

## Microplastic Leaching Rates for Different 3D Printable Plastic Filaments

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### Abstract

As 3D printing becomes increasingly common in engineering, research, and marine applications, the use of plastic components in aquatic environments raises many concerns about microplastic pollution and plastic leaching. Due to a lack of research focused on microplastic leaching from polymers commonly used in fused deposition modeling (FDM) 3D printing, this study investigates the leaching behavior of five commonly used FDM polymers: Polylactic Acid (PLA), Polyethylene Glycol (PETG), Acrylonitrile Butadiene Styrene (ABS), Thermoplastic Polyurethane (TPU), and Polycarbonate (PC). The goal is to use this data to encourage a better understanding of material choices for aquatic and research applications. 2 x 2 x 2 cm cubes of each polymer were printed and exposed to agitated water for 48 hours, and changes in the density of the water samples and the mass of the printed cubes were measured. The results showed that TPU had the highest leaching rate during the first 24 hours, followed by ABS, PLA, PC, and PETG, with short-term leaching generally corresponding to the polymers' water absorption rates. During the second 24 hours, PETG and PC exhibited more leaching at a more linear rate while other polymers' leaching rates slowed down, and their cubes showed the greatest decreases in mass. These results suggest that water absorption and polarity influence leaching behavior, with the former influencing rates in the short term and the latter influencing rates in the long term.

### Introduction

Ever since its inception, additive manufacturing, or 3D-printing, has become increasingly common in the workplaces of hobbyists, engineers, and researchers. 3D printing is regularly used for rapid prototyping and creating custom parts that would otherwise cost significantly more than their commercial alternatives. In terms of marine applications, additive manufacturing is used to create replacement parts for boats and sensor buoys as well as parts for research experiments, such as microfluidic devices, sensors, separation techniques, sample pre-treatment, and sampling platforms (3D Printing in the Marine Industry | BigRep, 2025)(Figuerola et al., 2025). The growing use of additive manufacturing in these applications means that printed polymers are increasingly being placed in environments where they can interact with water and scientific samples. Therefore, understanding how these materials behave in aquatic environments is important for understanding their potential environmental effects.

As plastics have grown increasingly common, so have their impacts. About 85% of plastic waste is placed in landfills or directly released into the environment, with plastic waste in the ocean leaching microplastics into aquatic environments. Due to their being plastic, 3D printed

materials will also contribute to the issue of plastic waste. Furthermore, 3D printed polymers contain additional additives and have varied properties to their more common counterparts (Cuiffo et al., 2017; Holt, 2024; Kumar et al., 2023; Taib et al., 2022). These differences are important because additives incorporated into a polymer to improve properties such as strength, flexibility, or printability may also interact with the surrounding environment. This raises the question of what substances can migrate out of a 3D-printed material when it is exposed to water.

The question of microplastic leaching becomes especially important when 3D-printed materials are used in scientific research. Components designed to collect, contain, or analyze samples could potentially release substances into those same samples, potentially compromising the results of an experiment. Therefore, selecting a 3D-printing material for aquatic research requires consideration of factors beyond its mechanical properties or ease of printing.

This experiment intends to collect data on the leaching of different 3D printing materials to better inform material choices for use in aquatic and research environments to minimize microplastic leaching. By comparing the leaching behavior of different 3D-printing materials, this experiment can help identify materials that are less likely to introduce microplastics into aquatic environments or interfere with scientific measurements. Ultimately, understanding these differences can help reduce the environmental impact of 3D-printed materials and improve the reliability of research that relies on them.

## Background

This study focuses on one common form of additive manufacturing: fused deposition modeling (FDM). Fused deposition modeling feeds spools of plastic through a heated nozzle and deposits the melted plastic layer-by-layer onto a heated build plate. The nozzle is often brass, stainless steel, or hardened steel.

