Accelerated Degradation Tests of Polylactic Acid (PLA) Scaffolds for Tissue Engineering Applications

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3D-Printed Poly (lactic acid) Scaffolds for Regenerative Medicine: How does Temperature Affect PLA Degradation?

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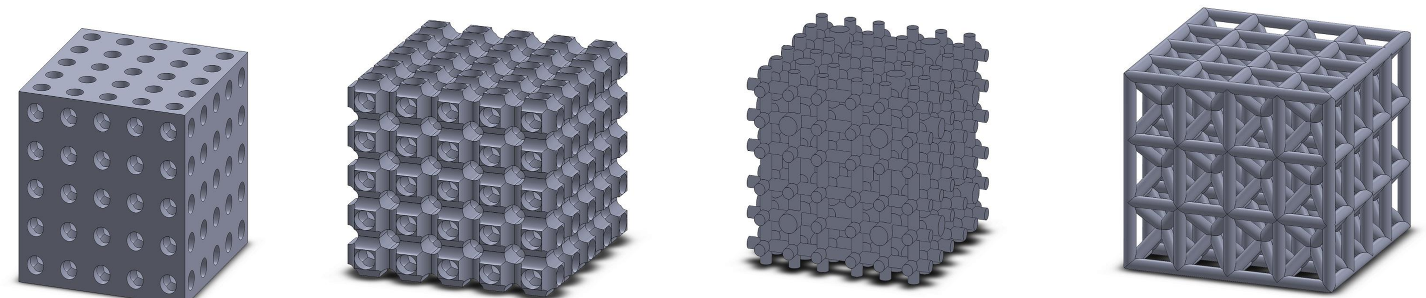
Introduction

Polylactic Acid (PLA) is a thermoplastic polymer that is safe for use in the medical field such as with orthopedic applications. It is widely chosen as an orthopedic material due to its mechanical properties along with its inexpensive and biodegradable nature (Pawar et. al). PLA can be used as implants such as scaffolds for tissue engineering applications (Fig. 1) as its resorbable trait results in not needing medical procedures to remove said applications, but rather allowing them to degrade on their own.

A common *in vitro* degradation test technique is to submerge a PLA sample into physiological saline at 37 °C, designed to imitate the environment within the human body. Being able to analyze the degradation of PLA in these conditions but at an accelerated rate is valuable in product development and further understanding how the material interacts with organic tissue. Implants and devices can then be efficiently tested for performance and mechanical properties as they degrade. This provides a significant benefit in design processes and providing new solutions to the medical field in a timely manner.

This project seeks to accelerate and analyze the degradation of 3D printed PLA using increased solution incubation temperatures and is based on a research conducted previously (Weir, et. al). Using varying temperatures and time, this research's goal is to determine the relationships between temperature, time, and the degradation of PLA as measured through scaffolds weight and stiffness.



1 Pore 2 Pore T Scaffold X Scaffold

Fig. 1: Candidate Scaffolds for This Study (Cole et al., 2018)

Objectives

The diamond (2 Pore) scaffold (Fig. 2) was selected for this project. Utilizing this 3DP PLA scaffold specimen soaking in physiological saline, the objectives of the project were to:

1) Determine the weight loss of PLA scaffolds with time and temperature
2) Determine the stiffness loss of PLA scaffolds with time and temperature

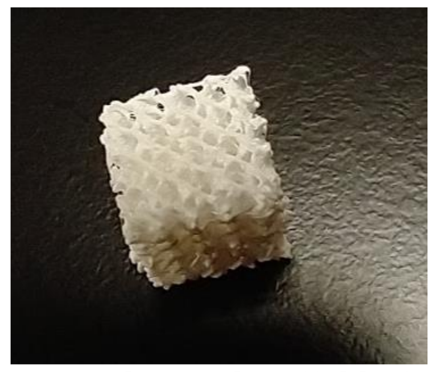


Fig. 2. diamond scaffold of this study

Experimental Methods

Eight diamond scaffold specimens were selected for the assessment of PLA degradation due to soaking in physiological (0.9%) saline. Specimens were weighted and mechanically tested at the onset of the protocol (t = 0 days) and at 3-4 day increments. This process was completed for specimens soaking at 70, 50, and 37 degrees Celsius. Physiological saline was prepared by combining distilled water and table salt with a ratio of 1000 mL water and 9g salt.

In order to maintain this temperature, the specimens were placed in a well plate on a hot plate (Fig. 3).held at a temperature required to maintain each of the test conditions. Temperature measurements were taken periodically to verify temperature Mechanical testing was conducted in compression at a displacement rate of 0.30 mm/min using a Mark-10 electromechanical testing machine (Copiague, NY) (Fig. 4).

Fig. 3. Specimen Setup on Hot Plate

Compression tests were made between steel plates and specimens were only loaded within the elastic region of the material. Following testing the structural stiffness (Load/displacement) was calculated form the slope of the load-displacement curve within the linear elastic region.

