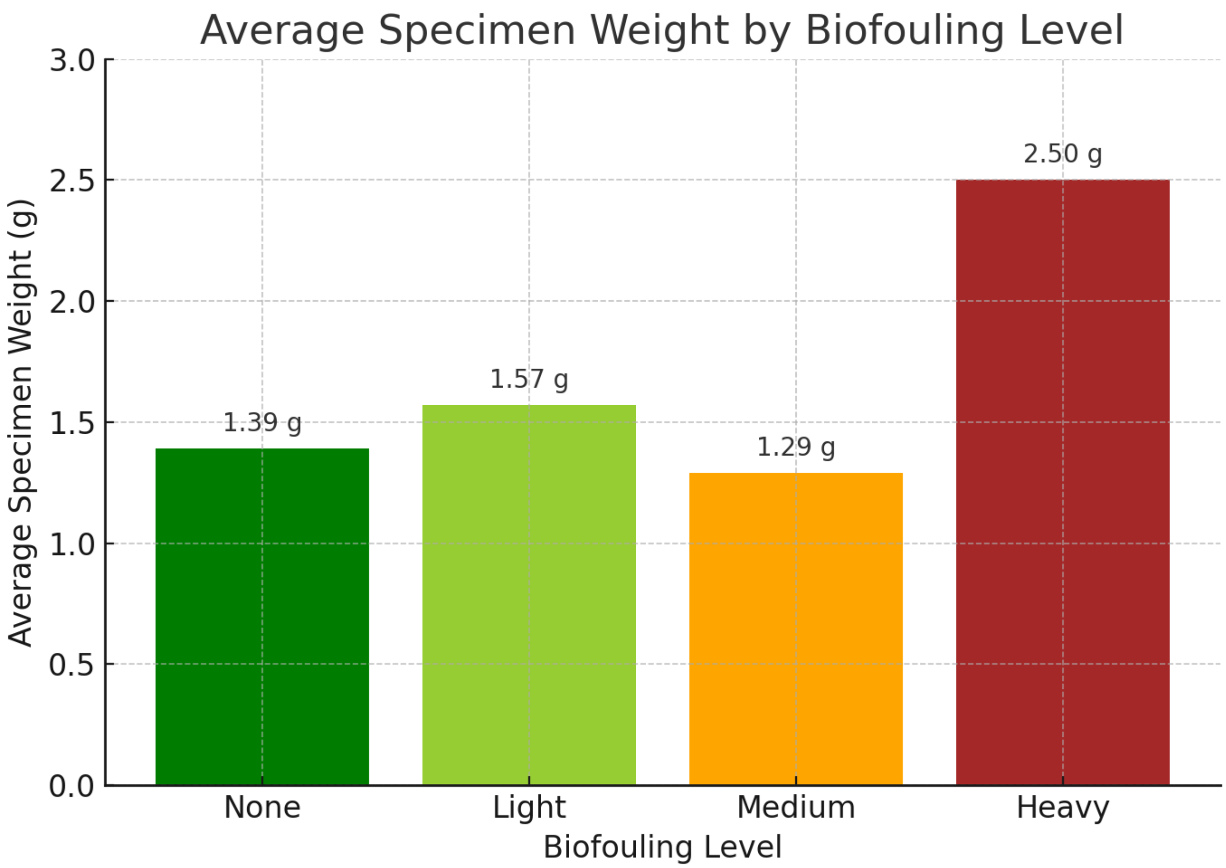
Appendix F – Dogbones & Testing (results)