Five plastics will be used in this experiment: Polylactic Acid (PLA), Polyethylene Terephthalate Glycol (PETG), Acrylonitrile Butadiene Styrene (ABS), Thermoplastic Polyurethane (TPU), and Polycarbonate (PC) (Figure 1). These plastics all have distinct properties, such as water absorption rates, water contact angles, Vicat softening temperatures, and glass transition temperatures. Water absorption rate, shown as a percentage of the material's total weight over time, measures how fast and how much moisture a polymer absorbs from the air or when submerged in water. Water contact angle measures the angle between a water droplet and the polymer's surface at the point of contact, indicating attraction to water. A low angle indicates that the surface is hydrophilic and is more polar. Softening temperature is the point at which a plastic begins to deform and lose its rigid properties, while the glass transition point is when plastics change from a hard state to a soft, rubbery state. It is important to note that aside from Thermoplastic Polyurethane, all filaments tested are being tested well over the softening and glass transition temperatures (Table 1).

PLA is the most commonly used material for FDM due to its ease of printing and affordability. PLA can biodegrade in certain artificial composting conditions. PETG is another extremely common material among hobbyists and engineers alike. It is tougher and has a higher resistance to water, UV, and temperature than PLA. ABS has high temperature, water, and UV resistance, but is known to warp and release fumes while printing. TPU is a rubber-like filament that can produce flexible parts due to its very low glass transition and softening temperatures. PC is a very durable plastic with high temperature and impact resistance. It is also naturally transparent. (3D Printer Filament | Bambu Lab US Store, n.d.)

| Material | Density(g/cm <sup>3</sup> ) | Melting Temp(°C) | Softening Temp(°C) | Glass Transition Temp(°C) | Water Absorption Rate | Contact Angle |
|----------|-----------------------------|------------------|--------------------|---------------------------|-----------------------|---------------|
| PLA      | 1.24                        | 160°C            | 57°C               | 60°C                      | 0.43%                 | ~ 82°*        |
| PETG     | 1.25                        | 240°C*           | 69°C               | 80°C*                     | 0.45%                 | ~ 78°*        |
| ABS      | 1.05                        | 200°C            | 94°C               | 102.5°C*                  | 0.65%                 | ~ 83°*        |
| TPU      | 1.26                        | 183°C            | -35°C*             | -40°C*                    | 1.20%                 | ~ 90°*        |
| PC       | 1.2                         | 228°C            | 119°C              | 145°C                     | 0.25%                 | ~ 78°*        |

Table 1. Material Specifications for different 3D-printable plastics used in this study. (3D Printer Filament | Bambu Lab US Store, n.d.)

\*Acquired from sources other than Bambu Lab(ABS Filament Temperature Resistance, n.d.; Glass Transition Temperatures of PLA, PETG & ABS | All3DP, n.d.; PETG Glass Transition Temperature, 2026; Thermoplastic PolyurethaneTPU Melting Point and Glass Transition Temperature, n.d.; Liu et al., 2015; Rodríguez-Vidal et al., 2018; Scherer et al., 2022; Xie et al., 2024; 이내윤 & 장민정, 2015)