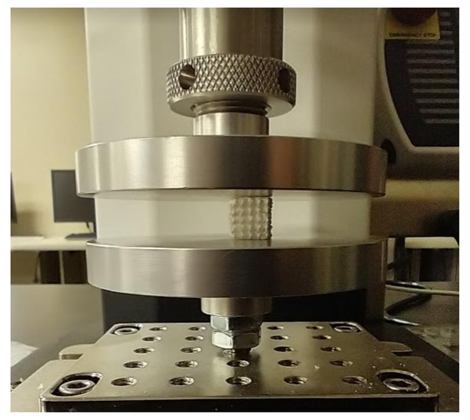


Fig. 4. Scaffold in Test Machine

Experimental Results

Average load-deflections curves for each temperature at each testing time were constructed and fits of the linear portions were made (Table 1). Figure 5 shows a comparison of all Load-displacement values for the three testing temperatures at days 1, 4, and 7 of the procedure. The scaffolds at 70 C lost all structural integrity by Day 4 (Fig. 7), and therefore does not have mechanical testing data. Scaffolds at 50 C had a comparable response by Day 7 (Fig. 8). 37 C scaffolds are still being tested, with the most current data provided in Fig. 5, but so far, they have displayed little mechanical change. There is a 17.2% change in k between Day 1and Day 4 for the 37 C scaffolds, and a 37.6% difference in k for the 50 C scaffolds over the same testing range. On Day 7, there was an 81.6% k decrease in the 50 C specimens as compared to Day 1. As mentioned, the 70 C specimens were unable to be tested on follow-up days due to mechanical instability.

Table 1. Mean k-values

	37 C	50 C	70 C
Day 1	0.0126	0.013	0.0122
Day 4	0.0106	0.0086	N/A
Day 7	N/A	0.0053	N/A

Table 2. Mean weights

	37	50	70
1	0.3291	0.3258	0.3281
4	0.3256	0.3196	0.3106
7	N/A	0.3135	N/A

While the 50 C and 70 C test scaffolds reached a point where they could not withstand any load from the compression testing, they were still weighed. Table 1 and Fig. 6 displays the mass results at each temperature and testing day. From the data collected, specimens could not withstand load with a Load-displacement value (k) of 0.0053 N/mm or less. The 37 C scaffolds demonstrated an average 1.1% difference in mass on Day 4. The 50 C scaffolds displayed an average mass difference from Day 1 of 1.9% at Day 4, and a 3.8% difference at Day 7. The 70 C scaffolds had a 4.8% mass difference on Day 4.

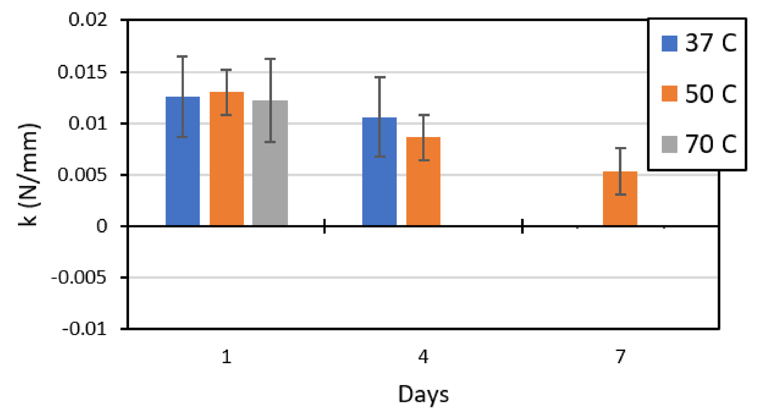


Fig. 5. Load-Displacement of scaffolds with standard deviations

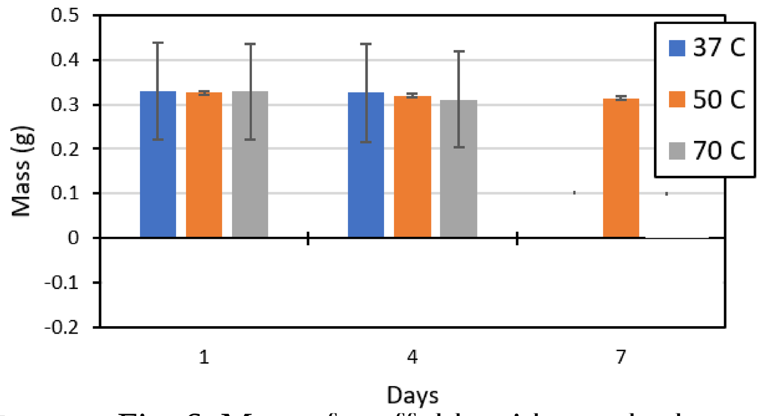


Fig. 6. Mass of scaffolds with standard deviations

Fig. 7. 70 C scaffold at Day 4

Fig. 8. 50 C scaffold at Day 7

Discussion

It was observed, that temperature has a significant effect on the degradation of PLA scaffolds. At 70 C, the scaffolds were unable to be mechanically tested by the 4-day mark, and at 50 C, they had similar results in 7 days. This is vastly different from the room temperature tests run by previous Cedarville research students. There is a clear trend in that higher temperature results in both more mass lost and lower load-deflection values which points to a correlation between higher temperature and faster degradation of PLA. As the temperature approaches the glass transition temperature of PLA, the degradation occurs more quickly.

References

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