

DEGRADATION BEHAVIOR OF INJECTION-MOLDED PLA: CRYSTALLINITY DEPENDENCE IN MARINE VS. LAB-ACCELERATED COMPOSTING

INTRODUCTION

Poly(lactic acid) (PLA) is widely used as a biodegradable polymer; however, its degradation behavior is strongly influenced by material formulation, processing history, and environmental conditions. This study evaluates the degradation of injection-molded PLA under natural marine exposure and lab-accelerated composting conditions to assess environment-dependent degradation mechanisms and realistic end-of-life performance.

MATERIALS

Injection Molding Specimens:
2³ factorial design experiment

- Factors:**
- Nucleating agent (OA)
 - Velocity
 - Pressure
 - Hold time

Result: 16 PLA Specimens

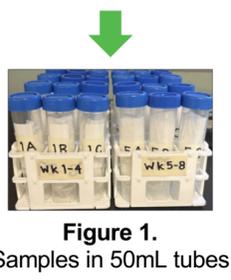
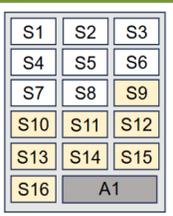
Table 1. Injection-molded PLA sample parameters

Variable	Unit	Low	High
Orotic Acid	%	0	2
Velocity	in/s	1	7
Pressure	psi	5,000	10,000
Hold Time (Neat)	s	6	12
Hold Time (PLA-OA)	s	10	40

EXPERIMENTAL SETUP

Marine

Samples were placed in 25-micron nylon sleeves and separated using a tabletop heat sealer. An initial dry mass was measured and recorded prior to placing the samples into the sleeves. Additionally, a metal tag engraved with the replicate number was placed in the bottom right section of each nylon sleeve. Each sleeve was sealed and placed in a 50mL polypropylene tube, marked with the replicate number and week. This was done so 3 replicates could be collected every week for a total of 8 weeks; 24 tubes in total.



The experiment was carried out at Shannon Point Marine Center of Western Washington University. Samples were exposed in an outdoor seawater tank supplied with continuously circulating natural seawater drawn from Samish Bay. The tank was located outdoors to allow direct exposure to natural sunlight, including ultraviolet radiation. Neither water nor ambient air temperature was actively controlled, enabling degradation to proceed under realistic marine environmental conditions.

Compost



Figure 2. Composting samples in oven

Three replicates of each PLA sample were prepared in 50mL polypropylene tubes for collection every two weeks for a total of six weeks; 144 tubes in total. Each tube was filled with a mature compost based on chicken manure, with a single PLA sample placed in the center. The tubes were placed in an oven set to 65°C. Water was placed inside the oven and refilled as needed to maintain moisture content. Additionally, each tube was sprayed daily with water to decrease dryness in the soil.

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ABSTRACT

As plastic waste management remains an important environmental consideration, many industries are turning to biodegradable alternatives such as (poly)lactic acid (PLA) as partial solutions. However, the biodegradability of PLA varies significantly depending on both formulation and environmental conditions. This study investigates the role of degradation of the environment by comparing natural marine exposure to lab-accelerated composting. Eight samples of injection-molded neat PLA and eight samples of PLA blended with 2% orotic acid nucleating agent to enhance crystallization during molding were prepared under varied processing parameters. This design enables comparison of degradation behaviors across PLA types, processing conditions, and degradation environments. Marine samples were monitored over an eight-week period, while composting samples were analyzed over six weeks. Degradation was assessed using both optical microscopy (OM) and scanning electron microscopy (SEM), mass loss, and differential scanning calorimetry (DSC).

Results demonstrated significant differences in degradation behavior across environments and formulations, highlighting the importance of optimizing both material processing and end-of-life scenarios. The insights gained from this study contribute to improving the design and lifecycle management of biodegradable plastics for more effective environmental performance.