Table 1. Dog Bone Dimensions

Level of Biofoul	Specimen Number	weight	Length (top to bottom)	cross section top middle		cross section bottom middle		overall		A1	A2	A
				width	depth	width	depth	width	depth	top section area	bottom section area	
		g	mm							mm^2		
None	1	1.35		3.50	3.25	3.50	3.25	3.50	3.25	11.38	11.38	11.38
	2	1.32	44.50	3.51	3.31	3.51	3.32	3.51	3.32	11.62	11.65	11.64
	3	1.39	46.65	3.54	3.34	3.55	3.33	3.55	3.34	11.82	11.82	11.82
	4	1.42	39.28	3.51	3.27	3.53	3.26	3.52	3.27	11.48	11.51	11.49
	5	1.43	46.86	3.51	3.32	3.51	3.33	3.51	3.33	11.65	11.69	11.67
	6	1.37	48.54	3.52	3.34	3.54	3.30	3.53	3.32	11.76	11.68	11.72
	7	1.45	47.28	3.53	3.31	3.53	3.29	3.53	3.30	11.68	11.61	11.65
	8	1.41	43.08	3.49	3.25	3.50	3.26	3.50	3.26	11.34	11.41	11.38
None - Average		**1.39**	**45.17**	**3.51**	**3.30**	**3.52**	**3.29**	**3.52**	**3.30**	**11.59**	**11.59**	**11.59**
Level 1 (Light)	9	1.33	46.85	3.53	3.44	3.53	3.49	3.53	3.47	12.14	12.32	12.23
	10	1.63	46.18	3.63	4.10	3.66	4.02	3.65	4.06	14.88	14.71	14.80
	11	1.27	48.08	3.52	3.50	3.53	3.50	3.53	3.50	12.32	12.36	12.34
	12	1.81	45.71	3.66	4.40	3.67	4.35	3.67	4.38	16.10	15.96	16.03
	13	1.58	48.26	3.55	3.95	3.53	3.93	3.54	3.94	14.02	13.87	13.95
	14	1.71	47.33	3.58	4.22	4.02	3.51	3.80	3.87	15.11	14.11	14.61
	15	1.69	44.83	3.55	4.13	3.55	3.95	3.55	4.04	14.66	14.02	14.34
	16	1.52	44.49	3.50	3.77	3.52	3.66	3.51	3.72	13.20	12.88	13.04
	17	1.58	45.13	3.55	3.98	3.58	3.79	3.57	3.89	14.13	13.57	13.85
Level 1 - Average		**1.57**	**46.32**	**3.56**	**3.94**	**3.62**	**3.80**	**3.59**	**3.87**	**14.06**	**13.76**	**13.91**
Level 2 (medium)	18	1.30	44.96	3.54	3.55	3.54	3.53	3.54	3.54	12.57	12.50	12.53
	19	1.34	47.08	3.48	3.67	3.57	3.62	3.53	3.65	12.77	12.92	12.85
	20	1.27	48.48	3.47	3.59	3.48	3.65	3.48	3.62	12.46	12.70	12.58
	21	1.25	46.77	3.43	3.58	3.45	3.59	3.44	3.59	12.28	12.39	12.33
	22	1.27	46.62	3.48	3.57	3.48	3.60	3.48	3.59	12.42	12.53	12.48
	23	1.32	44.43	3.47	3.70	3.55	3.65	3.51	3.68	12.84	12.96	12.90
Level 2 - Average		**1.29**	**46.39**	**3.48**	**3.61**	**3.51**	**3.61**	**3.50**	**3.61**	**12.56**	**12.67**	**12.61**
Level 3 (heavy)	24	2.82	46.41	3.69	4.91	3.47	3.96	3.58	4.44	18.12	13.74	15.93
	25	2.18	48.12	3.60	5.57	3.59	5.53	3.60	5.55	20.05	19.85	19.95
Level 3 - Average		**2.50**	**47.27**	**3.65**	**5.24**	**3.53**	**4.75**	**3.59**	**4.99**	**19.08**	**16.80**	**17.94**

Dimensional and mechanical property data of HDPE specimens across biofouling levels. Each row includes individual specimen mass, dimensions (length, width, depth), calculated cross-sectional areas (top and bottom), and average cross-sectional area used for stress calculations. Mechanical results include peak load, peak stress, elastic modulus, and strain at break. As biofouling level increases, specimens tend to exhibit larger and more variable cross-sectional areas, lower tensile performance, and reduced strain at break, suggesting that surface contamination and inconsistent geometry compromise mechanical integrity

Figure 11. Average Specimen Weight by Biofouling Level



Average specimen weight by biofouling level (mean ± 1 SD). Specimen weight increases with biofouling severity, peaking at Level 3 (heavy fouling), which had nearly double the mass of clean specimens. This trend reflects the accumulation of barnacles, sand, salt, and organic material on the HDPE surface. The large variability, especially at higher fouling levels, underscores the inconsistent nature of environmental contamination.