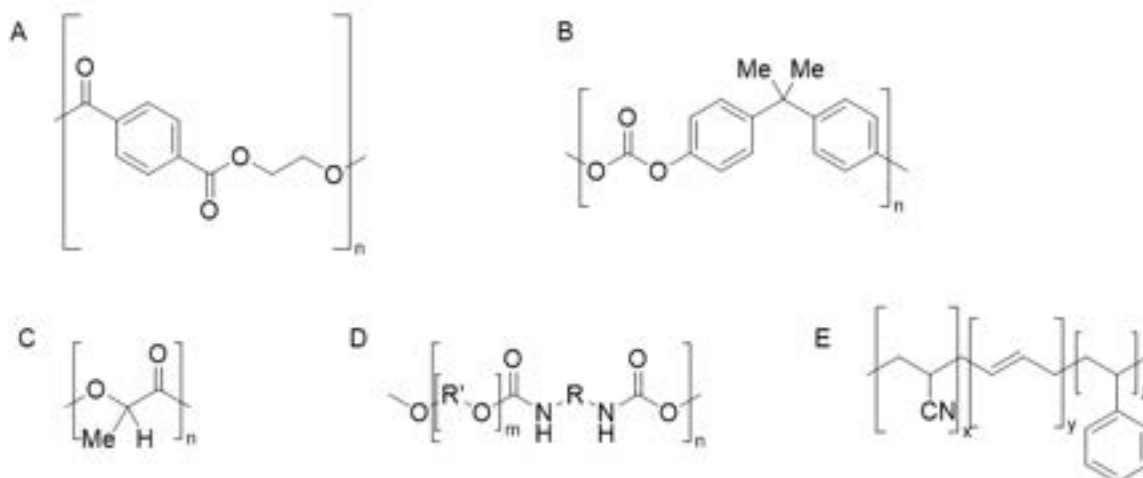


Figure 1. Molecular structures for all 3D-printable plastics. A) PETG, B) PC, C) PLA, D) TPU, E) ABS(Jung, 2025; Lukianchuk et al., 2022; Nam et al., 2012; Strabala, 2009; Weller & Kothe, 2011)

## Previous Research

Previous research on leaching from 3D-printed materials focuses on the leaching of a variety of metals (Figuerola et al., 2025)(Holt, 2024), yet there are no studies on the microplastic leaching of different 3D-printed materials. A study analyzing metal leaching revealed that PLA had the lowest total amount of metal leaching, but it released the largest variety of metals, while PP (Polypropylene) had the highest total amount of metal leaching overall, but it released a relatively small number of different metals.(Figuerola et al citation) Additionally, other studies exclusively analyze nanoplastic and antimony leaching from photopolymers fabricated using stereolithography (Rodríguez-Hernández et al., 2020; Short et al., 2014)(Holt, 2024; Rodríguez-Hernández et al., 2020), without focusing on polymers used in FDM. These experiments show that resin used in stereolithography can create nanoplastic waste. While there is research focused on the leaching of metals from 3D printing materials, the absence of research on microplastic leaching of FDM polymers, while microplastic pollution continues to grow in prevalence, incentivizes and necessitates further research to facilitate a reduction in microplastic pollution in aquatic environments as well as an increased reliability of 3D printed devices for use in research contexts.

## Materials & Methods

The plastic filaments used in this experiment were all purchased from Bambu Labs. The filaments were PLA Basic, PETG Basic, ABS Basic, TPU for AMS, and PC. All materials were used as purchased. A Bambu Labs P1P 3D printer, modified to have an enclosure, hardened steel nozzle, textured PEI build plate, and Bambu Labs AMS, was used to print all samples.



Figure 2. Figure 2A. Stirring apparatus used to agitate the water.

Figure 2B. Drying apparatus using the Bambu Labs P1P buildplate heated to 40°C to dry the cubes.

Four 2x2x2 cm cubes with 20% gyroid infill were printed from each material on a BambuLabs P1P with a hardened steel nozzle on a PEI build plate at standard speed. Of the 4 cubes, three were used for testing and one was a control. As seen in Figure 2A, the cubes were placed in separate glass containers filled with tap water. A separate trial just agitating the water with a stir rod was used as a control. These containers were placed on a stir plate to agitate the water for a total of 48 hours, and were covered during the experiment to prevent dust from entering the water. At 24 and 48 hours, 3 mL of water was collected from each glass container using 3 mL syringes. Samples were stored in 3 mL glass vials. The vials were measured with a precision scale and the mass of an empty vial was subtracted from the measured value. It was ensured that the empty vials all weighed the same on the scale used. Mass of leached plastic was determined by subtracting the average mass of the control samples from the mass of the experimental samples. The initial weight of each cube was measured with the precision scale before being put in the water. After 48 hours, the cubes were patted dry with tissues, then as seen in Figure 2B, placed on the 3D printer bed. Here, they were heated to 40°C for 24 hours to remove any absorbed water, then measured on the scale. This process was repeated for all trials and materials. Three trials were performed for each material and the control.