RESULTS & DISCUSSIONS

Microscopy

Samples were not cleaned before drying in order to monitor any contaminants present from either environment and observe environmental residues. Samples were then sputter-coated with 9nm Au for SEM preparation. Photos of each specimen were taken at 500x, 1000x, and 3000x for analysis.

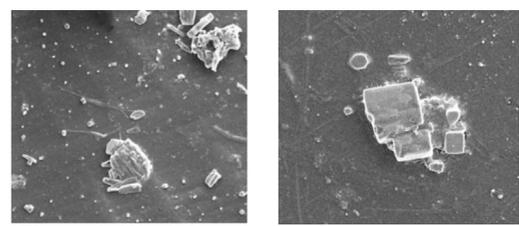


Figure 3. Week 8 marine samples (left and right) with evidence of microbial growth (1000x)

- Marine Observations:**
- Minimal surface degradation observed
 - Microbial growth consistent with diatom-like structures
 - Surface features dominated by biofouling

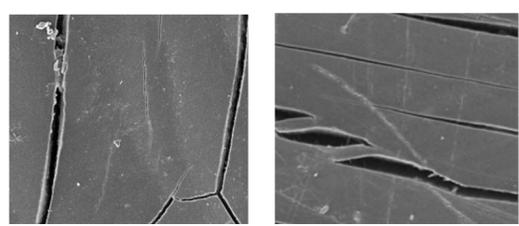


Figure 4. Week 4 composting samples with 0% OA (left) and 2% OA (right) (1000x)

- Compost Observations:**
- Clear surface degradation with crack formation
 - Cracks aligned with crystalline regions
 - Nucleating agent increased crack density

RESULTS & DISCUSSIONS

Weight Loss

- Marine Observations:**
- No direct trend in mass loss
 - Higher loss with Neat PLA

- Compost Observations:**
- Consistent increase in mass loss
 - PLA-OA consistently demonstrated higher mass loss
 - Much higher mass loss results than marine conditions

Table 2. Average % Mass loss of marine (M) and compost (C)

Sample	Avg. % Mass Loss
Neat (M)	0.359
PLA-OA (M)	0.226
Neat (C)	8.956
PLA-OA (C)	10.763

Marine (M) vs Lab-Accelerated Compost (C) Environments

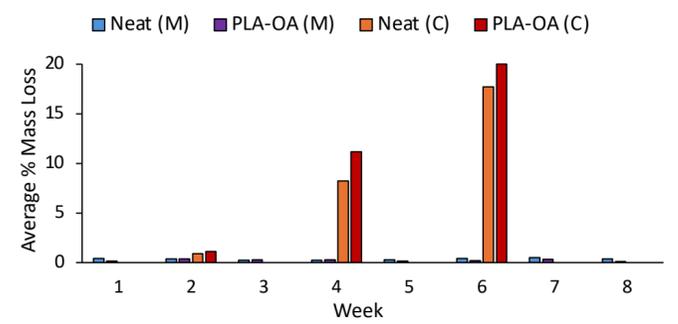


Figure 5. Graph of marine vs. compost environment average % weight loss.

Regression

- Results:**
- Processing conditions are not significant
 - Nucleating agent is significant
 - Only noticeable after 6 weeks
 - Large influence on marine conditions

Table 3. Mass Loss Regression P Values

	Week	O.A.	Velocity	Pressure	Hold Time
M	2	0.870	0.293	0.897	0.365
	6	0.026	0.376	0.200	0.126
C	2	0.648	0.274	0.934	0.443
	6	0.042	0.199	0.953	0.787

CONCLUSION

PLA degradation behavior was strongly dependent on environmental conditions, with composting environments producing substantially greater mass loss than marine exposure. The presence of a nucleating agent significantly influenced degradation behavior, while processing conditions showed minimal impact. These results highlight the limitations of PLA degradation in marine environments and emphasize the importance of aligning material design and disposal pathways with appropriate end-of-life conditions. Understanding these distinctions is critical for improving the environmental performance and responsible use of biodegradable plastics.

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