Table 2. Average Cross-Sectional Area of HDPE Dogbone Specimens by Biofouling Level, As Compared to Nominal Dimensions of ASTM D638 Type V Specimens

Biofouling Level	Average Area (mm^2)	% Larger than Standard
None	11.59	+14.6%
Level 1 (Light)	13.91	+37.6%
Level 2 (Medium)	12.61	+24.7%
Level 3 (Heavy)	17.94	+77.5%

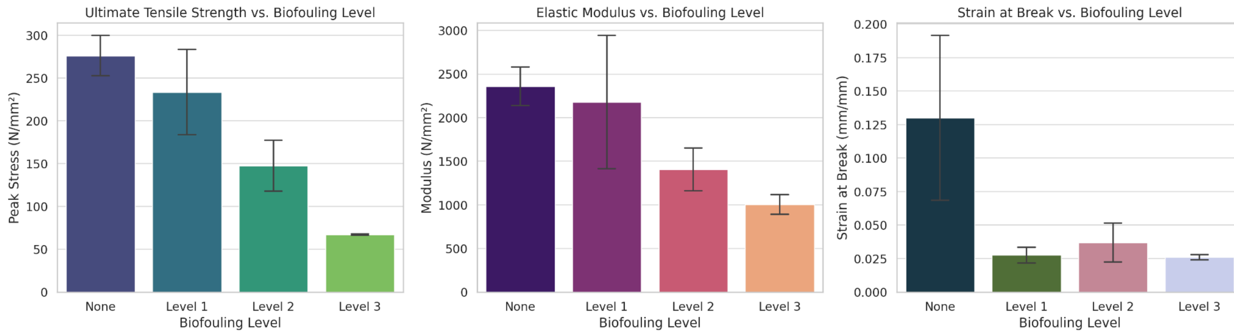
Cross-sectional area increased with biofouling severity, deviating from the nominal dimensions of ASTM D638 Type V specimens (~12.7 mm^2). Clean samples had the most consistent areas (~11.6 mm^2), while lightly and heavily fouled samples exhibited significant enlargement, particularly at Level 3, where average area reached ~18 mm^2. This change is likely due to biofoul build-up and irregularity during cutting or punching, which may affect stress normalization and mechanical performance comparisons.

Table 3. Results of Tensile Testing of Dogbone Specimens at Varying Biofouling Levels

Level of Biofoul	Specimen Number	Results			
		Peak Load	Peak Stress	Modulus	Strain at Break
		N	N/mm^2	N/mm^2	mm/mm
None	1	277.87	24.40	2577.96	0.12
	2	229.39	19.70	2007.56	0.03
	3	304.29	25.70	2325.66	0.19
	4	290.74	25.30	2362.65	0.18
	5	246.15	21.10	2216.11	0.04
	6	288.30	24.60	2777.02	0.12
	7	281.54	24.20	2210.31	0.21
	8	288.80	25.40	2386.92	0.13
None - Average		**275.88**	**23.80**	**2358.02**	**0.13**
Level 1 (Light)	9	200.18	16.40	4218.11	0.03
	10	249.93	16.90	1935.91	0.03
	11	199.38	16.20	1998.74	0.03
	12	158.90	9.90	1397.69	0.02
	13	295.52	21.20	2006.53	0.04
	14	264.21	18.00	1613.19	0.03
	15	309.88	21.60	2181.07	0.03
	16	247.58	19.00	2192.69	0.03
	17	174.92	12.60	2047.35	0.02
Level 1 - Average		**233.39**	**16.87**	**2176.81**	**0.03**
Level 2 (medium)	18	162.60	13.00	1528.82	0.07
	19	182.57	14.20	1691.36	0.03
	20	134.70	10.70	1266.25	0.03
	21	167.30	13.60	1504.53	0.03
	22	146.80	11.80	1507.49	0.05
	23	90.22	7.00	934.61	0.03
Level 2 - Average		**147.37**	**11.72**	**1405.51**	**0.04**
Level 3 (heavy)	24	66.16	4.20	889.05	0.02
	25	67.98	3.40	1116.94	0.03
Level 3 - Average		**67.07**	**3.80**	**1002.99**	**0.03**