## Results

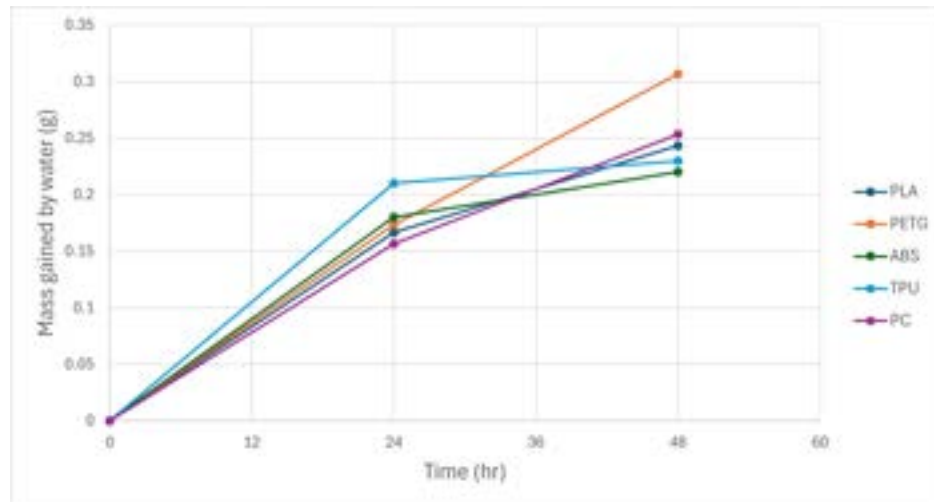


Figure 3. Average mass gained by water samples over 48 hours (three trials).

Over the first 24 hours, the mass of all samples increased as the cubes were agitated. TPU gained the most mass at 0.21g, while the other materials gained notably less mass. ABS was the second highest, gaining 0.18g followed by PETG(0.1733g), PLA(0.1667g), and PC(0.1567g). The rates for PLA, ABS, and TPU decrease over time while the rates for PC and PETG remain consistent.

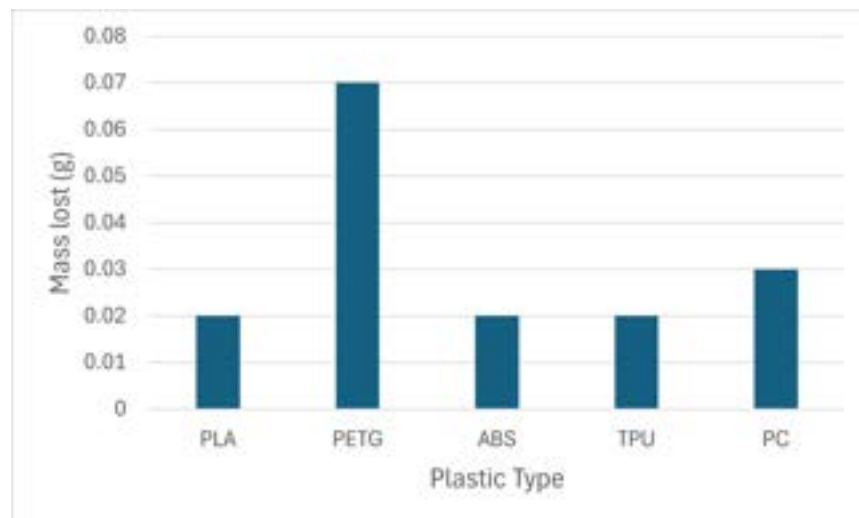


Figure 4. Average mass lost by plastic cubes over 48 Hours(three trials).

The PETG cube showed the largest decrease in mass of the materials, with the PC cubes on average decreasing the second most and the other cubes all tied for the least decrease in mass.