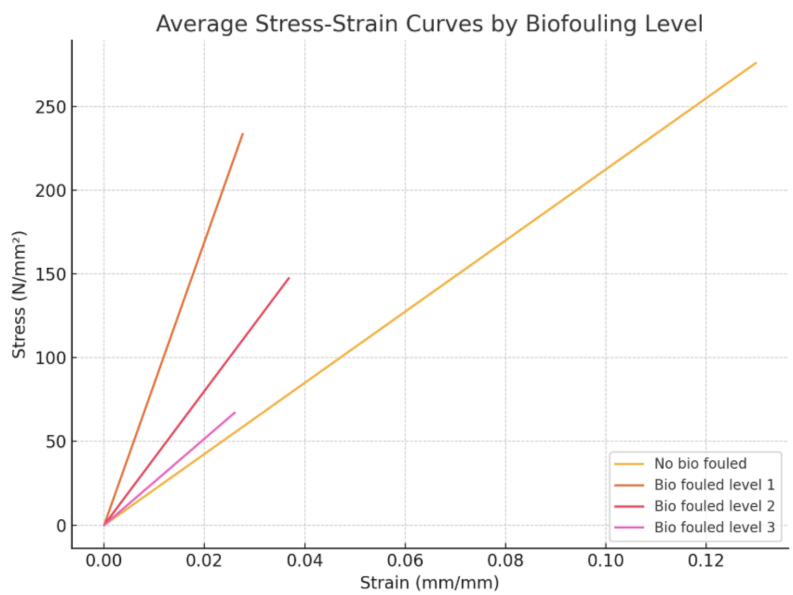
Tensile performance declined sharply with increasing biofouling. Average peak stress fell from 23.8 MPa in clean samples to 3.8 MPa in heavily fouled ones, while modulus and strain at break also decreased substantially. Lightly fouled specimens displayed high variability, with some unexpectedly high modulus values—likely due to cross-sectional area irregularities or data noise. By Level 3, all specimens exhibited uniformly poor performance, confirming that biofouling, particularly when unwashed, severely undermines tensile strength, stiffness, and ductility.

Figure 12. Tensile Mechanical Properties of HDPE Specimens Across Biofouling Levels



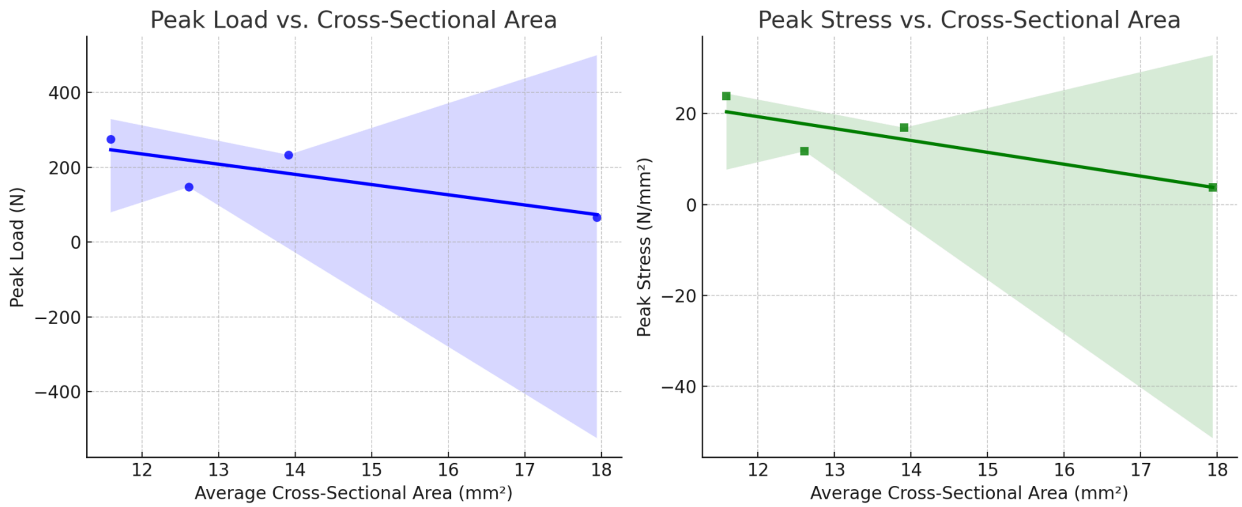
Effect of biofouling on tensile properties of HDPE specimens (mean ± 1 SD). Left: Ultimate tensile strength decreases sharply with increasing biofouling. Middle: Elastic modulus also declines, indicating reduced stiffness. Right: Strain at break drops significantly after light fouling and remains low, suggesting rapid ductility loss.

Figure 13. Average stress–strain curves for HDPE specimens by biofouling level.