## Discussion

As seen in Figure 3, over the first 24 hours, TPU had the highest rate of leaching, while the other materials leached significantly less. ABS was the second highest followed by PLA, PC, and PETG. With the exception of PETG, the leaching rates seem to correlate with the polymers' respective water absorption rates. TPU has the highest absorption rate of 1.2% which is much higher than ABS, which has the second highest rate of 0.65%. The other materials have smaller absorption rates, but the rates are significantly closer together than the rates of TPU and ABS. This correlation may be explained as high water saturation can compromise polymer integrity through plasticization and the breaking of polymer chains. All tested materials are polar and therefore are attracted to the water.

Interestingly, the leaching rates changed in the second 24 hours. PETG and PC leached at a constant rate, while the other polymers leached less during the second day. Notably, PETG and PC have a similar water contact angle that is lower than the contact angle of the other polymers. Since lower contact angle indicates a higher polarity, it can be concluded that PC and PETG leached more as a result of their higher polarity. One potential explanation can be that water is more attracted to polar molecules. As such, the more polar plastics likely had more interactions with the water and as stated earlier, high water saturation can compromise polymer integrity through plasticization and the breaking of polymer chains.

The findings from the first 24 hours roughly agree with other work focused on the leaching of metals from plastics over 24 hours of testing the plastics in pure water. Nylon, which has a higher water absorption rate at ~ 2.5-3.4% (Physical Properties | AMILANTM | TORAY PLASTICS | TORAY, n.d.), leached the largest mass of metals as well as the largest quantity of different metals than PLA and Polypropylene. Polypropylene, which has a very low water absorption rate at ~ 0.03% (Polypropylene - an Overview | ScienceDirect Topics, n.d.), leached the least mass and variety of metals. (Figuerola et al., 2025) This indicates that over the initial water exposure period, these plastics leach both microplastics and metals at a rate determined by their water absorption rates.

The results seen in Figure 4 show that the PETG cube showed the largest decrease in mass of the materials, with the PC cubes on average decreasing the second most and the other cubes all tied for the least decrease in mass. These findings align with the findings shown in Figure 5, further corroborating that PC and PETG leach the most due to their higher polarity. In general, these findings suggest that initial leaching rates are positively correlated to water absorption rates and that long term leaching rates are positively correlated to polymer polarity. These findings also suggest that the interaction between water and the polymer plays an important role in determining microplastic leaching.

## Conclusion

Microplastic pollution has been a growing problem in recent years, with the high usage of plastics in FDM 3D-printing further contributing to this problem. The purpose of this research was to better understand plastic leaching to encourage more ecologically friendly material choices for use in aquatic and research environments to reduce microplastic pollution and interference in research. Through analyzing the leaching rates of PLA, PETG, ABS, TPU, and PC, it was shown that PETG and PC leached the most and leached more consistently due to their higher polarity. During the first 24 hours, leaching rates were correlated to the polymer's water absorption rates, while over the second 24 hours, leaching rates corresponded to the polymer's polarity. This means materials such as PETG and PC leach less than their counterparts over short periods of time and leach more over longer periods. PETG and PC also showed the greatest decreases in cube mass. These results suggest that increased polymer polarity can lead to greater and more consistent leaching over longer periods of water exposure. Therefore, a material that appears to have a relatively low leaching rate during short-term exposure may still present a greater concern when used in aquatic environments for extended periods.

Further research should corroborate the results of this study using FTIR, perform statistical analysis, and investigate additional polymers, such as those used in stereolithography, as well as test longer exposure periods and different water conditions, such as salination, temperature, minerals, and bacteria.

These findings also support the need for greater consideration and potential regulation of plastics used in marine and aquatic environments. As 3D-printed components become more ubiquitous in research, engineering, and marine applications, manufacturers and researchers should carefully evaluate the environmental effects of their material choices. More research and appropriate regulations could help prevent avoidable plastic pollution while ensuring that 3D-printed materials can be safely and reliably used in aquatic and research environments.

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