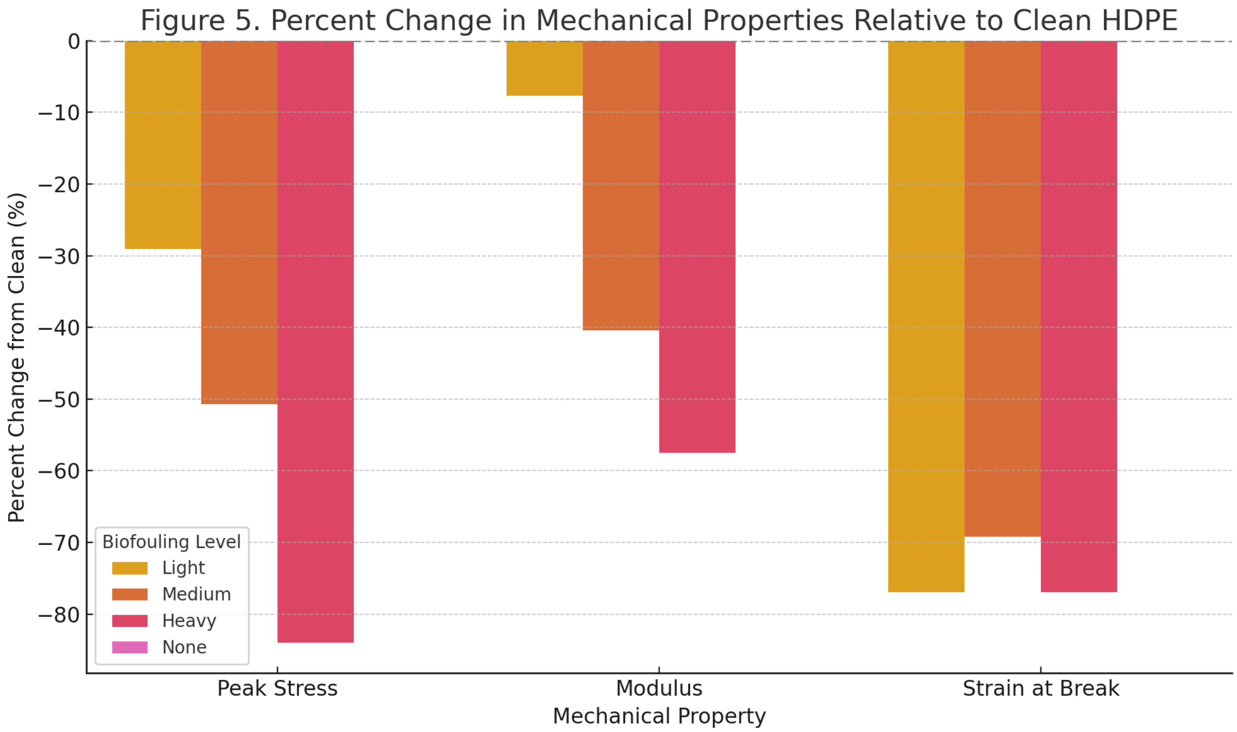
The average stress–strain curves reveal a clear degradation in tensile mechanical performance with increasing biofouling. Clean specimens exhibit higher peak stress, greater stiffness (initial slope), and extended ductile behavior. Lightly and moderately fouled samples show lower peak stresses and reduced elongation, while heavily fouled specimens fail quickly with minimal deformation and low stress capacity. The progression reflects the cumulative impact of biofoul material acting as voids, contaminants, or stress concentrators that accelerate failure and reduce the energy-absorbing capacity of the plastic.

Figure 13. Correlation between Cross-Sectional Area and Peak Load or Stress



Scatterplots showing the relationship between average cross-sectional area and (left) peak load and (right) peak stress for HDPE specimens. Linear regressions indicate whether variations in geometry contribute to differences in mechanical performance.

Figure 14. Percent Change in Mechanical Properties Relative to Clean HDPE



Bar plot showing the percent decrease in peak stress, modulus, and strain at break from clean ("None") specimens to each biofouling level. This visualization clearly illustrates the degradation in mechanical performance with increasing fouling.

Table 4. Summary of Percent Differences from Clean Condition

Level	Peak Load (%)	Peak Stress (%)	Modulus (%)	Strain at Break (%)
Light	−15.4%	−29.1%	−7.7%	−76.9%
Medium	−46.6%	−50.8%	−40.4%	−69.2%
Heavy	−75.7%	−84.0%	−57.5%	−76.9%

Percent decrease in key tensile mechanical properties of HDPE dogbone specimens at increasing biofouling levels, relative to the clean ("None") baseline. The largest declines occur in peak stress and strain at break, indicating that even light fouling substantially compromises material strength and ductility.